Multi-Objective Optimization Design for Horizontal External Sunshade Design of West-Facing in Cold Region

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Abstract. Building sunshade components can effectively control solar radiation getting into the room and play an important role in the building thermal insulation. The study takes the west facade of the graduate dormitory at Guzhenkou Campus of China University of Petroleum as the research object. The angle, length, quantity, spacing of the horizontal external sunshade louvers and the distance between the sunshade and the top edge of the window are used as independent variables. Heat protection in summer and heat gain in winter, energy saving and material reduction are used as optimization goals, using Grasshopper as platform to simulate, and finally calculating the optimal solution set for horizontal external sunshade of west-facing based on genetic algorithm theory. Then the optimal solution is selected base on the architecture project requirements. Finally, substituting optimal solution into the parametric model for verification and confirming the results of multi-objective optimization. Based on the concept of energy saving and material reduction, The study improves indoor thermal comfort by optimization design of horizontal external sunshade on west facade of student dormitories in cold region. The study has the certain practical application value for the design of student dormitories in cold region.

Keywords: school dormitory; multi-objective optimization; horizontal external sunshade; cold region

1 Introduction

The number of college students is increasing year by year as the scale of higher education expanding, which leads the number requirements of student dormitories to increase gradually[1]. With the improvement of people's living standards, students' demands for indoor comfort increase gradually. In recent years, optimization algorithms have been widely used in construction engineering practice. Algorithm tools are used to perform simulation and calculation, and then iterating optimization design results[2].

The student dormitory plays an important role for college students, thus improving the indoor thermal comfort becomes more and more important to improve students'

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quality of life. Xia bo and others studied the thermal comfort of university student dormitories in summer, and pointed out that the use of sunshade components can be considered to improve the indoor thermal environment during construction[3]. Lin Rongbo and others studied a large number of domestic and foreign case analyses, and pointed that the sunshade can effectively improve building performance and indoor comfort[4]. Cui Qiuyan and others studied the positive impact of external sunshade on saving building cooling energy in cold region[5]. He Zhimin and others studied the influence of the louver angle and the length of louver on the solar radiation received by the east and west sides of the building[6]. Wang Jiao and others verified that external sunshade has a significant effect on indoor temperature control in west-facing rooms by actual measurement[7]. Existing design of external sunshade mostly aims to reduce solar radiation getting into the room in summer, with less consideration of heat gain in winter. Therefore, the study takes the graduate dormitory at the Guzhenkou Campus of China University of Petroleum as an example, using the Grasshopper as platform to conduct the multi-objective optimization design of the external sunshade of west-facing, which achieves the goals of heat protection in summer, heat gain in winter, energy saving and material reduction.

2 Research methods and objects

2.1 Multi-objective optimization

Multi-objective optimization is used as realistic models for many complex engineering optimization problems. There are some sub-goals that mostly conflict with each other, and the improvement of one sub-goal may cause the performance of other sub-goals to decrease[8]. Therefore, multi-objective optimization is used to find a optimal solution. There is an obvious conflict between heat protection in summer and heat gain in winter. A substantial improvement in one performance will inevitably lead to a decrease in the performance of the other. At the same time, reducing sunshade louver consumption will also restrict the other two goals to a certain extent. The horizontal external sunshade design in this study has multiple goals that influence each other, which is a typical multi-objective optimization problem. Therefore, multiple goals need to be introduced. The optimization algorithm is parameterized for three performance goals. The most commonly used multi-objective optimization method was proposed by Pareto[9], which is the Pareto optimization method. It can systematically explore multiple combinations of parameters and generate a series of solutions through trade-offs between extreme situations. The solution can be determined with higher quality from solution set. The study' technical route of the research plan was formulated as Figure 1.

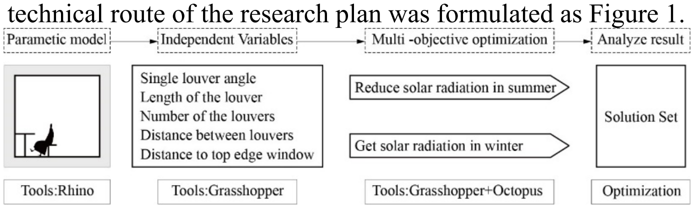

Fig. 1. Technical route of the research plan

2.2 Research objects

China University of Petroleum Guzhenkou Campus is located in the West Coast New District of Qingdao. The graduate dormitory is located on the southwest side of the main campus entrance. The windows on the west facade of the dormitory are evenly distributed with the same size. The window height is 2.7m, the width is 2.3m, and the wall width between windows is 0.4m.

Qingdao is located in the cold region, which belongs our country's building thermal design region. The design requirements are that buildings in the area should meet the need of thermal insulation in winter while taking into account heat protection in summer[10].The annual dry bulb temperature in Qingdao is shown in Figure 2. It can be seen from the figure that the temperature in summer (June to September) is around 27°C, and in winter (December to March) the temperature is around 0°C. Qingdao has a temperate monsoon climate, characterized by humid air, abundant rainfall, moderate temperatures, and four distinct seasons. The temperature rises slowly in spring, one month later than inland. The summer is hot and humid and rainy. In autumn, the weather is cool and pleasant. In winter, the wind is strong and the temperature is low, which lasts for a long time. According to the specific times of the vernal equinox, autumnal equinox, summer solstice, and winter solstice among the twenty-four solar terms, the period of heat protection in summer is from June 22nd to September 23rd, and period of heat gain in winter is from December 22nd to March 21st.

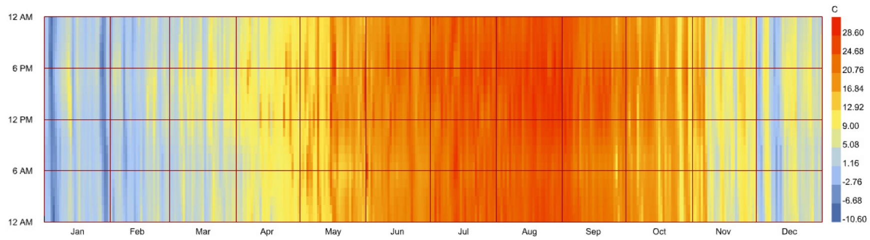

Fig. 2. Annual dry bulb temperature in Qingdao

The annual solar radiation in Qingdao City are shown in Figure 3. It can be seen that Qingdao has higher thermal radiation in summer and lower thermal radiation in winter, which is similar to annual temperature changes. At the same time, the altitude angle of sun is one of the factors that affects the intensity of solar radiation, which affects the selection of the form of sunshade components. The altitude angle of sun is larger in summer and smaller in winter. Choosing horizontal external sunshade as the form of sunshade because the characteristics of horizontal sunshade has good impact in summer[11].

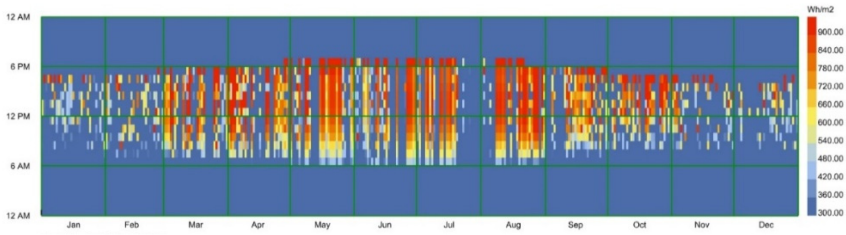

Fig. 3. Annual average solar radiation in Qingdao

It can be seen from Figure 4 that the solar radiation is highest in the west direction, so heat protection is particularly important for west-facing dormitories. Combining with the form of sunshade components, this study determines the horizontal sunshade on the west facade of the graduate dormitory at Guzhenkou Campus of China University of Petroleum as the research object and conducts multi-objective optimization design.

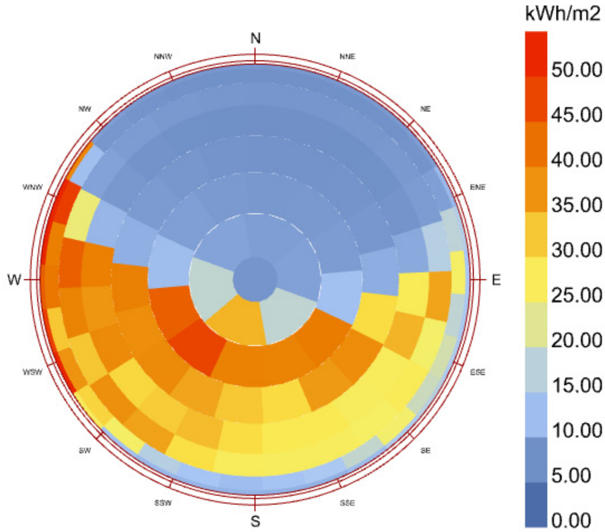

Fig. 4. Annual average solar radiation in different direction

3 Research steps

3.1 Parametric model

In order to facilitate calculation, this study simplifies the spatial form of a single dormitory on the west facade of the graduate dormitory on the Guzhenkou Campus of China University of Petroleum. A parametric model of a single dormitory is established based on the sizes of the project design as shown in Figure 5 [12].

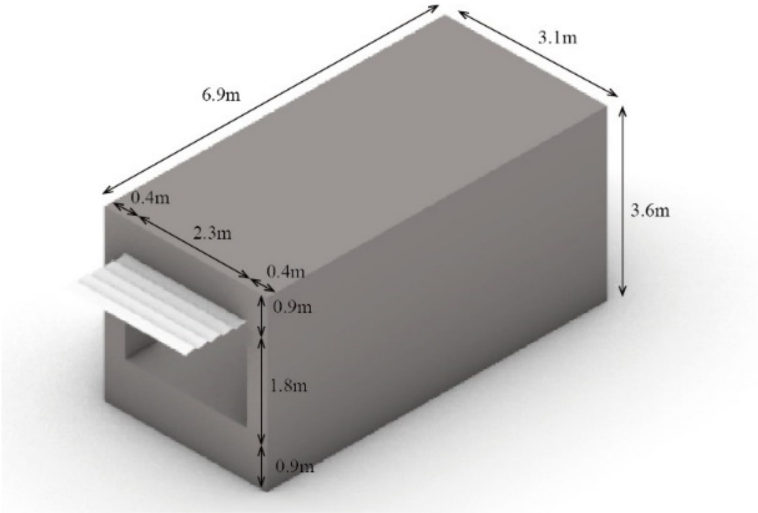

Fig. 5. Parametric model

3.2 Independent variable configuration

According to the common dimensions and characteristics of horizontal external sunshade, the following independent variables are established : ① The rotation angle of a single louver, 0° is set as the horizontal plane, with the window side as the axis, clockwise rotation is positive, counterclockwise rotation is negative, the range is −90 ° ~ 90 °, and the accuracy is 1 °; ② The length of the single louver, the range is 0.05 m ~ 0.20 m, and the accuracy is 0.01 m; ③ The number of louvers, from 1 to 15; ④ The spacing of the louvers, the range is 0.10 m ~ 1.50m, and the accuracy is 0.01 m; ⑤ The distance between the horizontal external shading and the upper edge of the window, the range is 0.0m ~ 1.8m, and the accuracy is 0.1m, as shown in Figure 6[13].

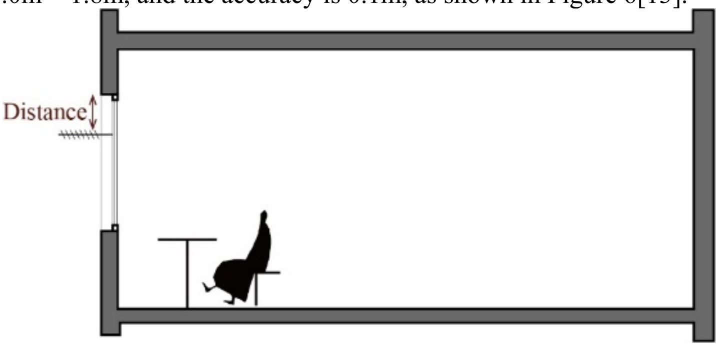

Fig. 6. The fifth independent variable

3.3 Design of optimization objectives

The shading effect of horizontal external shading is represented by the external shading coefficient. The external shading coefficient (SD) is defined as: under the same solar radiation condition, the ratio of the average solar radiation received by the window (hole) with external shading to the average solar radiation received by the window without external shading [14]. Based on the research objects and climate characteristics of the base, the following design objectives are established: ① Heat protection in summer: In order to ensure effective shading, the external shading coefficient (SD) in summer should be as small as possible. This effectively reduces the amount of solar radiation entering the room; ② Heat gain in winter: In order to ensure indoor heat gain, the external shading coefficient (SD) in winter should be as large as possible. This effectively increases the amount of solar radiation entering the room; ③ Reduce louver materials consumption: Based on the principle of energy saving and material reduction, less louver materials are used[15]. Using Ladybug, a plug-in of Grasshopper platform, the results of the average solar radiation of dormitory space in summer and winter with or without the horizontal external sunshade can be obtained. Then, the external shading coefficient in summer and winter can be calculated.

4 simulation and data analysis

4.1 Optimization process and results

Based on the genetic algorithm theory, using Grasshopper platform to do multi-objective optimization. The values of the independent variables are constantly changing, so that the calculation iterates through a large number of solution sets. When the computation finally converges, the optimal solution set will be obtained. This study performs multi-objective optimization on the horizontal external sunshade of west facade of the graduate dormitory, and iterates calculations until the solution set is stably distributed, as shown in Figure 7. The X-axis represents the summer SD, the Y-axis represents the winter SD, and the Z-axis represents the total length of the louvers. This study takes heat protection in summer, heat gain in winter, energy saving and material reduction as the optimization goals. Thus, summer external shading coefficient, total length of the louvers should be as small as possible, winter external shading coefficient should be as large as possible.

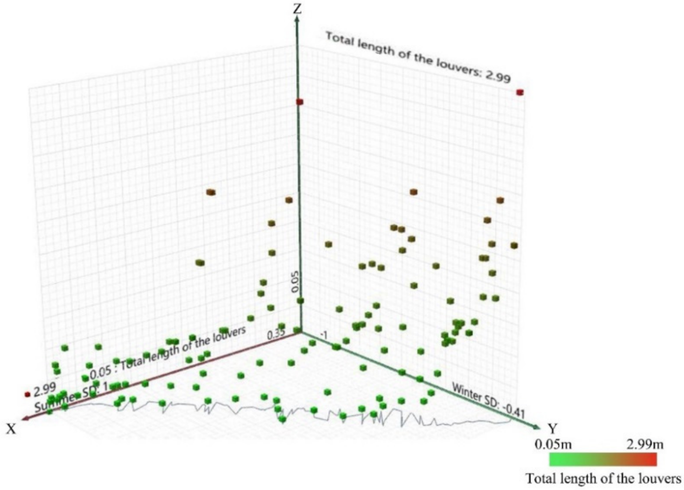

Fig. 7. The optimal solution set of optimization design

4.2 Result analysis and verification

Through optimization calculations, 223 sets of data were obtained after 2000 iterations of horizontal external sunshade components. To more intuitively determine the need for a smaller summer external shading coefficient and a larger winter external shading coefficient, the difference between them is calculated . This provides a more visual representation of whether the conditions are met. As shown in Table 1, the most representative 9 sets of data that have been selected are presented.

Table 1. Nine representative solution sets of horizontal external sunshade

NO.	Louver Angle /(°)	Length of Louver /(m)	Number of Louvers /(piece)	Distance between Louvers /(m)	Distance to top edge of window /(m)	Total Length of Louvers /(m)	Summer SD	Winter SD	Difference of SD
1	8	0.25	6	0.22	0.2	1.50	0.6526	0.7440	0.0914
2	-48	0.07	11	0.13	0.1	0.77	0.7206	0.8052	0.0846
3	-18	0.05	10	0.12	0.3	0.50	0.6854	0.7481	0.0627
4	-23	0.07	12	0.13	1.1	0.84	0.6495	0.7242	0.0747
5	5	0.10	10	0.14	0.4	1.00	0.5664	0.6546	0.0882
6	86	0.06	10	0.12	0.1	0.6	0.9030	0.9650	0.0620
7	-38	0.18	7	0.22	0.2	1.26	0.4769	0.5486	0.0717
8	84	0.06	6	0.20	0.4	0.36	0.7073	0.7788	0.0715
9	3	0.09	12	0.13	0.3	1.08	0.6221	0.7013	0.0792

The relationship among the total length of the louvers, summer external shading coefficient, winter external shading coefficient and the difference of external shading coefficient is clearly shown in Figure 8. Through analysis, it can be seen that Group 1 has the largest difference in external shading coefficient, but it has the most louver consumption. The total length of the louver reaches 1.50m in Group 1. Group 7 has the smallest summer external shading coefficient. However, the winter external shading coefficient is slightly smaller. Group 6 has the largest winter external shading coefficient. However, the summer external shading coefficient is slightly larger. Group 8 has the least louver consumption. However, the summer external shading coefficient is slightly larger. Group 2 and Group 5 has large difference of summer external shading coefficient and winter external shading coefficient. However, Group 2 has a larger summer external shading coefficient, and Group 5 has a smaller winter external shading coefficient. The indicators of Group 4 are relatively balanced. But the horizontal exterior shading component is located at a considerable distance from the upper edge of the window, approximately 1.7m above the indoor floor level, which may affect the sight of the student in dormitory. The indicators of Group 3 are relatively balanced, but the difference of summer external shading coefficient and winter external shading coefficient is slightly smaller. The indicators of Group 9 are relatively balanced. Horizontal external sunshade components from Groups 1 to 9 all have their own advantages and disadvantages, and the optimal solution can be selected according to the design needs of the construction project.

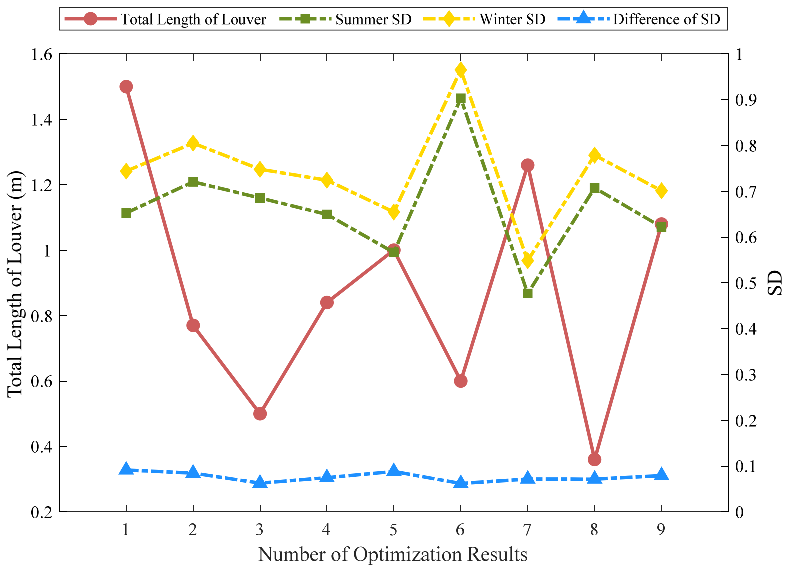

Fig. 8. The results of optimization target

The design requirement of this project is that all indicators are close to the optimal value and relatively balanced, so the horizontal external sunshade components of Group 9 were finally selected. Using the Ladybug in the Grasshopper platform, the independent variable data corresponding to group 9 is applied to the parametric model of a single dormitory space, and the distribution of solar radiation in the dormitory indoor space in summer and winter is calculated. As shown in Figure 9, when there is no horizontal external shading in summer, the dormitory space becomes partially overheated. Horizontal external shading effectively alleviates the local overheating indoors and achieves the goal of heat protection in summer. In winter, with horizontal external shading, the impact is as minimal as possible. Solar radiation enters the room, achieving the goal of gaining heat in winter.

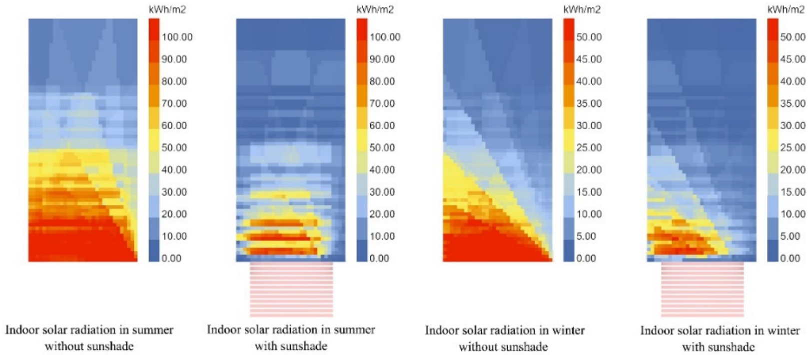

Fig. 9. Group 9 simulation diagrams of summer and winter solar radiation before and after horizontal external sunshade components

5 Conclusion

This study used genetic algorithm as the research theory, multi-objective optimization as the research method. With the goals of heat protection in summer, heat gain in winter, energy saving and material reduction, using Grasshopper as the research platform. Based on the actual situation of the construction project called graduate dormitory of Guzhenkou Campus of China University of Petroleum, the multi-objective optimization design of horizontal external sunshade on the west facade have been carried out. Using the Grasshopper platform plug-in named Ladybug to analyse the climate information of the site. Then the type of sunshade has been selected based on the climate information. The parametric model was simplified according to the size of construction project. Then establishing the independent variables

on the basis of characteristics of horizontal external sunshade. Finally, the Grasshopper platform plug-in named Octopus was used to complete multi-objective optimization based on genetic algorithm theory, thereby screening out the optimal solution. Through verification, it was determined that the louver length is 0.09m, the rotation angle is 3°, the spacing between the louvers is 0.13m, and a horizontal external sunshade component composed of 12 louvers. When the horizontal external sunshade component is 0.3m away from the upper edge of the outer window, it can effectively reach the goals of heat protection in summer, heat gain in winter, energy saving and material reduction, thereby improving the indoor thermal comfort of the dormitory space.

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