Influence of the Traditional Residential Building Eaves on the Indoor Light Environment

Long-fei YU* and Yu LIU
School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, China
*Corresponding author

Keywords: Traditional, Residential building, Eave, Indoor light environment, Ecotect simulation

Abstract. Noticing the large eaves and the insufficient indoor lighting in the traditional residential buildings in the south Shaanxi province of China, this paper analyzes the relationship between the eaves and the indoor light environment of such buildings. Length of roof eaves, height of cornices, and areas of external windows are selected as three main influential factors for discussion. Numerical simulation was conducted using Ecotect software to understand relationship between indoor lighting performance and the three factors. The results show that, with a fixed window area, the average illumination coefficient is decreased along with the increase of the length of roof eaves, which means that the greater the length of the eaves, the greater negative impact on the indoor lighting environment.

Introduction

Traditional buildings, as important parts of architectural culture in China, are facing a huge crisis of survival because of the hard living condition and the loss of the rural population. Unique geographical location and climate in Southern Shaanxi has formed special traditional houses. The deep space under building eaves has become one of the representative pattern language. This spacious and unique space is not only adapted to the rainy weather but also fits the traditional life of local residents. Although the building materials and construction technology has undergone tremendous changes, the broad space formed by the large eaves or singed corridors are still widely applied. Such a transition space brings a negative impact: indoor light environment is sharply weakened. Such problem can be easily seen in southern Shaanxi. Whether the under-eaves space will impact indoor light environment is the focus of this paper.

Over the years, the domestic research on the protection of traditional houses has made a lot of theoretical and practical results, but in the traditional residential indoor light environment research is still lackluster. Existing researches include the following: Zhai Yibo's research on the optimal design strategy of light environment in traditional residential areas in Chongqing [1]; Li Yanjun, Ma Ke, Yang Haozhong's research and protective measure of traditional Dwellings in Southern Shaanxi [2]; Zhang Yun's numerical stimulation and design optimization of sunshade construction in Zhejiang traditional dwellings [3]. However, the above research results mainly focused on the qualitative study of the traditional residential research, and lack numerical simulation. He Miao, Xue Jiawei and others' research for the Dongjiang Village, Jinjiang City, using a computer simulation analysis and optimization to study the traditional residential light environment, is a successful case[4]. Overall, existing researches on the indoor light environment of traditional houses in southern Shaanxi is still a blank.

This paper chooses a traditional farmhouse in Xuejiaba village of Gaozhaizi town in Ningqiang county as a case for study. Ecotect software is used as a tool for the analysis. The purpose was to explore whether the traditional under-eave spaces can meet the indoor lighting standards of contemporary residential buildings in the researched region.

Basic Conditions of the Farmhouse

The farmhouse selected in this study location on the hillside of Xuejiaba village (Fig.1). The farmhouse conforms to the terrain as a whole towards the northwest, possessing four rooms in total.
The west side of the living room lies two bedrooms, while the east is a room with kitchen and dinning room use. The east of the main body of the house is attached to a dwarf house outside the gable. The under-eave space is 4.2 meters high and 2.4 meters deep, it is mainly used to store debris farm tools, and dry food.

**Figure 1. Plan, elevation and sections of the investigated farmhouse.**

**Ecotect Simulation**

**Overview of the Simulation.** The Ecotect simulation experiment is divided into two steps: Firstly, establish the experimental model of the selected traditional residential case, and simulate the indoor light environment data with Ecotect, to analyze the indoor light environment in such farmhouse given other factors fixed. Based on the first part of the simulation model, change the length of the eaves, the height of the cornice and the size of the window, to simulate and compare several times, and explore the impact of the eaves on indoor light environment, in addition to the optimum design strategy of lighting standard.

**Analytical Model for Simulation.** The test points set for different rooms are shown in Fig. 2. The simulation results are shown in Table 1.

From the analysis results in Table 1, we can see that the lighting coefficient and illumination value of each room in the house are very small, the average lighting coefficient is only 0.43%, the average illumination value is 34.61 lx, far less than the minimum lighting standard in the region of the 2% lighting factor and 300 lx illumination.

**Table 1. Simulation Results in Different Positions.**

| Room | I -A | Illumination(lx) | I -B | Illumination(lx) |
|------|------|-------------------|------|-------------------|
| Simulation result | Daylight factor | 0.69 | 58.73 | Daylight factor | 0.41 | 32.51 |
| Room | I -C | Illumination(lx) | I -D | Illumination(lx) |
| Simulation result | Daylight factor | 1.37 | 109.39 | Daylight factor | 0 | 0 |

**Setting of Variable Parameters.** Based on the simulation model set in the first step, living room which mostly requires indoor lighting is select for further simulation. Dimensions of the test model are set as the following: width 4200 mm, depth 5400 mm deep, floor to ceiling height 3000 mm, wall thickness 200 mm. Its orientation is south.

**Figure 2. Positions of the test points.**

**Figure 3. Test points sketch map.**
This study set the minimum and maximum window area as two critical values for the simulation. According to the "Standard for Daylighting Design of Buildings (GB50033) " and "Design Standard for Energy Efficiency of Residential Buildings in the Hot Summer and Cold Winter Zone (JGJ134)" of China [5,6], the two values are set as the following:

The minimum critical value: according to division of China's light climate zone, Ningqiang belongs to area II, light climate coefficient (K) is 1.10, so the area of living room window/floor area ratio is \(1/6 \times 1.10 = 0.183\), the minimum window area should be \((4.2 \times 5.4) \times 0.183 = 4.15\) square meters. Window Wall area ratio of 0.33. Equivalent to the window size: 2300 millimeters window width, 1800 millimeters window height, 900 millimeters high from ground to the window sill.

The maximum critical value: "hot summer and cold winter residential energy-saving design standards JGJ 134-2001" provides that the south of the window area ratio should not be greater than 0.45, in the daily architectural design, often this area as The maximum size of the living room window design, the external window area of 5.67 square meters \((S\text{ wall area} \times 0.45)\), equivalent to the window size: 3000 millimeters window width, 1800 millimeters window height 1800mm, 900 millimeters high from ground to the windowsill.

According to the local traditional roofing practices, the slope of the pitched roof is taken as 23\(^\circ\). Based on this, the different eaves length corresponds to the different cornice height, the minimum limit of the eaves limit is set to the summer solstice, The length is set to the winter solstice sun just into the room. The solar altitude on summer solstice day is 80°26′, and on winter solstice it is 33°34′. Then the minimum length out of the eaves is 380mm, take a reasonable integer value of 400mm, the maximum length of 3200mm, and the length of the eaves are 8 layers, \(L_1(400\text{mm}), L_2(800\text{mm}), L_3(1200\text{mm}), L_4(1600\text{mm}), L_5(2000\text{mm}), L_6(2400\text{mm}), L_7(2800\text{mm}), L_8(3200\text{mm})\).

### Results of the Simulation

The simulation results show the area ratio of window to wall on the minimum and the maximum limit, change the eave length of the building model respectively, and simulate the change of the lighting factor and the average illumination. In order to comprehensively analyze the change of indoor illumination, we select different four points A, B, C and D in the model plane, and count the simulation values of illumination coefficient and illumination at each point, as shown in Figure 3.

| Eave length(m m) | Daylight factor(%) | Illuminance(lx) | Daylight factor(%) | Illuminance(lx) | Daylight factor(%) | Illuminance(lx) | Daylight factor(%) | Illuminance(lx) | Daylight factor(%) | Illuminance(lx) |
|------------------|-------------------|-----------------|-------------------|-----------------|-------------------|-----------------|-------------------|-----------------|-------------------|-----------------|
| 400              | 16.02             | 1295.83         | 5.06              | 442.60          | 4.71              | 334.69          | 4.51              | 365.53          |
| 800              | 13.01             | 1040.81         | 4.11              | 330.15          | 3.47              | 294.54          | 3.42              | 342.29          |
| 1200             | 10.76             | 860.90          | 3.68              | 294.01          | 3.21              | 258.44          | 3.94              | 319.44          |
| 1600             | 9.47              | 757.23          | 3.40              | 272.21          | 3.00              | 250.10          | 3.13              | 257.68          |
| 1800             | 8.55              | 679.75          | 3.07              | 251.89          | 2.81              | 230.57          | 2.90              | 239.07          |
| 2400             | 7.80              | 624.18          | 2.87              | 229.63          | 2.66              | 213.19          | 2.68              | 221.51          |
| 2800             | 7.25              | 579.71          | 2.62              | 209.55          | 2.47              | 197.87          | 2.49              | 205.41          |
| 3200             | 6.35              | 549.37          | 2.45              | 196.07          | 2.30              | 186.59          | 2.31              | 190.45          |

The study respectively simulates and records data about daylight factors and illumination on two limited circumstances on the four test points, as shown in Table 2 and Table 3. By simulating the numerical results we can draw the curve of the illumination coefficient and illumination in different cases, as shown in Figure 4 and Figure 5.
Table 3. Simulation Results in Maximum Limit.

| Eave Length (mm) | Simulaton Position | A | B | C | D |
|------------------|---------------------|---|---|---|---|
|                  | Daylight factor (%) | 400 | 16.96 | 1355.40 | 6.46 | 517.54 | 6.25 | 495.22 | 5.85 | 477.08 |
|                  | Illuminance (lx)    | 800 | 13.69 | 1095.23 | 4.93 | 393.26 | 4.61 | 465.11 | 5.49 | 446.79 |
|                  |                    | 1200 | 11.39 | 991.37 | 4.56 | 363.12 | 4.28 | 339.92 | 5.12 | 417.02 |
|                  |                    | 1600 | 10.06 | 803.80 | 4.21 | 336.86 | 3.97 | 329.04 | 4.21 | 336.75 |
|                  |                    | 2000 | 9.05  | 724.07 | 3.91 | 312.01 | 3.77 | 301.52 | 3.89 | 312.17 |
|                  |                    | 2400 | 8.32  | 666.39 | 3.61 | 285.93 | 3.48 | 278.67 | 3.59 | 289.18 |
|                  |                    | 2800 | 7.73  | 618.60 | 3.31 | 261.57 | 3.24 | 259.01 | 3.26 | 267.99 |
|                  |                    | 3200 | 7.32  | 584.98 | 3.09 | 244.55 | 3.01 | 240.99 | 3.09 | 248.12 |

Analysis of the Results

The Area Ratio of Window to Wall Area in the Minimum Limitation Situation. It can be seen from Fig. 4 and Fig. 5 that as the length of the building eaves grows, the value of the lighting coefficient and the illumination value of point A decreases gradually, and the decreasing range is obvious. When the length of the roof is over 1600mm, the diminishing amplitude began to decrease; and in the B, C, D points, although the lighting coefficient and illumination value decreases with the eaves length increasing, the reduction is small. When the eave length gets over 1600mm, the curve is almost like a straight line. This shows that the deeper the room is, the smaller its influence is.

The Area Ratio of Window to Wall Area in the Maximum Limitation Situation. In a similar way, we analyzed the condition in the maximum limit. At A point, daylight factor and illuminance values began to show a significant reduction in amplitude, and the reduction of amplitude gradually tended to be gentle. The impact of the increase in the eave length on the three points of B, C and D, shows a gentle posture as a whole.

According to the results of the two simulation results, we record the average daylight factor to the average illuminance curve with the eaves changing. As shown in Fig. 6 and Fig. 7, with the increase of the eave length, the average daylight factor and the average illuminance show a decreasing trend, and this decreasing trend tends to be gentle. This analysis can draw the following conclusions: the longer the length of the house eaves, the greater the degree of impact on the indoor lighting. When the eave length reaches a certain value, this influence began to weaken.

According to the "architectural lighting design standards" (GB50033-2013), Ningqiang County is located in the area II, the indoor lighting needs to meet the standard value of 2%, natural light standard value of 300lx. Considering Figure 5 and Figure 7 it can be concluded that when the window wall area ratio is set to 0.33, the eaves out of the length should not be higher than 1600mm; when the window wall area ratio of 0.45, the eaves out of the length should not be greater than 2800mm.

![Figure 4. The daylight factor to eave length curve in minimum limited area ratio of window to wall.](image1)

![Figure 5. The illumination to eave length trend in minimum limited area ratio of window to wall.](image2)
Conclusion

This paper investigated the problem of insufficient indoor lighting in traditional residential building in southern Shaanxi, we puts forward the design parameters and optimization strategies. When the window area and roof slope are constant, the indoor average daylight factor and illuminance in the building will decrease with the increase of the eave length. When the window to wall area ratio of the southern outer wall satisfies minimum value of 0.33, the length of the eaves shall not exceed 1600mm; when the window to wall area ratio satisfies maximum value of the winter energy saving design standard of the area, the eave length should not exceed 2800mm.

Acknowledgement

The research of this paper was supported by the 2016 International Science and Technology Collaboration and Communication Program of Shaanxi Province (No.2016KW-031) and the 12th Five-Year Science and Technology Support Program of China (2015BAL03B04-2)

References

[1] Zhai Yibo, Study of Light Environment Optimization Strategy for Traditional Residence of Chongqing Area [D], Chongqing: Chongqing University. 2014 [6].

[2] Li Yanjun, Ma Ke, Yang Haozhong. A Tentative View and the Protective Measures of the Architectural Morphology of the Traditional Dwellings in Southern Shaanxi [J]. Journal of Xi'an University of Architecture & Technology (Social Science Edition), 2012, 4: 006.

[3] Zhang Yun, Numerical Stimulation and Design Optimization of Sunshade Construction in Zhejiang Traditional Dwellings [D]. Zhejiang: Zhejiang University. 2015 [4].

[4] He Miao, Xue Jiawei, Light Environment and Optimization of DongShan Village Traditional Residence in JinJinag City [j]. 2016, 44(6): 826-832.

[5] GB50033-2013 Lighting Design Standards For Buildings[s]. 2012[12]

[6] Energy Saving Design Standard for Residential Buildings in Hot Summer and Cold Winter Zone JGJ 134-2001.[s]. 2001[10].