ENERGY CONSERVATION RESEARCH AND OPTIMIZED DESIGN OF NATURAL LIGHTING ATRIUMS
—AS THE EXAMPLE OF INTERNATIONAL TRADE CITY IN JIAXING

Zhuojia Wang* & Jie Wang**

* Department of Architecture, Zhejiang University, 310058, China, Email: js_kaiyuan@hotmail.com
** Department of Architecture, Zhejiang University, 310058, China, Email: wangjie@zju.edu.cn

ABSTRACT: Atriums is a spatial form that often appears in buildings, atriums with good natural lighting can not only be used for their own, but also gives consideration to the rooms around atriums. It can be effectively reduce the lighting energy consumption. In this paper, Zhong Gang International Trade City as example, use computer to simulate the effect of atrium's natural lighting, analyze the benefits and shortcomings. Then refer to the best cases of natural lighting atrium, conclude the natural lighting modes, propose lighting optimal solutions for Zhong Gang International Trade City, and use computer simulation to verify the results.
KEYWORDS: atrium, natural lighting, computer simulation, reflector

According to statistics, China's lighting energy consumption accounts for 13% of total electricity consumption, it almost accounts for 40% of total energy consumption in large commercial buildings. So there is enormous energy saving potential of architecture lighting. (Figure 1 is the proportion of the equipment power consumption of a large commercial building in Beijing.)

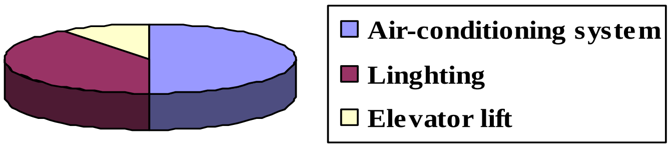

Figure 1[1]

Figure 2[2]

1 PROJECT INTRODUCTION

Zhong Gang International Trade City is located in South Lake District, Jiaxing City, Zhejiang Province. It is a multi-merchandise center facing the whole Yangtze River Delta. Its total gross area is 250000 square meters. It is the first professional market with energy-saving and environmental protection in China. The main building of International Trade City is Y-shape, in which six floors on the ground and one floor underground, 40m of total height, and 6m of story height. The two wings of the building have seven atriums in three forms. All of the atriums use natural lighting to reduce lighting energy consumption.

2 ATRIUMS' STATUS QUO AND LIGHTING SIMULATION

The atriums studied in this paper are located in the Y-shape's two wings of the building, marked the atriums No 1 to No 7 as Figure 3. No 1 to No 6 are six-story-high, and have top natural lighting. No 1 and No 6 have side-lighting at the same time. Top light plane which supported by the metal grid is parallel to the roof. Space around the atriums was directly connected with the atriums. The space can maximize using light from the atrium. Atrium No 7 is located in the left of the north wing. It has three-story-high and north-side lighting.

This paper will simulate the natural lighting effects of these atriums. The simulation software is Ecotect Analysis 2010 which presented by Autodesk company.

2.1 Model simplification and establishment

Using Ecotect to simulate the natural lighting, we should simplify the model first. The simplified result is as Figure 3 and Figure 4. After finishing the model, establish the analysis grids according to each plane. The density of grid number is 140X85. China's architectural lighting standards ordain that illuminance value is got at 0.75m height from the ground, so set the analysis grids at 0.75m height from each floor.

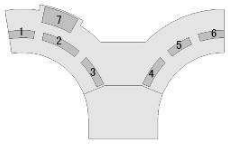

Figure3

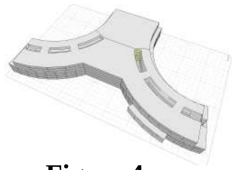

Figure 4

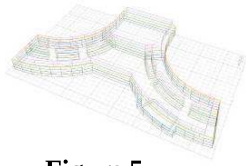

Figure 5

2.2 Interior illuminance simulation

Use the option of Natural Light Levels in Ecotect, which can calculate indoor illuminance, daylight factors, and reflected components along with the Design Sky Illuminance. According to the provision of China's architectural lighting standards, set the sky illuminance model as CIE Overcast Sky Condition, set Design Sky Illuminance value as 5000lux. Then calculate each story's illuminance, Figure 6 to Figure 11, respectively floor 1 to floor 6.

2.3 Full-time natural lighting simulation

Based on the illuminance simulated data, use the option of Daylight Autonomy in Ecotect, which gives percentage of time throughout the year that each point will need no additional light to maintain the selected level. Set the time as whole year, in accordance with China's architectural lighting standards, set the Required Lighting Level as 500lux. And then do the calculation of each story, data of Floor 1 to 6 is respectively shown in Figure 12 to Figure 17.

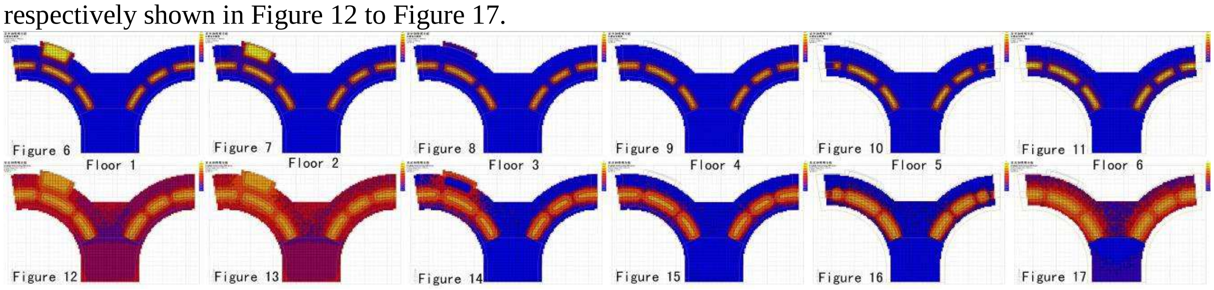

Figure 6 to Figure 17

3 ANALYSIS OF SIMULATION RESULTS

As the illuminance simulated results shown in Figure 6 to Figure 11, the atriums' own space can get adequate natural lights. On Floor 1 of the atriums, illuminance is still 1200lux, fully satisfy the requirements for 500lux of luxury store. Begin with the edge of the atriums, Light Level decays sharply, and the situation is different on each floor. There is an atrium in the north side of the left-wing, so left-wing's lighting condition is considerably better than the right-wing. The simulated results of second floor (Figure 17) show that Floor 2 has a greater range of lighting than Floor 1 (Figure 6). Because the lights reflect from first floor's ground to second floor's ceiling, then re-reflect to second floor's ground. On Floor 3 (Figure 8), Light Level of No. 7 atrium in the left wing decays most sharply. Although it has north-side lighting, the window height is only one third of Floor 1's. It shows that the height of windows have a great effect on side-lighting atriums. In other words, illuminance of side-lighting atrium is very uneven at different heights. In the case of top lighting, the results show that there are slight differences between various heights in the atrium space. Look at the simulated results of Floor 4 to Floor 6 (Figure 9 to Figure 11). Floor 6 (Figure 11) is the top floor, so the lighting range is much larger than Floor 4 (Figure 9) and Floor 5 (Figure 10). Synthesizing simulated results, we can find that in top-lighting atriums the lowest and the highest floors have better lighting effects than middle floors. Lights can better diffuse on the top floor, but the lights can't reach the lower stories because of blocking and height. Due to light reflection and diffusion on the surface of first floor's ground, the lighting effects of Floor 1 and Floor 2 have been enhanced. But the lights can't reach the higher stories.

Full-time natural lighting simulation takes into account the weather conditions throughout the year. It can measure more comprehensive conditions of natural lighting. As shown in Figure 12 to Figure 17, with natural lighting, each story can reach the required illuminance in most of the year. In poor weather conditions, as shown in illuminance simulated results, only the atriums' own space and the surrounding areas can reach the required illuminance, most space still need artificial lighting. Both two simulations have shown that lighting conditions of the junction area between the two wings is worse than the others. In the full-time natural lighting simulation, this area has the least time of satisfying the illuminance requirement. Therefore, natural lighting of the area should be improved.

4 NATURAL LIGHTING OPTIMIZATION AND SIMULATION

There are quite a number of outstanding cases in the use of atriums' natural lighting. The atrium of Genzyme Center (Figure 18) is set the reflectors falls from the top to the bottom floor. The atrium of Germany Capitol (Figure 19) has a fixed structure of the inverted cone-shaped reflector. Dacheng Sapporo Edifice in Japan (Figure 20) sets a system of reflective panels in the edge of each floor around the atrium. The reflective panels can automatically adjust in accordance with the direction of sunlight. These methods have achieved good effects of natural lighting.

International Trade City's atriums are located in two wings of the building, not as large and complete as the Genzyme Center's and the Germany Capitol's, the space is too narrow because of plane's constraints. If installing a central reflector system, the view of the atriums will be blocked. The atrium of Dacheng Sapporo Edifice is also small, so its reflector system is more appropriate for International Trade City. But its automatic control system is very expensive, taking the cost into considerations, we decide to use fixed-type reflective panels in International Trade City.

With the analysis of the plane, atrium No 3 and No 4 are beside the worse-lighting area, and they have greatest impact on natural lighting of the area, so we consider setting reflectors in these two atrium space. As there are beams on the floors' edges in the atriums, the reflectors can be installed on the surfaces of the beams. Modeling 1m high beams in the previous Ecotect model and set beam material as paint.

Figure 18[3]

Figure 19[4]

Figure 20[5]

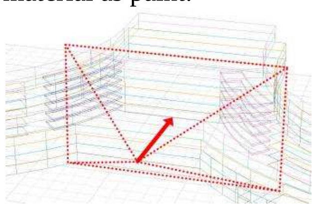

Figure 21

4.1 Selection of the reflectors' location

First, calculate the natural lighting conditions of the area without reflective panels. As Ecotect does not support calculating multiple reflections of light by itself, we need to export the original data to Radiance. Calculation condition set to CIE Overcast Sky Condition, viewing angle is set as shown in Figure 21. Profile was shown in Figure 22, the results shown in Figure 23 to Figure 28.

Refer to the setting approach of reflectors location in Dacheng Sapporo Edifice, installing reflectors staggered by floors. Atrium space is provided with handrails on both sides of the floor, so set up reflectors on handrails in the model, reflectors' material is set to metal. Now there are 2m high reflective panels, as shown in Figure 29. Calculate the lighting conditions, the results are shown in Figure 30 to Figure 35.

According to the light reflection principle, the area can get reflected lights though setting reflectors on the south-side beams of the two atriums. Change back the north-side beams in the atrium to the original material, remove the reflectors on handrails, change the south-side beams into reflective panels, install reflectors on south-side handrails , as shown in Figure 36, then calculate, and the results are shown in Figure 37 to Figure 42.

Finally, calculate the lighting effects of the area with 2m high reflectors around the atriums, as shown in Figure 43, and the results as shown in Figure 44 to Figure 49.

Comparing the results, staggered installation and south-side installation of reflectors exert better effects. And then compare with these two kinds of installation, from Floor 2 to Floor 5, the effect of south-side installation is better than the effect of staggered installation. Overall consideration, installing reflective panels on the south-side of the atriums is the best choice.

Figure 22 to Figure 49

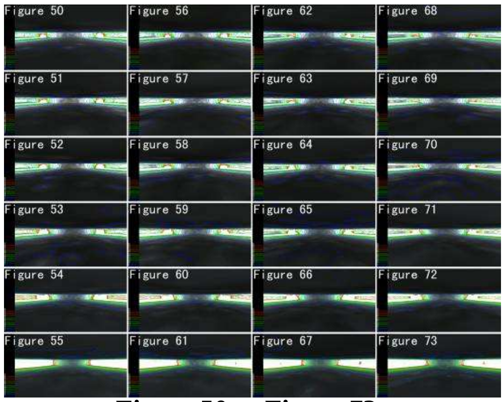

Figure 50 to Figure 73

4.2 Selection of the reflectors' height

The heights of reflectors can also affect the lighting condition. After determining the installation location, we need to simulate natural lighting effects of reflective panels with different heights.

In the previous step, we have completed the simulation of 2m high reflective panels, then remove reflectors of the south-side handrails, stimulate lighting effects with 1m high reflectors, the results are shown in Figure 50 to Figure 55.

Figure 56 to Figure 61 are the Figure 37 to Figure 42 in the previous step.

As each story is 6m high , reflectors can be installed below the beams. Therefore, we stretch the reflective panels of south-side beams to 2m, and remove reflectors of the handrails. Calculate again to research the impact of the different location of 2m high reflective panels, the results are shown in Figure 62 to Figure 67.

Lastly couple with the reflective panels of the south-side handrails, calculate the area's lighting effect with 3m high reflective panels. The results are shown in Figure 68 to Figure 73.

Comparing the results, overall consideration, 3m high reflectors have the best effects. Installing 2m high reflective panels on the beams and handrails is the second. Comparing the results of the respective stories, setting 1m high reflectors has the best results on the first floor. The lighting effects of Floor 2, Floor4 and Floor 5 have slight differences between installing 2m high and 3m high reflectors. With economic considerations, 2m height is more appropriate. On Floor 3 and Floor 6, the effect of 3m high reflectors is more excellent than other heights.

The final optimized design is integrated of all plans. As shown in Figure 74 and Figure 75, reflective panels have been installed on the south-side of the atriums. Set 1m high reflectors on the beams of the first floor. Set 2m high reflective panels on the beams and handrails of Floor 2, Floor4 and Floor5. Set 3m high reflectors on the beams and handrails of Floor 3 and Floor6. In this way, we can achieve the best results. Lighting simulated results are shown in Figure 76 to Figure 81.

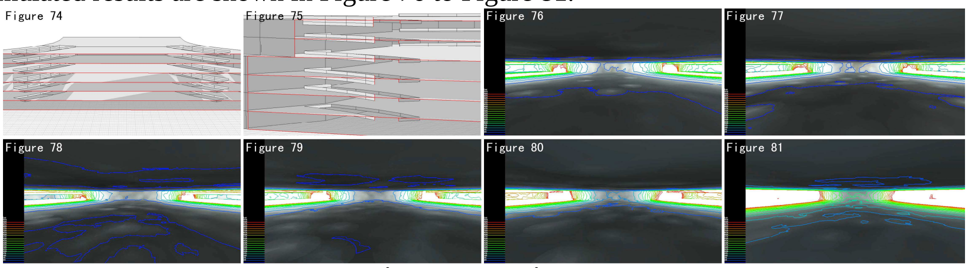

Figure 74 to Figure 81

In the situation of setting reflectors by the simulation results, lighting situation of the area is improved obviously. Although it is difficult to reach the illuminance requirements in cloudy days, artificial lighting energy consumption can be reduced.

5 SUMMARY AND FUTURE DIRECTIONS

Architects should have a comprehensive understanding of the architecture. In the design process, architects should take into account the effect on energy-saving by architectural form itself. The research method of this paper can be combined with the design process. Bring energy-saving design into preliminary design phase, in order to arouse the architects' awareness of energy saving in lighting. This paper only studies on the problem of atriums' natural lighting with computer simulation, the actual operational should be verified, so in subsequent studies, the results of the studies need to be applied to practical design projects, to gradually execute and verify effects, and obtain the actual measured data.

REFERENCES

[1] Zhifeng Xue, "Energy Conservation for Public Buildings," China Building Industry Press, pp.25.
[2] Http://jx.efw.cn/uploadfiles/NewHouse/w_12f78795fc51960c1a838e6cdcb41201.jpg
[3] Http://www.inhabitat.com/wp-content/uploads/genzyme_8.jpg
[4] Http://www.fosterandpartners.com/Projects/0686/Default.aspx
[5] "Urban Buildings," Spring & Autumn Publishing, pp.139.