Design and Optimization on Natural Lighting of One Large Shopping Mall in Guangzhou

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Abstract: this paper uses methods of combining with DEST and Radiance software to make simulation research on energy consumption of one large shopping mall in Guangzhou, it makes research on expression of indoor light environment and energy consumption of building under design strategy of different natural lighting by changing the shading way and skylight area of building on computer simulation.

1 Modeling parameter setting

The skylight of this building adopts Low-E window of hollow double silver(CED13-40S/TS film), the thickness is 6+12+6（mm）and heat transfer coefficient K is 1.63W/m^2·K，shading coefficient SC is 0.27.

According to the above parameters, the modeling in DEST and Radiance is as follows:

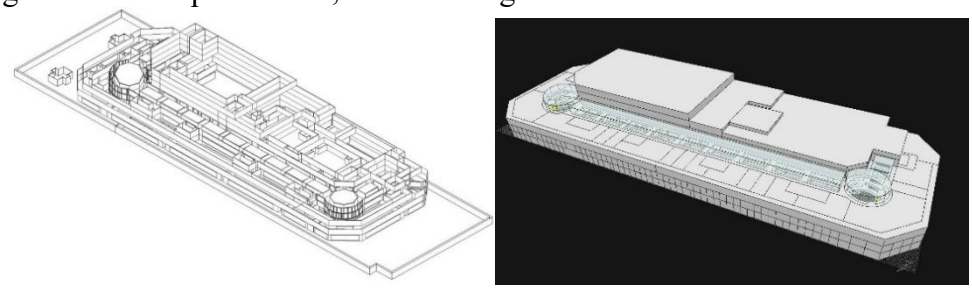

Figure 1 Building model diagram in DEST and Radiance

2 Demonstration on simulation accuracy of Radiance

In order to demonstrate the accuracy of Radiance lighting simulation software, we went to project site to make actual measurement on June of 2015 and recorded indoor illumination distribution under 2 kinds of working conditions on the first floor: sunny day and cloudy day in this project, this distribution is used to demonstrate accuracy of Radiance simulation.

This building only opens some lights under condition that there is natural light in daytime, during 2 days of actual measurement, the indoor lighting of building is mainly natural lighting in daytime and artificial lighting in nighttime, the lights basically keeps completely opening.

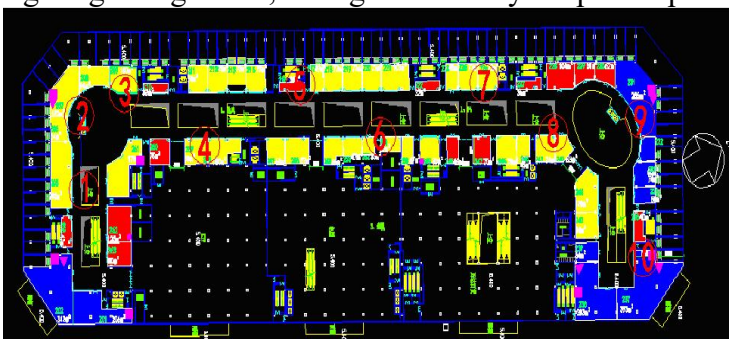

Figure 2 Schematic diagram of illumination test point

The outdoor illumination in sunny day on test is 8000lx or so and 2000lx or so in cloudy day.

Take pedestrian area on the first floor as object and set simulation time as middy 12 of 15th in June, it sets the same time with the test time. This paper respectively adopts CIE sunny day model and CIE cloudy day model to make simulation on 1200mm working plain (it keeps the same plain height on actual measurement) in sunny day and cloudy day, the comparison is as follows compared with actual measurement:

From the diagram we can see that the sunny day working condition simulated by Radiance using CIE sunny day model basically keeps the same with actual measurement result in sunny day, there is only some simulation data in some areas higher than actual measurement value, but the cloudy working condition simulated by using CIE cloudy model has big difference from the actual measurement result in cloudy day. By analyzing its causes, this is may be cloudy weather on actual measurement tends to be cloudy, the penetrated natural light has irregular distribution due to effect of cloud layer in the sky, so it has certain difference from the weather conditions in the cloudy day.

Under the working condition of sunny day during actual measurement, sunlight is hardly shaded by cloud layer, so the rule of indoor illumination change is relatively close to the ideal sky state in June. At 12 of 15th in June, the illumination change calculated by Radiance using CIE sunny model and CIE cloudy model keeps the same, it can judged that its simulation result is relatively correct.

The simulation result under sunny day working condition is indicated by the following diagram:

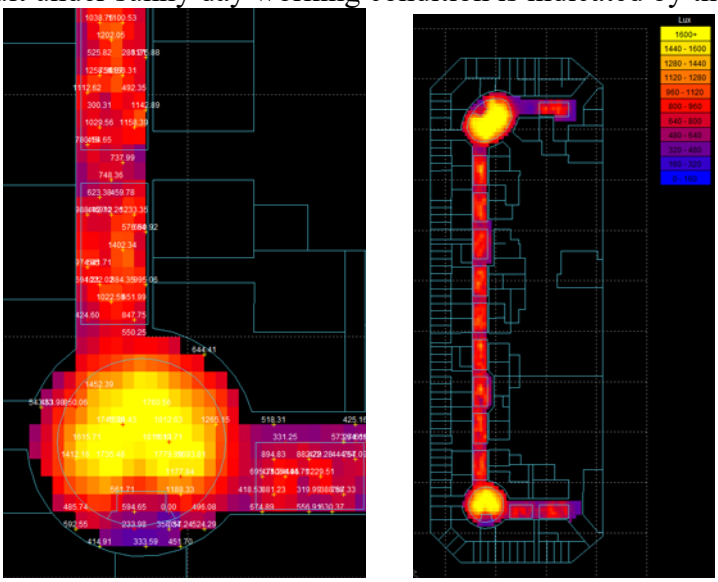

Figure 3 Overall simulation result and atrium peak value by Radiance

3 Effect of skylight area on energy consumption and lighting effect of building

Of which, the blue area is cold load and red area is hot cold, the load undertaken by cold engine in the whole year is 717800kWh. The accumulated air conditioning energy consumption of pedestrian area unit square in the whole year is 119.63kWh/m^2.

In DEST, this paper respectively sets skylight square as 85%, 70%, 55% of current square, the air conditioning energy consumption table by simulation calculation in the whole year is indicated by 2.1:

Table 2.1 Analysis table on cold load of indoor pedestrian mall area of different skylight area

	Accumulated air conditioning load of indoor pedestrian mall in the whole year （kWh)	Accumulated air conditioning load of indoor pedestrian mall unit square in the whole year （kWh/m2)
Original design skylight	71.78	119.63
Skylight educed to 85%	70.01	116.68
Skylight reduced to 70%	67.63	112.72
Skylight reduced to 55%	65.08	108.46

It can be seen that reduction in skylight square can decrease indoor radiation heat and heat transfer penetrates into skylight, so that it can reduce indoor air conditioning cold load in the whole year. This point will increase hot load of air conditioning in winter, but it only takes up a small part compared with reduced cold load, especially in Guangzhou, the hot load of building itself only takes up very small part of energy consumption, so the overall air conditioning load has been reduced.

However, because of reduction in skylight square, effect of indoor natural lighting also reduces, some time section only relies on illumination of natural lighting dose not need to open lighting in the past can no longer meets illumination requirement of indoor 300lx in the upscale mall, so it needs to make simulation by Radiance and calculate the standard area of indoor Pedestrian area of skylight area under 4 percentage, and then it can calculate change of lighting energy consumption.

Usually, the lighting energy consumption saved by natural lighting adopts the following formula to make calculation:

The average lighting power density of pedestrian area in one large shopping mall of Guangzhou at present is 14W/m^2， the amounted hour number of completely opening in one day is 10.9 h, the accumulated lighting energy consumption in the whole year is 334200 kWh, the accumulated lighting energy consumption of unit area in the whole year is 55.70kWh/m^2. In the Radiance simulation, it respectively makes simulation at middy 12 of 15^{th} in March, midday 12 of 15^{th} in June, midday 12^{th} of 15^{th} in September and midday 12 of 15^{th} in December, which respectively represents spring, summer, autumn and winter. It uses CIE cloudy day model to make simulation, which represents cloudy day and when it uses CIE sunny sky model to make simulation, which represents sunny day.

The simulation results are as follows:

Table 2.2 The standard area percentage of pedestrian area on the first floor (%)

		Current skylight	85% skylight	70% skylight	55% skylight
spring	Sunny day	95	92	88	82
	Cloudy day	88	71	68	64
Summer	Sunny day	95	95	90	87
	Cloudy day	95	90	86	84
autumn	Sunny day	95	95	92	87
	Cloudy day	95	89	87	81
winter	Sunny day	95	95	90	85
	Cloudy day	93	88	81	75

Table 2.3 The standard area percentage of pedestrian area of the second floor (%)

		Current skylight	85% skylight	70% skylight	55% skylight
spring	Sunny day	85	77	75	72
	Cloudy day	71	65	62	60
Summer	Sunny day	85	80	77	75
	Cloudy day	85	72	67	65
autumn	Sunny day	85	81	79	76
	Cloudy day	85	74	72	66
winter	Sunny day	85	80	76	74
	Cloudy day	76	71	66	63

Table 2.4 The standard area percentage of pedestrian area of the third floor (%)

		Current skylight	85% skylight	70% skylight	55% skylight
spring	Sunny day	90	90	90	84
	Cloudy day	90	84	84	77
Summer	Sunny day	90	90	90	85
	Cloudy day	90	88	87	79
autumn	Sunny day	90	90	90	84
	Cloudy day	90	89	86	77
winter	Sunny day	90	90	90	84
	Cloudy day	90	88	86	78

Because 2 atriums and middle area in the first floor are all raised ceiling, so the pedestrian area in the second and third floor is composed of many annular regions, the area is very small. The area ratio of pedestrian area in the first, second and third floor is about 2:1:1.

From the simulation result we can see the following:

The standard area percentage in the first floor decrease with skylight area, which presents linear decline trend

The standard area percentage on the second floor abruptly decreases in 100% skylight area and 85% skylight area, it also presents linear decline trend. This is because the center in the first floor is raise ceiling space, the pedestrian area on the second floor is annular region, of which some parts are right below the skylight, and the natural lighting is not affected by reduction of skylight area. While the other part is in the outer side of skylight, when skylight reduces, natural lighting will be shaded by structure on the third floor, which causes some areas can not achieve the standard.

The third floor is just below the skylight, incidence angle of natural light is very broad, so area can not achieve standard will increase when skylight area is reduced from 70% to 55%.

From simulation result, we can calculate the completely opening time amounts to every day under different skylight area is as follows

Table 2.5 The completely opening time every day amounts

	Original skylight area	85% skylight area	70% skylight area	55% skylight area
Completely opening time（h）	10.9	11.07	11.19	11.37

According to lighting energy consumption saved by natural lighting and calculation formula it calculates lighting energy consumption and air conditioning energy consumption of pedestrian mall with different opening area, which is indicated by the following table:

Table 2.6 Analysis table on lighting energy consumption of indoor pedestrian mall with different skylight area

	Accumulated air conditioning load of indoor pedestrian mall in the whole year（10000 kWh)	Accumulated lighting load of indoor pedestrian mall in the whole year（10000 kWh)	Air conditioning +lighting（10000 kWh)
Original design skylight	71.78	33.42	105.2
Skylight reduced to 85%	70.01	33.94	103.95
Skylight reduced to 70%	67.63	34.31	101.94
Skylight reduced to 55%	65.08	34.87	99.95

It can be seen that as for building, reduction in skylight area can decrease energy consumption in the pedestrian mall, when skylight is reduced to 55%, it can reduce 5% energy consumption in the pedestrian mall.

Some simulation results calculated by Radiance are as follows:

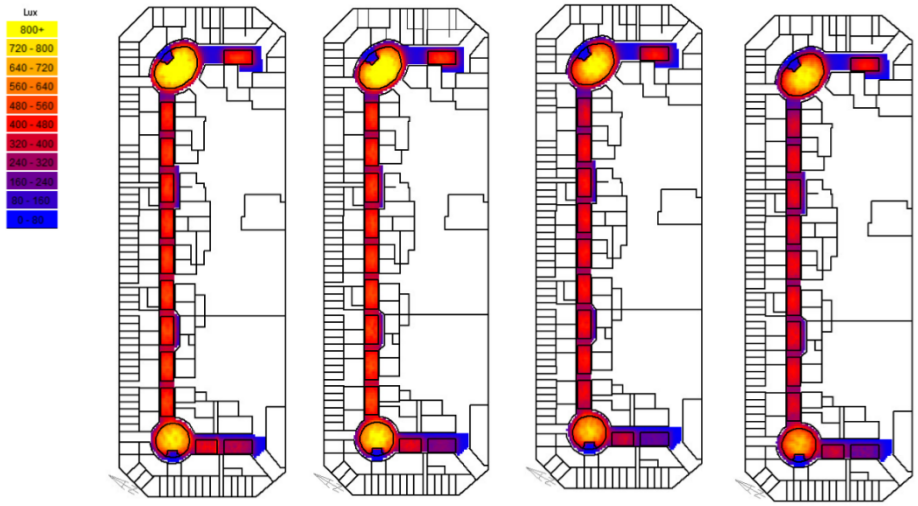

Figure 4 Illumination simulation result in summer of skylight of 100%, 85%, 70% and 55% on the first floor in summer

4 Conclusion

This paper uses and combines with DEST energy consumption simulation and lighting simulation of Radiance to make analysis on air conditioning energy consumption and lighting energy consumption of one large shopping mall in Guangzhou affected by different skylight areas,

and it gets the following conclusion:

As for this building, reduction in skylight area cannot obviously increase the opening time of lights. Therefore, on condition of taking no consideration of indoor satisfaction, we can possibly reduce skylight area, so that reduce the overall energy consumption. When skylight area is reduced to 55% of current area, it can reduce the overall energy consumption of pedestrian area.

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