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Simulation Analysis and Optimization of the Light Environment for Two Types of Stone-built Folk Houses in Taihang Mountains—Taking Changping Township as an Example

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Abstract: *The folk houses in this area all use bluestone as the building material, constructing cave-style folk houses and gable-roofed folk houses. The indoor lighting of the folk houses depends on the doors and windows on the front facade of the buildings. By comparing the advantages of the lighting effects of the two types of indoor folk houses, the results show that the lighting effect of the cave-style folk houses is slightly better than that of the gable-roofed folk houses, but the difference is not obvious enough. And it is far below the lighting requirements stipulated in relevant regulations. Meanwhile, an optimized comparative study on the indoor lighting of the buildings was carried out, including optimizing the cleanliness of the windows by renovating them, renovating the styles of the doors, and increasing the number of windows. The results show that increasing the number of windows can greatly improve the indoor light environment of the folk houses, and renovating the styles of the doors and windows can also improve the indoor light environment to some extent.*

Keywords: *Stone-built folk houses, Indoor light environment, Simulation comparison, Optimization analysis*

1. Introduction

Changping Township in Qinyang City is located in the Taihang Mountains. It has obvious differences from plain areas in geographical conditions, climate and temperature, as well as human culture. That is to say, the stone masonry folk houses constructed by utilizing natural resources can be roughly divided into two types, namely cave-style folk houses and flush gable roof folk houses. The cave-style folk houses are built adjacent to the mountain, with the main body of the building constructed of bluestone. The flush gable roof-style folk houses use bluestone to build the walls, adopt the flush gable roof form for the roof, and are built into a two-story stone masonry quadrangle courtyard form to expand the usable area within the limited floor area. There are no columns indoors in the stone masonry folk houses, and the walls are the main load-bearing structures, resulting in a residential style with short eaves and windows only on the front facade. Based on the ECOTECT software, this paper simulates and compares the advantages and disadvantages of the two types of folk houses in terms of day lighting. Meanwhile, combined with the local temperature and climate conditions, it explores the optimization methods for the folk houses and the day lighting performance indicators after optimization.

As the most intuitive perception of residents' living conditions, the light environment affects the architectural forms of folk houses and the living habits of residents. In daily life, people always pay attention to building houses facing south, so as to ensure sufficient sunlight. The same is true for stone-built folk houses. Given that folk houses have gradually drawn the attention of many researchers, it has become a trend to evaluate the green construction techniques of folk houses from the perspective of the light environment. For example, the ECOTECT model is used to simulate the indoor sunlight environment and conduct further optimization analysis. Pang Lu used the computer software ECOTECT to simulate and calculate the lighting coefficients of two courtyard houses in Shanxi and Shaanxi, and then obtained detailed numerical analyses of the courtyards and the interiors, fully demonstrating the wisdom and experience in creating the light environment of folk houses [1].. He Miao carried out indoor lighting experiments and software simulation analyses on the folk houses in Dongshan Village. The error between the simulation results and the measured results was controlled within 10%, which is within a

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reasonable range. Based on this simulation analysis, adaptive optimization strategies were proposed, providing useful references for the protective renovation of traditional folk houses [2]. Huang Haijing first obtained the basic theory based on the actual measurement of the light environment, and then simulated and optimized the protective renovation plan of the indoor light environment of traditional folk houses, providing examples for reference in this field [3].

In view of this, this research utilizes the ECOTECT software to conduct a comprehensive and systematic in-depth exploration of two types of stone masonry folk houses in Changping Township. By simulating the relevant parameters of the indoor day lighting of the folk houses and comparing the differences in the day lighting coefficients of these two types of folk houses, it aims to fully demonstrate the outstanding wisdom contained in the green construction of traditional stone masonry folk houses. At the same time, customized optimization and adaptability renovation plans are formulated for traditional stone masonry folk houses, thus providing a solid theoretical support and reference basis for the protection and adaptability renovation of the traditional historical style. We will strive to create a building characteristic style that not only meets the regulatory requirements but also carries the inheritance of scientific experience, promoting the traditional architectural culture to radiate new vitality and vigor in modern society.

2. Selection of Research Objects

2.1. Overview of the Basic Situation of the Selected Folk Houses

The folk houses selected for this study are located in the mountain forest area of Changping Township, Qinyang City. The aim is to compare the light environment characteristics of different types of folk houses. The research objects come from two natural villages, Zhanglaowan Village and Changping Village. The straight-line distance between the two villages is approximately five kilometers, and the elevation difference is similar. These folk houses are mainly built with bluestone, supplemented by wood and bricks. The selected folk houses are shown in Figure 1. Among them, the No. 1 folk house is of the cave-house type, with a total of three rooms. The front facades of the central room and the left wing room are both in the layout of one door and two windows, while the front facade of the right wing room has three windows. The left wing room is relatively independent, while the central room and the right wing room are connected indoors. The selected folk houses in Changping Village are very common in the local village. In this village, most of this type of folk houses are in the form of two-story buildings with three bays. They can be used either as independent buildings or as wing rooms in a courtyard house. The research object selected in Changping Village this time is an independent building. There is one window in each of the left and right wing rooms on the first floor, and a door is set in the central room. Each bay is connected to each other. To divide the indoor space, the residents only made simple partitions between the bays, and the second floor is a completely open overall space layout.

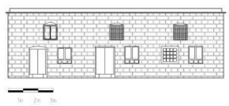
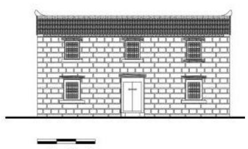
Folk house number	Exterior elevation	Interior space	Front elevation
ONE			
TWO			

Figure 1: General situation of the folk houses.

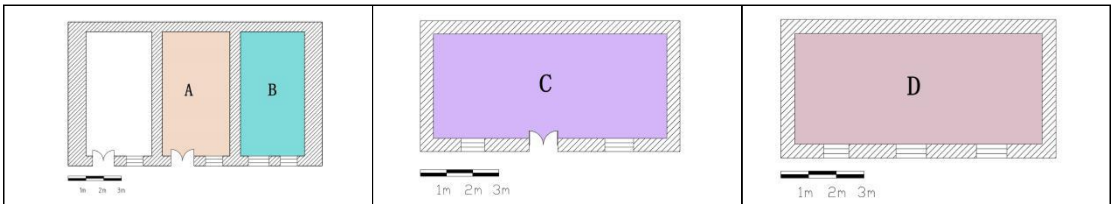
2.2. Selection of the research object area

The selected folk houses all have three bays. In order to conduct a quantitative analysis of the indoor

ISSN 2663-1563 Vol. 7, Issue 1: 114-121, DOI: 10.25236/AJAGE.2025.070115

light environment of the folk houses and compare the day lighting forms of the building spaces of the folk houses, different indoor spaces in the folk houses are selected for comparison. Therefore, the folk house areas shown in the Figure 2 are selected. To simplify the names of the folk houses, they are named as follows: Living room A (the central bay of the No. 1 folk house), Bedroom B (the left secondary bay of the No. 1 folk house), Living room C (the first floor of the No. 2 folk house) and Storage room D (the second floor of the No. 2 folk house). These four areas are used for comparative analysis. According to the principle of quantitative comparison, two groups, A vs C and B vs D, are compared to analyze the indoor day lighting effect under the condition of the same gable composition.

Areas with similar sizes in the folk houses are selected, with an area range of 26.14 - 29.75 m^2 The day lighting of the indoor light environment mainly depends on the windows. In the selected areas, windows are the only day lighting source, and factors such as the layout, shape, and quantity of the windows affect the indoor light environment. Restricted by their own conditions, the stone-built folk houses mainly rely on the front facade for indoor day lighting, and the area of the window openings does not exceed 1.2 m^2 Under natural conditions, the eaves of the folk houses do not project far, only about 400 mm. The building facades can be directly exposed to sunlight, The dimensions of the selected area are shown in Table 1.



Area A,B	Area C	Area D

Figure 2: Selected areas of folk houses.

Table 1: Selected area dimensions.

Number	Depth(m)	Width(m)	Depth-width ratio	Area(m^2)
A	7	3.8	1.84	26.6
B	7	3.61	1.94	25.27
C D	3.42	8.7	0.39	29.75

3. Light Environment Simulation

3.1. Setting of Natural Environmental Conditions and Simulation Conditions

3.1.1. Natural environmental conditions

The two natural villages are both located in the mountainous area of Qinyang City, belonging to the temperate monsoon climate. It is characterized by a mild climate, distinct four seasons, abundant sunlight, and a long frost-free period. In spring, it is dry and windy; in summer, rainfall is concentrated; in autumn, it is mild and cool; and in winter, it is dry and cold with little snow. For the mountainous environment, the main impact of natural lighting on folk houses focuses on the indoor lighting needs. Buildings try to obtain sufficient sunlight conditions indoors as much as possible. In addition, the thickness of the stone walls ranges approximately from 600 mm to 800 mm, which gives the indoor temperature of the buildings the characteristic of being warm in winter and cool in summer.

3.1.2. Setting of Simulation Conditions

In view of the existing problems in the light environment of folk houses, the Ecotect 2011 software is used to simulate the indoor light environment. The simulation parameters are set according to the "Standard for Architectural Day Lighting Design (GB500333 - 2013)": The sky illuminance model is set as an overcast sky. In this way, the natural light exists in the form of diffused light, which can ensure that the building facades of the research objects receive uniform sunlight conditions and are not affected by the orientation of the houses. The simulation work plane is set at a height of 0.75 meters from the ground. The cells set in the indoor day lighting area are in an approximately square shape to more accurately simulate the light distribution. The windows of the selected objects are grid windows or vertical lattice

ISSN 2663-1563 Vol. 7, Issue 1: 114-121, DOI: 10.25236/AJAGE.2025.070115

windows. Due to the low cleanliness of the windows, the default parameter value of the window is set as x=0.75, which represents that the window is in a dirty state. The two villages are both located in light climate zone III, and the outdoor natural light critical illuminance is 5000lx [4]. During the simulation, the slight differences caused by the model building process are temporarily ignored, and the focus is on the comparative analysis and optimization effect exploration of the research objects, aiming to provide strong data support and theoretical basis for the subsequent day lighting optimization strategies.

3.2. Analysis of the Simulation Results of the Light Environment

3.2.1. Minimum Daylight Factor

Based on the Chinese daylight climate zoning table in the "Standard for Architectural Day lighting Design (GB50033 - 2013)", it is determined that the daylight climate zone where the two natural villages are located belongs to Zone III, and its daylight climate coefficient K is 1.00. According to the relevant regulations on side day lighting of folk houses, the minimum value of the daylight factor for side day lighting in the local area, Cmin, can be calculated by the formula "standard value × daylight climate coefficient (K = 1.00)". After calculation, the corrected value should be 2, which means that for spaces such as living rooms and bedrooms in buildings, the minimum daylight factor should not be lower than 2.00%, and the indoor natural illuminance should not be lower than 300 lx [4 - 5]. Observing from the results obtained in the simulation experiment, the actual situation of the minimum daylight factor in each area is as follows: Cmin in Area A is 0.6%, Cmin in Area B is 0.8%, Cmin in Area C is 0.5%, and Cmin in Area D is 0.6%. Obviously, compared with the minimum standard value of the daylight factor stipulated by the state, none of these areas meet the requirements. However, among them, the minimum daylight factor in Area C performs relatively better compared with the daylight factors in other areas. This advantage fully demonstrates that in architectural design, a reasonable increase in the number of windows and the setting of a high interior ceiling structure can effectively improve the lighting conditions obtained in the indoor space, allowing the indoor space to obtain more natural light.

3.2.2. Daylight Uniformity

It is found through simulation experiments that due to factors such as single day lighting methods and window shapes, the indoor day lighting conditions of the folk houses are not satisfactory, and most areas cannot meet the minimum day lighting requirements. The results are shown in Figure 3.Specifically, the daylight factor in Area A varies from 0.6% to 10.6%, among which about 90.56% of the area does not reach the minimum daylight factor standard; the daylight factor in Area B ranges from 0.8% to 10.8%, and approximately 88.8% of the area does not meet the minimum daylight factor requirement; the daylight factor in Area C is between 0.5% and 10.5%, and about 81% of the area fails to meet the minimum daylight factor; the daylight factor in Area D fluctuates from 0.6% to 10.6%, and about 88.8% of the area does not satisfy the minimum daylight factor. In addition, according to the "Green Building Evaluation Standard (GB/T 50378 - 2019)" [6], for a building that meets the green building standard, its indoor day lighting area should account for 75% of the indoor building area. From the simulation results, it can be seen that neither of the two folk houses meets the day lighting standard requirements of the green building.

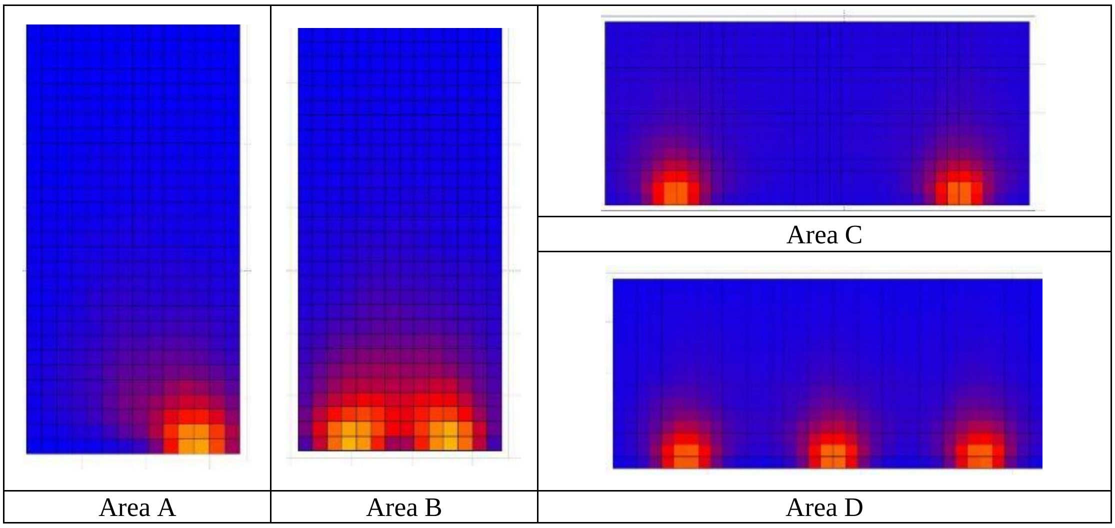


Figure 3: Simulation analysis of the light environment in the selected area.

ISSN 2663-1563 Vol. 7, Issue 1: 114-121, DOI: 10.25236/AJAGE.2025.070115

Through a detailed comparison between Area A and Area C as well as Area B and Area D, it can be found that the indoor day lighting effect of House No. 1 is somewhat better than that of House No. 2. This clearly shows that under the condition that the gable shapes are the same but the window sizes are different, House No. 1 can obtain relatively better day lighting results. However, the advantage gap between the two is not significant. Compared with House No. 1, House No. 2 has a more considerable usable area and a more reasonable spatial layout. This makes people in mountainous areas more inclined to adopt the architectural form of the front facade of House No. 2 when the building usable area is limited.

4. Measures and Simulation of the Light Environment Optimization

Based on the above analysis, it can be clearly seen that under the condition of the same gable form, the difference in the daylight factor between the two types of folk houses is not significant. In mountainous areas, the distribution of the second type of folk houses is more widespread. Its first floor is usually used as a living room, and the second floor is mainly used as a storeroom or a temporary bedroom. This layout endows it with better usability. Therefore, this study selects the second type of folk house as the key object for optimization simulation, and then proposes targeted optimization strategies and conducts a comparative study of the light environment optimization simulation to deeply explore the impact of different conditions on the indoor day lighting situation. For stone-built folk houses, there are great difficulties in renovating the light environment of the indoor space, and the setting of door and window openings is restricted by the traditional form. At the same time, considering the need to protect the traditional folk house style, on the basis of preserving the integrity of its historical style as much as possible, it is necessary to coordinate the relationship between style protection and day lighting condition optimization.

4.1. Day lighting Optimization Measures

The folk houses in the Taihang Mountains area are significantly affected by the dry and cold climate in winter. In view of this, doors and windows, as the key channels for indoor and outdoor air circulation, should be opened as little as possible in winter to prevent heat loss. At the same time, it is necessary to ensure that the indoor has good ventilation conditions to maintain the freshness and circulation of the air. Although the door also affects day lighting to a certain extent, this impact is relatively limited. Among the folk houses where people live, there are mainly two common ways to renovate the windows: First, replace the original windows with modern sliding windows made of glass; Second, use glass or plastic film to completely cover the traditional grid windows and vertical lattice windows. However, neither of these two renovation methods can simultaneously meet the multiple needs of day lighting, ventilation, and the protection of the traditional folk house style. Therefore, we have proposed the following window optimization scheme (see the figure for details), aiming to renovate and upgrade the traditional grid window. The renovated window consists of two parts: One part is the traditional grid window that retains its original style. It is fixed on the wall, not only forming a characteristic element of the building's exterior appearance but also serving as the window frame, without any covering material added, so as to preserve its traditional charm to the greatest extent; The other part is the newly added casement window part. Its sash is installed inside the grid window and opens inward. In this way, not only is the traditional architectural style of the folk house ensured to be continued, but also the indoor day lighting effect is effectively optimized, and the ventilation environment is improved at the same time, realizing the organic integration of tradition and modernity, aesthetics and practicality.

In addition, as another factor affecting indoor day lighting, the door has a significant impact on the indoor lighting conditions. During the field research, we observed that residents divided the door into two parts: the outer part and the inner part. The design of the outer part mainly focuses on functions such as day lighting, ventilation, and preventing mosquitoes. The upper part of the outer part adopts a grid wooden strip structure, and the lower part is equipped with wooden boards. The inner part is equipped with a complete door panel. When the door panel is closed, it can fully ensure the privacy of the indoor space (as shown in the figure below). Based on this, we selected the C area on the first floor of House No. 2 as the research object and carried out a detailed comparative analysis of the day lighting conditions before and after the implementation of the optimization measures. At the same time, for the windows in the D area on the second floor of House No. 2, we have also formulated a series of targeted optimization strategies, including appropriately increasing the number of windows and optimizing the day lighting angle and glass material of the windows, so as to comprehensively improve the indoor day lighting quality and create a brighter and more comfortable living space for the residents, The results are shown in Figure 4.

ISSN 2663-1563 Vol. 7, Issue 1: 114-121, DOI: 10.25236/AJAGE.2025.070115

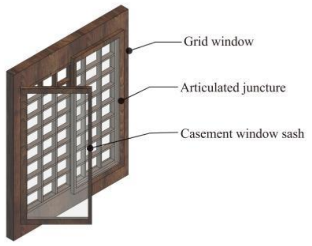
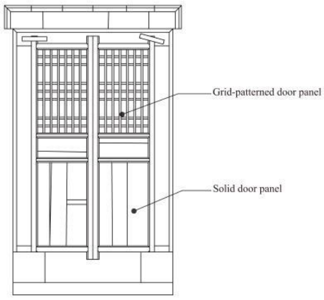
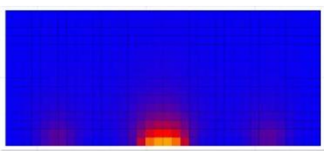
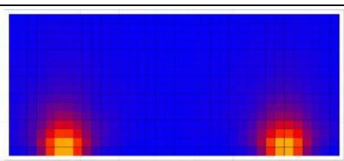
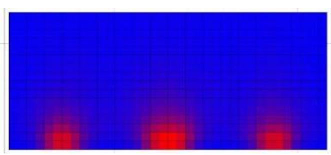
		
Window improvement	Examples of some grid-pattern wooden doors	Illustration

Figure 4: Door and window optimization

4.2. Simulation Scheme for Day lighting Optimization

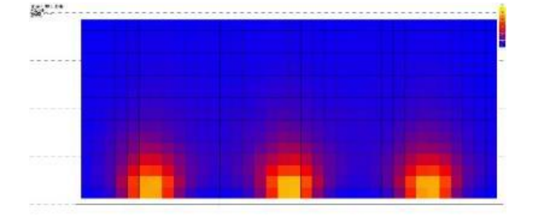
The residential houses in the mountainous areas of Qinyang City are mainly built with bluestone, which gives them the unique advantage of being warm in winter and cool in summer indoors. However, restricted by the local natural conditions, the window openings of these residential houses are relatively small during construction, resulting in poor day lighting conditions. To improve this situation, this research has implemented a series of day lighting environment optimization measures for the No. 2 residential house and carried out a comparative analysis of the day lighting coefficients before and after optimization to evaluate the optimization effect. In addition, in order to gain an in-depth understanding of the specific impact of the open and closed door states on the indoor day lighting of stone-built residential houses, in this simulation, the cleanliness of the optimized windows is set at an average level, that is, X = 0.9. Given that the interior walls of the residential houses are mostly grayish-black and hardly have any reflective properties, indoor light reflection and other minor factors are ignored during the simulation process to ensure that a scientific and reliable basis is provided for the day lighting optimization of residential houses in this area.

As another crucial factor for indoor day lighting, doors have a significant effect on improving the indoor day lighting coefficient. In this regard, a day lighting simulation with the door open was carried out for Area C and D, and the results are shown in the Figure 5 and Figure 6 below. The data indicates that by opening the door, the minimum indoor day lighting coefficient has jumped from 0.5% to 1%, and the day lighting range has also expanded to 1.0% - 41.0%. The average day lighting coefficient has been substantially increased from 1.14% to 3.07%, which has greatly improved the indoor day lighting conditions of the residential house and has had an important impact on the overall indoor layout. By comparing the day lighting coefficients before and after the window optimization, it can be clearly seen from Table 2 that after the optimization, the percentage value of the area with a low day lighting coefficient shows an obvious downward trend, while the other day lighting coefficients have all increased. Especially for the day lighting coefficient in the range of 8.5% - 10.5%, a breakthrough change from none to existence has been achieved, and the average day lighting coefficient has been increased from 1.14% to 1.31%. It can be concluded that although the improvement in indoor day lighting brought about by the window optimization is relatively limited in magnitude, the effect is still noticeable. In addition, the use of a wooden door with a grid pattern on the upper part has a favorable effect on improving the indoor day lighting. The average day lighting coefficient has been further increased to 2.22%, and the day lighting range has been expanded to 0.8% - 20.8%, providing a new and effective way for the day lightingoptimization of residential houses.

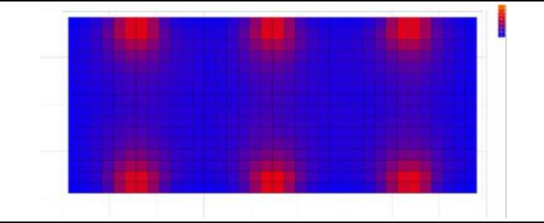
		
Open the door in Area C	Window optimization in Area C	Door and window optimization in Area C

ISSN 2663-1563 Vol. 7, Issue 1: 114-121, DOI: 10.25236/AJAGE.2025.070115

Figure 5: Comparative analysis of the C region simulation



Window optimization in Area D



Window optimization and window addition in Area D

Figure 6: Comparative simulation analysis in Area D

Each bay on the second floor of Residence No. 2 is equipped with a window. After the window is optimized, the average day lighting coefficient is increased from 1.72% to 1.97%. According to the green building standard limits stipulated by the specifications, the area with a day lighting coefficient greater than 2% accounted for approximately 19.87% before optimization and increased to 25.58% after optimization. However, overall, the improvement effect on the day lighting of the residence is not significant. If more sufficient day lighting is to be obtained for the residence, increasing the number of windows is undoubtedly the most direct and effective way. Among the other residences in Changping Village, there are a small number of residences with windows installed on the front and rear walls of each bay on the second floor. A simulation analysis was carried out on this, and the results showed that increasing the number of windows can bring about a qualitative leap in indoor day lighting. The area with a day lighting coefficient greater than 2% accounts for as high as 93.8%, meeting the day lighting standard requirements of green buildings and providing a practical and feasible direction for the day lighting optimization of residences.

Table 2: Comparison of window optimization before and after in Area C

State	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	6.5-7.5	7.5-8.5	8.5-9.5	9.5-10.5
Before optimization	85.06	7.47	2.07	1.91	0.95	1.27	0.64	0.32	0	0
After optimization	81.72	8.74	2.86	2.07	1.11	0.95	0.95	0.48	0.64	0.32
Difference (Before-After)	3.34	-1.27	-0.79	-0.16	-0.16	0.32	-0.31	-0.16	-0.64	-0.32

5. Conclusion

This research takes the current situation of the light environment in traditional folk houses as the starting point and conducts a day lighting simulation analysis on two traditional stone masonry folk houses in the mountainous area of Qinyang City from aspects such as type, roof form, and window type. It focuses on comparing the respective advantageous characteristics of these two folk houses under the condition of the same number of doors and windows. The specific results are as follows: First, the cave-style stone folk houses in this area create a relatively good indoor day lighting environment by virtue of their high-ceilinged spatial structure and centralized window layout. Second, the day lighting performance of the main functional rooms in the two traditional stone masonry folk houses is far from meeting the requirements of the national building day lighting design standards, and the indoor light environment quality is poor. Third, through an in-depth analysis of the day lighting data of the No. 2 folk house and the implementation of improvement measures on the windows of the traditional stone masonry folk houses, although the day lighting effect has been improved to a certain extent, the improvement range is not significant. Compared with the indoor light environment with the door open, there are large differences in both the day lighting coefficient difference and the day lighting range. To effectively meet the standard requirements for indoor day lighting in buildings, methods such as increasing the reflectivity of the indoor building environment and appropriately increasing the number of windows can be adopted to achieve the optimization goal, thus providing a practical way to improve the day lighting of traditional stone masonry folk houses.

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References

[1] Pang Lu, Han Weiran, Yan Shaofei. Research on the Light Environment of Traditional Courtyard Houses in Shanxi and Shaanxi—Taking the Indoor Day lighting of Two Residential Houses as an Example[J]. Journal of Xi'an University of Architecture and Technology (Natural Science Edition), 2022, 54(05): 701-709.

[2] He Miao, Xue Jiawei. Simulation and Optimization of the Light Environment of Traditional Folk houses in Dongshan Village, Jinjiang City[J]. Journal of Fuzhou University (Natural Science Edition), 2016, 44(06): 826-832.

[3] Huang Haijing, Dong Zhang. Field Measurement and Simulation Optimization of the Light Environment of Traditional Folk houses—Taking the Miao Folk houses in Huangtu Village, Danzhai County, Southeast Guizhou as an Example[J]. Journal of Chongqing University, 2021, 44(09): 17-30.

[4] Wang Yansong, Xu Boyu. Research on the Light Environment of Folk houses in the Southern Region of Yongzhou Based on Software Simulation—Taking Shanggantang Village and Tan Tian Folk houses as Examples[J]. City & Architecture, 2022, 19(04): 24-27.

[5] Ministry of Housing and Urban-Rural Development. Standard for Day lighting Design of Buildings (with Explanatory Articles): GB50033-2013[S]. Beijing: China Architecture & Building Press, 2013: 6-8.

[6] Ministry of Housing and Urban-Rural Development. Assessment Standard for Green Buildings: GB/T50378-2019[S]. Beijing: China Architecture & Building Press, 2019: 11-13.