

Multi objective optimization of window to wall ratio of University Gymnasium in severe cold area by coupling natural lighting and energy consumption

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Abstract. Objective To explore the relationship between window opening ratio and natural lighting and energy consumption of University Gymnasiums in severe cold area, and put forward optimization strategies. **Methods** Digital simulation technology was used to simulate the energy consumption and natural lighting of University Gymnasium window opening ratio, and the window opening scheme with natural lighting and low energy consumption was obtained. **Conclusion** The side window lighting should be used in the window opening scheme of small and medium-sized university gymnasiums. Within the range of experimental data, the North-South lighting is the main lighting mode, and the East-West lighting is the auxiliary.

1 Construction of typical information model

1.1 Establishment of general model of University Gymnasium in cold regions

With the reform and development of China's higher education, the scale of higher education is gradually expanding, and the cultivation of students' sports quality has been widely valued. Gymnasium has gradually become one of the indispensable components of the architectural group in colleges and universities. Due to the large building volume, the energy consumption and the operation and maintenance costs of various facilities in the process of using the stadium are far higher than expected [1-3]. In recent years, with the wide application of digital technology in green design, the single building performance analysis of building energy consumption, such as natural lighting and lighting ventilation, has gradually developed into a multi-objective building performance evaluation. For example, the paper for Zhang on Bin [4] aimed at urban buildings in Beijing, aiming at lighting coefficient, visual comfort and building heat

consumption, This paper studies the optimization of the window form of residential buildings in the city. There are also similar simulation experiments that aim at building cluster shape, Da, UDI and various energy consumption, such as , Liu Yao [5], sun Cheng [6], etc. In this paper, grasshopper parametric modeling, ladybug & honeybee energy consumption simulation tools are used. On this basis, the multi-objective optimization tool octopus is used to optimize the window wall ratio of typical university. The natural lighting and energy consumption coupling optimization is carried out, and the window design strategy of University Gymnasiums considering both natural lighting and energy consumption is summarized, It provides a theoretical basis for the natural light environment optimization and low energy consumption design of large space buildings in cold regions.

Gymnasium is a typical large space building, which is obviously different from other general education buildings in space scale, function and structure. In order to get more information about the characteristics of University gymnasiums, the author systematically combs 20 famous University Gymnasiums built in recent years in severe cold areas in China, as shown in Table 1.

Table1. Survey data of University Gymnasium

Region (province)	Building name	Scale	The measure of area (m ²)	height (m)	Number of seats (seats)	Natural lighting	Architectural form	Site size (m)
Liaoning	Shenyang University Gymnasium	Medium-sized	18900	—	5000	Side window	Rectangle	
	Liaoning University Gymnasium	Medium-sized	16500	17.5	4000	Side window	Cylinder	
	Shenyang Jianzhu University	Medium-sized	14000	19.4	1600	Skylights and side	Rectangle	54×32

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	Northeast University Gymnasium	Small-scale	11000	17.2	1500	Side window	Ellipse	
	Shenyang University of Technology Gymnasium	Medium-sized	13000	22	4644	Side window	Ellipse	42×55
	Gymnasium of Dalian University of Technology	Medium-sized	17000	25	5800	Side window	Ellipse、rectangle	39×25
Jilin	Jilin University Gymnasium	Medium-sized	36000	24	—	Side window	Circular、rectangle	
	Gymnasium of Changchun Institute of	Medium-sized	11000	17.6	2700	Side window	Rectangle	
	Jilin University of architecture Gymnasium	Small-scale	—	22	2300	Side window	Rectangle	
	Gymnasium of Changchun University of traditional Chinese	Small-scale	—	19	800	Side window	Rectangle	
Heilongjiang	Harbin Institute of Technology Gymnasium	Small-scale	7500		3000	Skylights and side	Irregular rectangle	61×30
	Gymnasium of Harbin University of science and	Medium-sized	33000	22	2700	Skylights and side	Ellipse、circular	
	Gymnasium of Northeast Agricultural University	Small-scale	16000	—	—	Skylights and side	Diamond	
	Heilongjiang University Gymnasium	Small-scale	17000		3000	Side window	Rectangle	

The analysis shows that the basic plane shape of University Gymnasiums in severe cold areas are mostly regular shapes such as rectangle, circle and ellipse, as well as a small number of irregular shapes. Based on the above considerations, this paper constructs a typical information model of University Gymnasium. The scale of University Gymnasium is small and medium-sized, with 3000 seats and 6000 seats respectively. The size of the stadium is about 38m×54m、32m×44m、24m×26m。 In this paper, using grasshopper parametric modeling, the general model is divided into two cases of medium-sized and small university gymnasium, and the size of medium-sized stadium is selected as 38m ×54m, with 3000 seats in the auditorium. According to the seat size (seat width 0.5m, row spacing 0.85m), the plane size is calculated to be 51m×69m, building height 25m; The size of the small playground is 32m ×44m, with 1500 seats in the auditorium, and its plane size is 42m×54m, and the height is set at 15m. According to the design code for sports buildings^[7], the starting height of the auditorium stands is about 2m, and the slope angle of the stands is between 28°~ 30°.

1.2 Parameter setting of natural lighting and energy consumption simulation

1.2.1 Setting of natural lighting parameters

Effective natural lighting intensity is an important index to evaluate indoor lighting effect. In this paper, the daylight simulation system module of honeybee tool is used to simulate the natural daylighting experiment. The effective natural daylighting intensity in the year-round dynamic evaluation daylighting simulation is used as the evaluation standard of natural daylighting experiment simulation. The concept is to meet the target space illumination demand in a period of time in the test plane as a percentage of the whole year. The acceptance range of illumination is generally defined as 100lux ~ 2000lux.

The main function of University Gymnasium is daily class and training. According to the standard for lighting design of buildings (GB 50034-2013), the required illumination of University Gymnasium in daily training is 300lux, so the effective illumination in this paper needs to be adjusted to the minimum value of 300lux(hereinafter referred to as udi300) during training.

(1) Lighting test point setting

As shown in Figure 2, the test method of light environment in software simulation is the same as the physical test method of light environment. The square grid composed of test points needs to be set in the sports ground part of the model, so the distance between each test point is 2m, and the height of test plane is 1.67m.

(2) Reflectivity setting of enclosure interface

In order to achieve the real indoor natural lighting effect, in the natural lighting simulation experiment, it is necessary to set the reflectivity of transparent materials and materials in the building in honeybee. According to the Architectural Lighting Design Manual, the reflectivity of roof, wall, ground and glass in the general model of University Gymnasium is set as 0.8, 0.5, 0.2 and 0.6 respectively.

(3) Natural lighting simulation experiment process

Finally, the external shape of the building, climate and enclosure interface material information are input into the main simulation engine, and the UDI value data group is obtained through simulation. The data group is the percentage of the illumination time of each lighting test point in a year to meet the daylighting evaluation index, that is, the corresponding UDI value of each test point. Finally, the average value of the data group is taken for comparison.

1.2.2 Building energy consumption parameter setting

The energy consumption of University Gymnasium Building generally comes from the power consumption and building heat consumption of daily classes, training,

competitions, air conditioning, fans, lamps and other equipment. The total power consumption includes the power consumption of artificial lighting and the operation of some equipment. Therefore, in this paper, we mainly focus on the energy consumption of cooling in summer, heating in winter, artificial lighting and other equipment operation in cold regions, and count the total energy consumption and energy consumption per unit area as the evaluation index of energy consumption.

(1) Thermal parameter setting

In this paper, Shenyang City is selected as the simulation site, according to its building climate zoning, and with reference to the "design standard for energy efficiency of public buildings" (GB 50189-2015). The general model of this paper is set according to the design standard of Low-E double-layer glass curtain wall, and the relevant setting parameters and simulation settings of external wall, roof and window are shown in Table 2.

Table2. Thermal parameters

Position	Heat transfer coefficient (W.m ⁻²)	Solar heat gain coefficient	Visible light transmittance
Exterior wall	0.43	_____	_____
Roofing	0.35	_____	_____
Outer window	2.00	0.4	0.45

(2) Indoor environment setting

a. Air conditioning parameter setting

Referring to the relevant parameters of air conditioning design manual, the design temperature of indoor air conditioning in summer and winter of University Gymnasium is set at 26 °C and 20 °C respectively. According to the climate and temperature characteristics of Shenyang area, the cooling time in summer is set from June 1 to August 31, and the heating time in winter is set from November 1 to March 31 of the next year. During the transitional season, natural ventilation is used for adjustment.

b. Human factor parameter setting

The utilization mode of University Gymnasium is very different from that of conventional gymnasium. In terms of operating time, the university gymnasium can be described as a full-time operation, with very high use efficiency. From Monday to Friday, it is used by university teachers and students in class all day, and provides fitness activities for students on weekends and evenings. In this paper, the maximum indoor personnel density is 0.4 person / m², the average metabolic capacity is 120 W / person, the equipment density is 8 w / m², and the lighting load density is 15.0 w / m².

(3) Energy consumption simulation experiment process

In the same process as the natural lighting simulation experiment, the external shape of the building, the information of climate and enclosure interface materials, and the information of building indoor environment are input into the main simulation engine. Through the simulation, the energy consumption data of heating, cooling, lighting, fan heat pump and other equipment of University Gymnasium is obtained, and the energy consumption data are accumulated together, and the total energy consumption of the whole year and the energy consumption per unit area of the building can be obtained through calculation.

2 Coupling simulation analysis of natural lighting and energy consumption

2.1 Simulation method of natural lighting and energy consumption coupling research

The natural lighting and energy consumption simulation is modeled by grasshopper under rhino platform, and the skylight and side windows of University Gymnasium are simulated. In the "Design Standard for Energy Efficiency of Public Buildings", it is stipulated that the area of transparent part of building roof should not be greater than 20% of the roof area, and the area ratio of single facade window to wall (including transparent curtain wall) of Class A public buildings should not be greater than 0.6. Therefore, the window wall ratio of University Gymnasium side interface is set as 0 ~ 0.6, the growth gradient is 0.05, and the south facade is as shown in the table; The window to wall ratio of skylight is 0 ~ 0.2, and the growth gradient is 0.02.

Then, using the genetic algorithm in the octopus calculator, and the parameter settings are shown in the table below. Through the continuous combination of various parameter variables, similar to the exchange and variation of gene fragments in genetics, the "individual" is a random combination of many parameter variables. Through the selection of building performance evaluation indicators (survival of the fittest), the variable parameter group that ultimately meets the conditions is obtained; After that, the Pareto economics is used to calculate the optimal solution of many parameters that meet the conditions. The parameter settings of octopus are shown in Table 3.

Table3. Octopus parameter setting

Elitism	Mutation Probability	Mutation Rate	Crossover Rate	Population Size
0.5	0.2	0.9	0.8	50

2.2 Simulation experiment of natural lighting and energy consumption coupling research

In the experimental evaluation index, the minimum value of natural lighting is $udi_{300} > 75\%$, and the energy consumption per unit area is the minimum value by default, that is, the minimum energy consumption. Considering that the main function of University Gymnasium is divided into daily training in class and taking into account the needs of competition, this paper discusses two cases separately.

2.2.1 Simulation experiment of natural lighting and energy consumption coupling research under training mode

(1) Experimental simulation results of gymnasium in medium sized Universities

This iteration has a total of 50 generations. After 125 hours of calculation, the results in the panel tend to be stable, and the results are convergent enough. The solution distribution is shown in Figure 1.

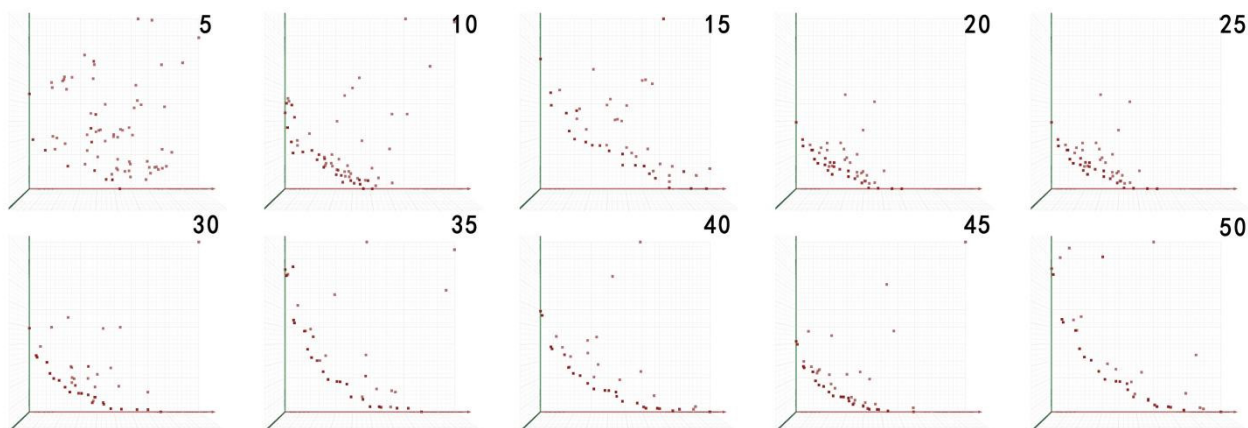


Figure 1. Solving distribution (medium)

(2) Experimental simulation results of small University Gymnasium Similarly.

after 125 hours of calculation, the results in the panel tend to be stable, and the solution distribution is shown in Figure 2.

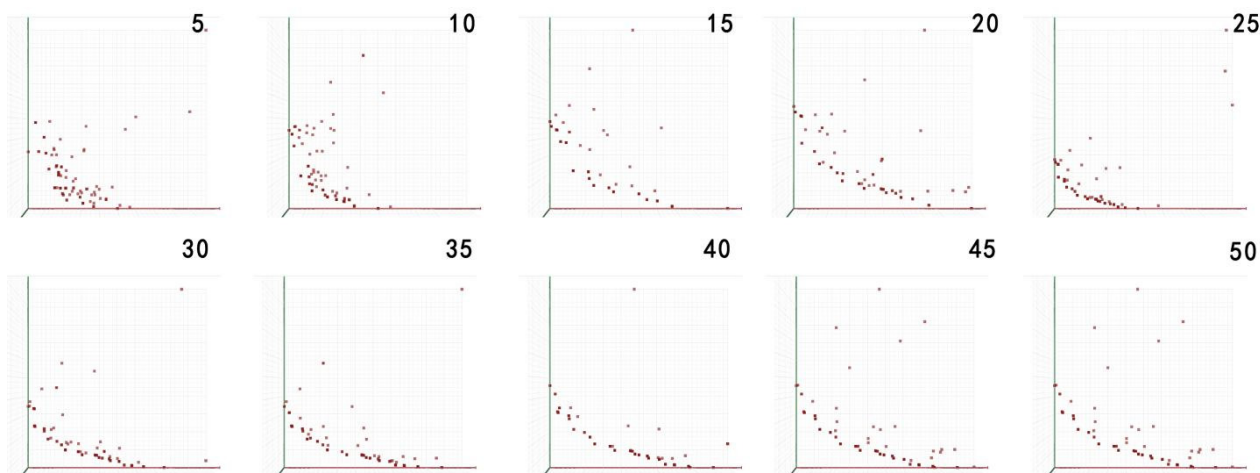


Figure 2. Solving distribution (small)

3 Natural lighting and energy saving design strategy

(1) In the coupling optimization design of natural lighting and energy consumption of medium-sized university gymnasiums, the 50th generation optimal solution analysis shows that the lighting mode should adopt side window lighting, mainly South lighting, or supplemented

by less East, West and North lighting, so as to obtain the minimum energy consumption and better effective illumination design values, such as figure 3 (a) and (b); In addition, North lighting can be used as the main lighting, while East, West and South lighting can be used as auxiliary lighting, so as to obtain the optimal effective illumination and less energy consumption design values, such as figure 3 (c) and (d).

The following are some of the optimal non-dominated solution sets in medium-sized University Gymnasiums:

Table4. Optimal non dominated solution set (medium)

Number	Window to wall ratio (East)	Window to wall ratio (South)	Window to wall ratio (West)	Window to wall ratio (North)	Window to wall ratio of skylight	UDI (300)	Energy consumption per unit area (kWh/m ²)
1	0	0.45	0	0	0	57.3	133.3
2	0	0.25	0.05	0.05	0	69.4	135.1
3	0.05	0.1	0.05	0.2	0	83.9	140.8
4	0.05	0.05	0.05	0.3	0	85.3	145.6

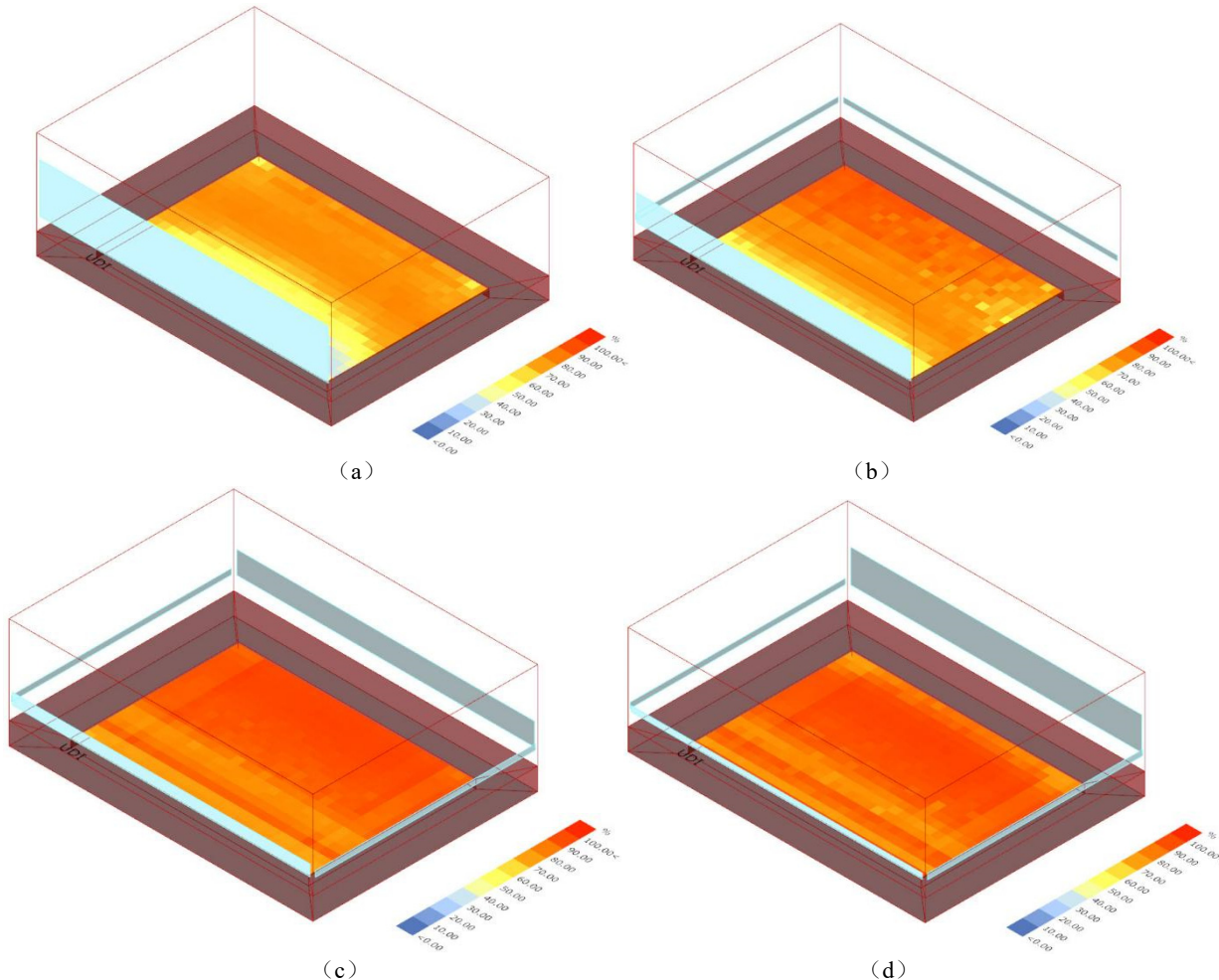


Figure 3. Effective illumination photothermal map (medium)

(2) In the coupling optimization design of natural lighting and energy consumption of small university gymnasium, the 50th generation optimal solution analysis shows that the side window lighting should be adopted in the lighting mode, with the South lighting as the main lighting mode and the East, West and North lighting as the auxiliary. The minimum energy consumption and better effective illumination design values can be obtained, such

as figure 4 (a) and (b); It can also be mainly North lighting, supplemented by East, West and South lighting, which can obtain the optimal effective illumination and less energy consumption design values, such as figure 4 (c) and (d).

The following are some of the optimal non-dominated solution sets in small University Gymnasiums:

Table5. Optimal non dominated solution set (small)

Number	Window to wall ratio (East)	Window to wall ratio (South)	Window to wall ratio (West)	Window to wall ratio (North)	Window to wall ratio of skylight	UDI (300)	Energy consumption per unit area (kWh/m ²)
1	0	0.35	0	0.05	0	66.5	118.9
2	0.05	0.2	0.05	0.1	0	78.0	120.8
3	0	0.1	0	0.3	0	85.0	125.2
4	0.05	0.1	0.05	0.35	0	86.8	126.5

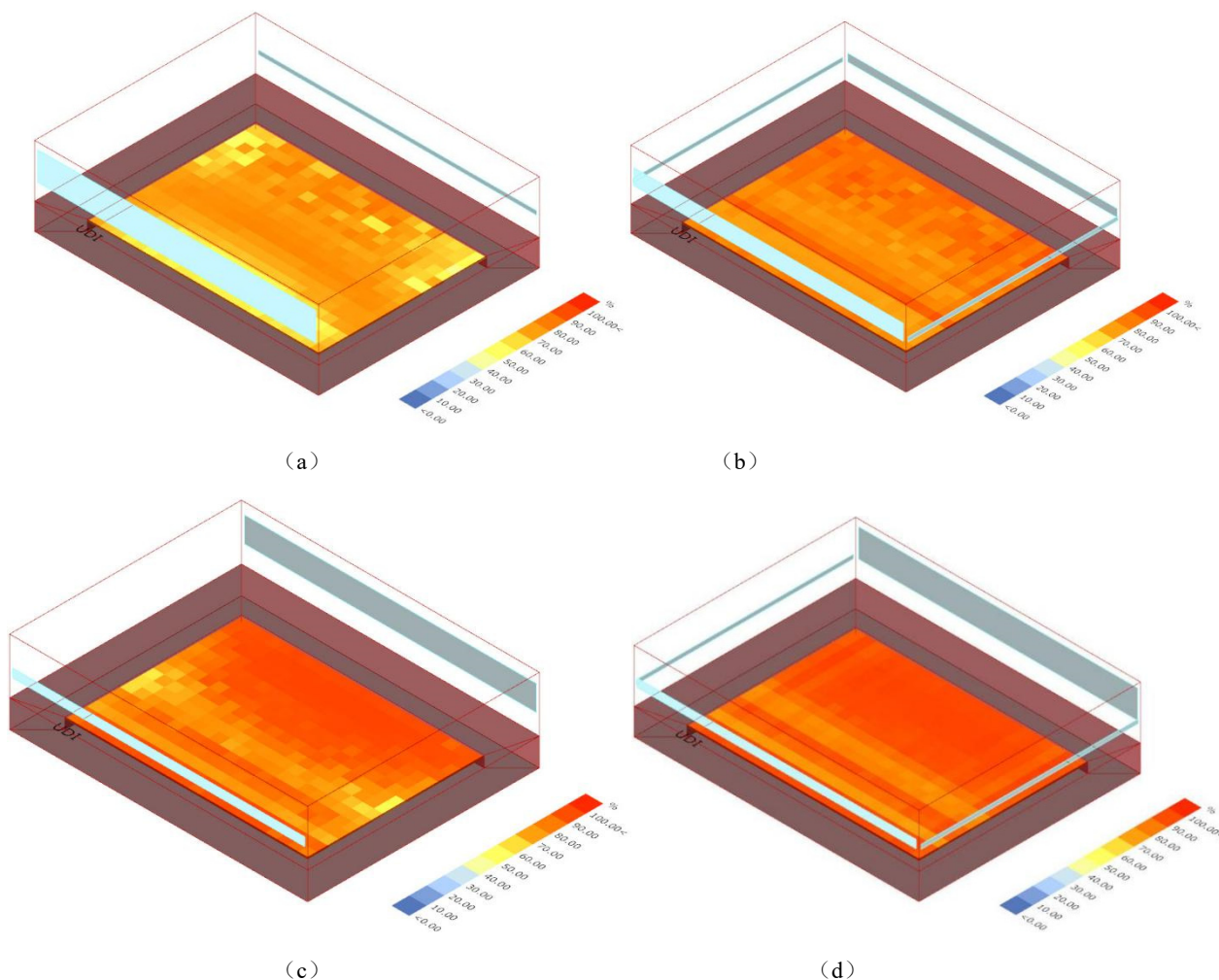


Figure 4. Effective illumination photothermal map (small)

4 Conclusion

Under the background of building energy conservation and emission reduction, the construction of low energy consumption and high comfort University Gymnasium is the general trend. It is more and more important to apply multi-objective optimization design to solve the coupling problem of natural lighting and energy consumption. Based on the sampling survey of University Gymnasium Building, this paper summarizes its basic form, establishes the double objective optimization model of natural lighting and energy consumption by using digital simulation technology, obtains the window opening scheme with consideration of natural lighting and low energy consumption through experiments, reveals its influence law, and summarizes the window opening design strategy of University Gymnasium Building. It provides theoretical basis and design reference for multi-objective performance optimization of large space buildings in cold regions.

Acknowledgments

This paper was completed under the careful guidance of Mr. Zhang Longwei. From the topic selection of the paper,

to literature research and data collection, and then to case research, it helped me build up confidence and firm intention to overcome difficulties when I encountered difficulties. I benefited a lot from the profound knowledge and rigorous teaching attitude of Mr. Zhang Longwei. I would like to express my heartfelt thanks to all the teachers, seniors, friends and family members who have helped me.

The authors gratefully acknowledge the support of National Natural Science Foundation of China (Grant 51978418, 51738006) and Scientific Research Plan of the Educational Department of Liaoning Province (Grant Injc202003).

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