Numerical Simulation and Optimization of a Large-depth Rural Residential House Daylighting

Hui Miao and Wei Li

ABSTRACT

In this paper, IES VIRTUAL ENVIRONMENT is used to simulate, analyze and optimize the lighting of a large rural house in Tianjin with enclosed lighting atrium. Using numerical simulation, the daylighting coefficients of the house before and after the adoption of daylighting atrium are compared and analyzed. The results show that the use of daylighting atrium can effectively improve the lighting effect of the main rooms in the central and north of the house, and the values of the daylighting coefficients of the main room is about 70% higher than that without using daylighting atrium. Meanwhile, in light of characteristics of the house, the lighting design of the lighting atrium and the main lighting room in the north is carried out and the numerical simulation is analyzed. The result show that the lighting atrium with a flat roof window has better lighting effect without changing the area of the daylight opening: the values of the lighting coefficients of the main room in the central and north is increased by about 30%.

KEYWORDS

Rural Residence   Lighting   Numerical Simulation

INTRODUCTION

With the acceleration of the process of urbanization in Chinese villages and towns, the design and research of rural residences are increasingly important. As an important part of indoor environmental quality of residential buildings, lighting is

1Hui Miao, Wei Li, Institute of green architecture technology and Application, Tianjin Chengjian University, Jinjing Street, Tianjin, China. E-mail:348333755@qq.com
particularly valued by rural residents. In this paper, a large-depth rural house with a closed atrium in Bangjun Town, Jixian County, Tianjin is taken as an example to simulate and compare the lighting condition, existing problems and the lighting optimization plan of the house by using numerical simulation method. Suggestions on lighting design are presented to provide quantitative numerical references for rural residential lighting design.

OVERVIEW OF THE CASE

The residence is located in Sanbaihu Village, Bangjun Town, Jixian County, Tianjin. The village is densely populated and with a population of about 1,600. The village residential layout is concentrated. In most cases, there is a courtyard in the residence and around this yard are rooms for all purposes. Most living room and bedrooms face south (as shown in Figure 1), and auxiliary rooms are on the east and west sides.

Given the large population, sufficient rooms are necessary to meet the needs of family members. In fact, the residents adopted a deepening approach to increase the number of functional rooms. The reasons are as follows: First, the two-story or three-story residential buildings in the form of small houses will increase the budgets of building, and block the light of the neighborhood; second, single-storey houses conform to the living habits of the local residents while other forms of residence fail to serve their needs. Therefore, on this premise, the depth of the house was enlarged to ensure sufficient rooms for use.

![Figure 1. Plane photo and real-world photo of the residence as well as the software model.](image)

In the layout of the flat room, the hall, passage hall and wear sets of space are the passages to every room (as in Figure 1), and on the left side of the hall there are three north-south bedrooms; to the left side of the entrance hall there are two small
bedrooms in the middle; to the north of these bedroom are two storerooms, to the south living room; to the right of the living room is auxiliary space for kitchen and dining room. Due to the relative complexity of functions of different rooms in this case, there are many rooms in this residence. Therefore, it will inevitably result in poor lighting in some of the rooms if the space is not divided properly. To ensure better lighting of the main rooms in the middle area of the house, the residents adopted the following measures: (1) Enclosed lighting atrium (as shown in Figure 2) is used to increase the natural lighting of some main rooms. For instance, the bedroom 2,3 and 4 are lightened by the atrium skylight, and the utility room 1 which is to the right of the atrium is also lightened.(2) the local small skylights are used to handle the problem of insufficient light in some main rooms. For instance, due to its location, the kitchen needed further daylighting or artificial lighting as the natural light from the south-facing dining room is faint. However, with the skylights (as shown in Figure 2) on the roof of the kitchen and utility room 2, the original lighting in these rooms is increased significantly.(3) partition window holes (as shown in Figure 1) were used to add lighting. In order to add light to bedroom 2 and 3, extra windows are opened in partition wall of the south-facing bedroom 1 and 2 to better the lighting of bedroom 2 and 3.

![Figure 2. Skylights of the house in this case.](image)

![Figure 3. Daylighting simulation results of interior rooms.](image)
### INDOOR DAYLIGHTING NUMERICAL SIMULATION AND ANALYSIS

In order to further understand the daylighting conditions of the rooms in the house, the daylighting condition of every room is simulated and analyzed by means of numerical simulation. As a very important method in indoor daylighting analysis [1-2], numerical simulation has the characteristics of strong flexibility and high accuracy. It is a kind of advanced lighting analysis method. The simulation software, British IES VIRTUAL ENVIRONMENT (IES VIRTUAL ENVIRONMENT, version: 6.2), is used in this study. After the simulation of the indoor environment of the room daylighting (as shown in Figure 3), the lowest value of daylighting in each room is listed in Table 1:

<table>
<thead>
<tr>
<th>Room</th>
<th>The lowest value of daylighting coefficient (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedroom 1</td>
<td>4.09</td>
</tr>
<tr>
<td>Bedroom 2</td>
<td>0.45</td>
</tr>
<tr>
<td>Bedroom 3</td>
<td>4.52</td>
</tr>
<tr>
<td>Hall</td>
<td>18.90</td>
</tr>
<tr>
<td>Passage hall</td>
<td>3.50</td>
</tr>
<tr>
<td>Atrium</td>
<td>2.12</td>
</tr>
<tr>
<td>Living room</td>
<td>3.08</td>
</tr>
<tr>
<td>Bedroom 4</td>
<td>0.17</td>
</tr>
<tr>
<td>Utility room 1</td>
<td>1.72</td>
</tr>
<tr>
<td>Utility room 2</td>
<td>7.64</td>
</tr>
<tr>
<td>Dining room</td>
<td>2.76</td>
</tr>
<tr>
<td>Kitchen</td>
<td>8.17</td>
</tr>
<tr>
<td>Bathroom</td>
<td>1.63</td>
</tr>
</tbody>
</table>

It can be seen from the above table that most of the rooms meet the minimum requirements of the daylighting coefficient of the main room according to China Lighting Design Standard, and only a few rooms fail to reach that standard.

In order to analyze the effect of lighting atrium on the lighting effect of the house, the day lighting conditions of every main room in this house are simulated without the lighting atrium, which means removing the high side windows above the lighting atrium in the software-built model, while keeping high side windows over the atrium. The simulation results are shown in Figure 4. In this case, the minimum value of daylighting coefficient of each main room lightened by atrium space such as bedroom 2, bedroom 3 and bedroom 4 is 0.26%, 3.41% and 0.11% respectively.

Through the comparison of simulation results, it can be seen that in the case of bedroom 2 with high-side-window lighting, the minimum value of the room-lighting coefficient is 0.45%, while after removing the atrium high-side window (keeping the north-facing high side window), the minimum value of the simulated daylighting coefficient dropped to 0.26%. The minimum value of daylighting coefficient of bedroom 2 with atrium lighting is 73% higher than that without atrium lighting.
Therefore, the adoption of daylighting atrium significantly boosted the lighting effect of some main rooms. This is an effective way to handle the problem of insufficient daylight and is of great practical significance for bettering indoor lighting quality of the large-depth residence.

Figure 4. Daylighting simulation results after removing the atrium high-side window.

Figure 5. Daylighting simulation results after adopting daylight window.

DAGLIGHTING OPTIMIZATION AND SIMULATION ANALYSIS OF THE ATRIUM AND NORTH-FACING BEDROOM

Daylighting Optimization and Simulation Analysis of The Atrium

The use of the atrium has its positive significance in improving the daylighting of the main rooms in this case. However, the use of high side windows in the
lighting atrium has limited lighting effect on bedroom 2 and 4. When analyzing the reasons for the lack of daylight in bedrooms 2 and 4, we think, on the one hand, this is partly due to the fact that there is no window in the western wall (which is shared with another residence) in the north-facing bedroom 2 and that the bedroom 4 is in the middle area of the house; on the other hand, that is due to the location of the high side windows and the limitations of the windowed form. The precondition of renovating the atrium high-side window is that the total area of original atrium high-side windows is fixed (keeping the north-facing high-side windows in the atrium). In the simulation model, the daylight opening in the atrium is modified to the form of casement window and the lighting numerical simulation, results are shown in Figure 5. In this case, the minimum values of daylighting coefficients of the main rooms lightened through atrium such as bedroom 2, 3 and 4 are 0.57%, 3.36% and 0.42% respectively.

Through the comparison of the simulation results before and after the renovation of the atrium, it can be seen that the lowest value of the room lighting coefficients is 0.45% when using the original atrium high-side-window lighting in the bedroom 2, and the lowest value becomes 0.57% after the optimization and simulation of the atrium. The lowest value of the daylighting coefficients of the bedroom 2 after atrium optimization increases by 27% than the original value. From this it can be seen that the optimized lighting atrium is very effective in increasing the daylighting of some of the main rooms in this large-depth house.

**Daylighting Optimization and Simulation Analysis of the Atrium**

The use of the atrium has its positive significance in improving the daylighting of the main rooms in this case. However, the use of high side windows in the lighting atrium has limited lighting effect on bedroom 2 and 4. When analyzing the reasons for the lack of daylight in bedrooms 2 and 4, we think, on the one hand, this is partly due to the fact that there is no window in the western wall (which is shared with another residence) in the north-facing bedroom 2 and that the bedroom 4 is in the middle area of the house; on the other hand, that is due to the location of the high side windows and the limitations of the windowed form. The precondition of renovating the atrium high-side window is that the total area of original atrium high-side windows is fixed (keeping the north-facing high-side windows in the atrium). In the simulation model, the daylight opening in the atrium is modified to the form of casement window and the lighting numerical simulation, results are shown in Figure 5. In this case, the minimum values of daylighting coefficients of the main rooms lightened through atrium such as bedroom 2, 3 and 4 are 0.57%, 3.36% and 0.42% respectively.

Through the comparison of the simulation results before and after the renovation of the atrium, it can be seen that the lowest value of the room lighting coefficients is 0.45% when using the original atrium high-side-window lighting in the bedroom 2, and the lowest value becomes 0.57% after the optimization and simulation of the
atrium. The lowest value of the daylighting coefficients of the bedroom 2 after atrium optimization increases by 27% than the original value. From this it can be seen that the optimized lighting atrium is very effective in increasing the daylighting of some of the main rooms in this large-depth house.

**Daylighting Optimization and Simulation Analysis of the North-facing Rooms**

There are two same-sized north-facing daylight openings in the original north-facing bedroom 3 (as shown in Figure 1), and the lowest value of daylighting coefficients is 4.52%, which far exceeds the 1% coefficient value for the bedroom in the daylighting standard. Two design plans are adopted in optimizing the daylight opening of the room: The two window openings of the bedroom 3 in the model is reduced to one and the shape of the atrium lighting port remains unchanged. After the simulation, the lowest value of the daylighting coefficients of the room is 2.32%, which can meet the lighting standards, but the decrease rate is large. 2. In the bedroom 3, only one window opening is reserved, and the lighting opening of the lighting atrium is changed to the flat roof window mentioned above. In this case, the minimum value of the lighting coefficients of the room is changed to 3.36%, which is higher than that of the first design plan by 50%. From this, we can further find out that the lighting effect of the atrium with the flat roof window is better. Meanwhile, the use of the flat roof window reduces the opening of the window to the north. As the lighting effect is fully ensured, it also has good effect on the energy saving of the enclosure structure [3].

**CONCLUSIONS**

First of all, it is a relatively better way to adopt atrium lightening in the large-depth rural residence, and through comparative analysis it can be concluded that for the main rooms lightened by atrium such as bedroom 2, 3 and 4, the supplementary effect of atrium lighting is quite significant.

Secondly, in this case, for the rooms to the east and west side of the atrium, they have better daylight when the flat roof window is adopted in the atrium. The daylighting coefficient values of the main room in the central and northern areas increase by about 30% on the condition that the area of the daylighting port remains unchanged.

Finally, taking the north-facing bedroom 3 as an example, the design of room lighting port is presented by using numerical simulation. That is to say, numerical simulation analysis method is used to provide the quantitative value of the size and form of lighting port. On the premise of ensuring good lighting of the main rooms, the window opening of the peripheral protection structure is minimized to achieve the integration of daylighting and energy saving.
ACKNOWLEDGEMENTS

This work was supported by Tianjin Science and Technology Support Project: [Grant Numbers 15ZCZDSF00080]; Open Project of Ministry of Housing and Urban-Rural Development of the PRC (MOHURD) and Beijing University of Civil Engineering and Architecture: [Grant Numbers UDC2017030912]; Tianjin Construction Administration Committee Science and Technology Project: [Grant Numbers 2016-22].

REFERENCES