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Construction and Control Strategy of Dynamic Façade Model of Office Building in Severe Cold Region

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Abstract. With the development of urbanization, more and more office buildings are emerging. The daylight comfort of office buildings has become one of the key issues that architects pay attention to. As an indoor and external interface, dynamic facade has great research value. Based on the unit office space, this paper established a dynamic facade model, and put forward a control strategy to cope with the daylight comfort in severe cold region. The results show that the dynamic skin has great potential in improving the daylight comfort of office buildings. Compared with the office space without the dynamic skin, it has increased the lighting control by 64% and the glare by 84%.

1. Introduction

In recent years, as an important research direction to solve the energy consumption problem of office buildings, daylighting has been used more and more widely. Daylighting has many advantages that cannot be replaced by artificial lighting, such as economy, energy saving, comfort and so on. However, it is difficult to maintain a stable daylighting environment in the interior that daylighting will change with time. So many problems will arise, such as glare, excessive illumination and so on, which will affect the comfort of office workers. As the interface between indoor and external environment, building's facade has an important influence on the stability of indoor daylight comfort. Dynamic facade can respond to the changing environment dynamically, balance the changes of daylight intensity and temperature inside and outside, and enhance the stability of indoor daylight comfort^[1].

Due to different climatic conditions in different regions and different demands for building environment, dynamic facade has different forms^{[2][3][4]}. Therefore, the dynamic facade should be designed according to the local conditions and climate types^[5]. Because of its special climate and low solar altitude angle, the problem of indoor daylight comfort is the most serious in severe cold region. Therefore, the purpose of this paper is to construct a dynamic facade model suitable for indoor daylight comfort in severe cold region, and put forward a dynamic facade control strategy.

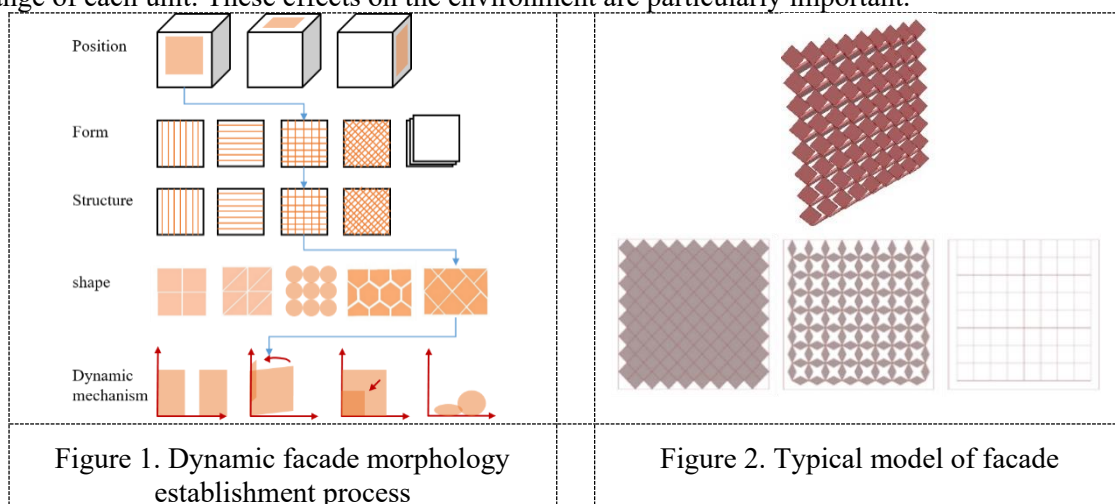
2. Dynamic façade model

2.1. Process

The structure of the dynamic facade is divided into four levels, the boundary, the core control layer, the dynamic layer and the skeleton layer. Due to the different forms of the skeleton layer are constructed differently, it is the key to the dynamic facade shape design. It includes five parts: the location, form, skeleton, shape and dynamic mechanism of the facade. Figure 1 depicts the



establishment of dynamic facade morphology. Firstly, the dynamic facade should be positioned in the building, which can be set at any interface between the building and the environment; secondly, the reasonable dynamic form should be chosen, such as linear, grid, planar tilling and overlap; thirdly, the reasonable supporting structure should be selected, and the supporting structure can be used to construct. There are many kinds of existing structures or additional structures in buildings, such as horizontal or vertical linear arrangement of support rods, or grid arrangement of support structures, etc. Then it is to choose a reasonable shape, which is the most intuitive visual expression of dynamic epidermis, and should be based on the form of dynamic facade, design concepts and materials. Finally, the dynamic mechanism with the same location, shape and skeleton of the dynamic facade, if the it is different, the impact on the environment is also very different. Four basic dynamic mechanisms are listed in the figure: movement, rotation, scaling and elasticity. It also involves the dynamic location of the facade. It is the same way to change the whole facade. It is the zonal change or the individual change of each unit. These effects on the environment are particularly important.



2.2. Typical Morphological Model

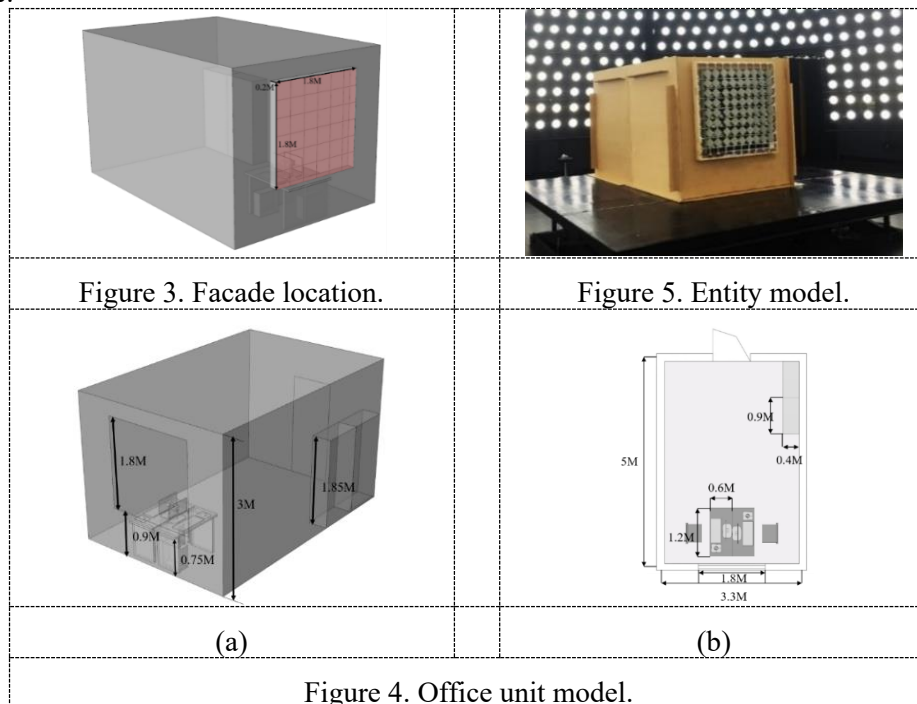
Due to the planar tilling can take into account the various elements of the facade and respond to environmental changes in a multi-dimensional way in the basic form of dynamic facade, thus improving the indoor light environment, the typical morphological model uses the planar tilling dynamic facade. The most suitable skeleton of the planar tilling dynamic facade is the grid supporting structure, and each element can be changed independently. Shape selection is more easily controlled in both horizontal and vertical directions. The rotary form is used here to cross the horizontal rotation and the vertical rotation, and the part is rotated by the horizontal center. The other part is rotated with the vertical centerline as the axis, visually showing the shape of the cell grid (Figure 2).

The most important influence of the indoor daylight environment of office buildings lies in the location of the daylighting openings. The choice of the shape of the daylighting openings directly affects the indoor daylight environment and the comfort of the staff. Therefore, the skin is placed at the lighting opening, and the distance from the lighting opening is 20cm. As a buffer layer, there is room for structural members and mechanical members of the dynamic skin. The dynamic skin is laid on the daylighting surface, with a length of 1.8m and a width of 1.8m. It controls the daylighting of the daylighting outlet, thus achieving control of the indoor daylight environment and achieving a comfortable effect (Figure. 3). The layout and size of office units are shown in the Figure 4. (a) is the perspective view, and (b) is the plan. At the same time, a 1:2 scale model was established for the indoor daylight comfort measurement to verify the advantages of the dynamic skin model in terms of daylight comfort (Figure 5).

3. Control strategy

The control of dynamic facade mainly involves two requirements, one is to control glare and the other is to control daylighting, and the two aspects work together to control indoor daylight comfort. Due to the dynamic characteristics of the dynamic facade and the coupling of multiple indicators is a very complex system, this paper proposes an idea to simplify it, that is, to set the partition.

First of all, the generation of uncomfortable glare should be avoided, and the open-loop control strategy is adopted. A logical preset is first performed to predict the position of the potential glare in the room to determine the target change position of the dynamic facade. The computer is then parameterized to simulate the indoor daylight environment to determine the location of the potential glare source.



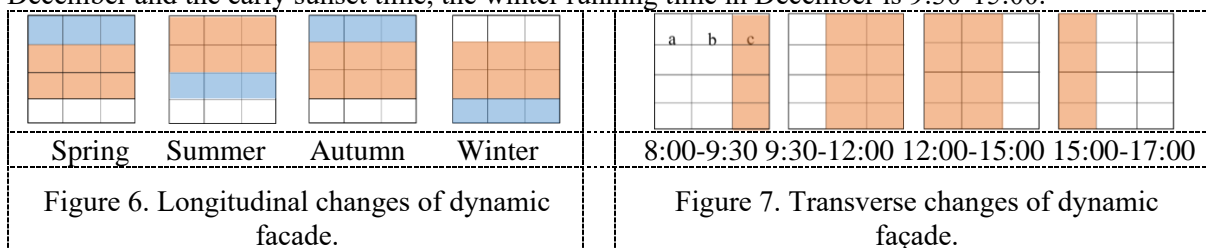
3.1. Glare regulation

3.1.1. Glare prediction. The glare prediction is based on computer simulation. Based on Grasshopper and Rhinoceros platform, this paper establishes the parameterization model of office unit. The interior surfaces have been assigned a reflectance of 80% for ceiling, 80% for walls, and 20% for floor, 20% for table, 60% for monitor, and 55% for bookcase. The meteorological data input is the CSWD typical meteorological year-by-hour data representing Harbin in the severe cold city. The Radiance platform was used to simulate the 12-month glare of the office unit to determine the location of the glare source. The results show that the position of the glare has an obvious path with time. The potential path reflects the trend from bottom to top and then from top to bottom throughout the year. During the day, a parabolic trend from right to left is shown. It shows that its motion trajectory has a direct relationship with the solar elevation angle and azimuth angle. Therefore, the control of glare is mainly to block direct sunlight.

3.1.2. Glare control strategy. Based on the simulation results, the glare control strategy was proposed. In the position where glare is easy to occur, part of the facade is directly perpendicular to the sun's rays, and the rest is in a state of 90° . In this way, the facade is partitioned so that it can control the glare while increasing the daylighting area as much as possible. The facade is divided into four horizontal

and three vertical, and the longitudinal direction mainly deals with the change of the solar elevation angle, and the lateral direction mainly deals with the change of the solar azimuth.

As shown in Figure 6, it is divided into four states in the vertical direction. The yellow area is a glare-prone area. This part of the facade is used to directly block the sunlight, perpendicular to the sun's rays, and rotates up and down with the lateral direction as the axis. However, the change of the solar elevation angle during the day is small, and the change with time is slow. Therefore, the blue area is set as the linkage area, and this part is in the middle state of the epidermis opening and closing, set to 45° , with the four seasons. The white area is not responsive. It is divided into three segments in the lateral direction (Figure 7). The yellow region is the region perpendicular to the sun's rays. Because it varies with the azimuth of the sun, this region rotates left and right in the longitudinal direction. The time period in the figure is the running time of spring and autumn. Due to the summer glare, the summer running time is 9:30-15:00. At the same time, due to the late sunrise time in December and the early sunset time, the winter running time in December is 9:30-15:00.



The horizontal and vertical directions are combined to form the entire facade. In order to prevent the horizontal and vertical directions from colliding, the skins are arranged horizontally and vertically. The basic facade is four horizontal segments and three vertical segments. In this paper, the facade unit is set to a side length of 15cm, a horizontal direction of eight sections, and a vertical section of nine sections, so that the skin is equally divided, and the size of the detail is not too small.

3.2. Daylighting regulation

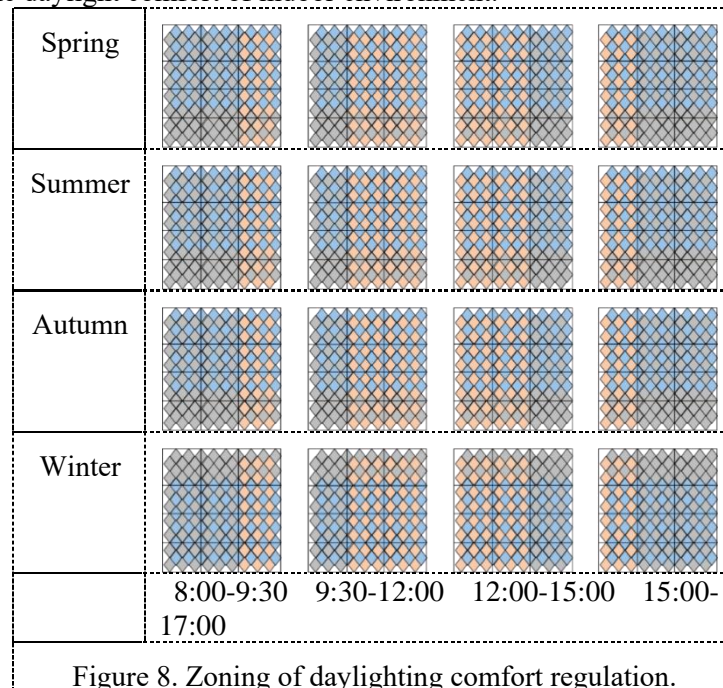
The illuminance of the working face should first meet the standard for daylighting design of buildings^[6], the standard value of the daylight in the office room is 450lx. At the same time set him a limit of 2000lx. The dynamic facade adopts closed-loop control, and a closed loop is formed between the input and output signals to control the illumination of the working surface between 450lx and 2000lx. When the illumination of the working surface is above 2000lx, the facade rotates to the daylighting area. Rotation in a smaller direction; when the illumination of the working surface is above 450lx, the skin rotates in a larger direction of the daylighting area. During the rotation of the facade, instead of blindly increasing the daylighting area or reducing the daylighting area, the upper and lower limits should be set. The division of the facade is consistent with the glare strategy, rotating in the east-west direction, responding to the azimuth of the sun, rotating vertically up and down, in response to the solar elevation angle.

3.3. Daylighting comfort regulation

The daylighting control should be combined with the glare control. The glare control is open-loop control, which is pre-set based on the simulation. At this time, not every unit of the dynamic facade is involved in the glare control, and the rest is left. The facade unit provides an opportunity for daylighting control. Under the premise of satisfying the glare control, the remaining facade changes according to the change of the illumination of the indoor working plane, thereby realizing the dual control strategy.

According to the season and time, the facade is divided as shown in the figure (Figure 8). The gray area is the area that changes according to the illumination of the working surface. When the indoor illumination is below 450lx, the area moves in the direction of large daylighting area. When the indoor illuminance is 2000lx or more, the area moves in a direction in which the daylighting area is small. The movement method is the same as the daylighting strategy in the previous section. The color

portion is a glare control strategy, which is consistent with the previous text. Yellow represents the facade unit that rotates left and right in the vertical direction, and blue represents the skin that rotates up and down in the lateral direction. The blue area is always perpendicular to the sun's elevation angle, obscuring the daylight that changes in the vertical direction. The yellow area is always perpendicular to the sun's azimuth, thus obscuring the horizontally varying daylight. The dual control of daylighting and glare realizes the daylight comfort of indoor environment.



4. Conclusion

As an interface between indoor and outdoor, the facade has an important influence on the stability of indoor daylight comfort. Based on the unit office space, this paper establishes a dynamic skin model based on the Rhinoceros & Grasshopper platform, which enables data interaction between building parametric modeling and daylight comfort simulation, and evaluates its daylight comfort based on the severe cold climate. In terms of the control strategy of light comfort, from the aspects of preventing glare and controlling daylighting, the principle of dividing the facade region is proposed, so as to realize the daylight comfort control of the dynamic skin.

In order to prove the validity of the model and the self-control strategy constructed in this paper, a entity model was established to conduct daylighting and glare experiments under the intelligent artificial sky system. The results show that the dynamic facade has great potential in improving the daylight comfort of office buildings. Compared with the office space without increasing the dynamic facade, it has increased the daylighting control by 64% and the glare by 84%. Therefore, the dynamic facade can provide a more comfortable daylighting environment for office buildings, and has a greater advantage than the static facade.

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