

Experimental Study on Daylighting of Office Buildings

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Abstract: This paper provides an experimental study on daylighting of office buildings. Firstly, the illuminance distribution comparability of the model and antetype is validated with theoretical and simulating study, based on which office model is established. Then, daylight factor is put forward to substitute illuminance for experimental analysis. Lastly, the study of the influence of window-to-wall ratio, sill height and transmittance on indoor illuminance distribution is carried out respectively with experimental test, and the reasons causing testing difference are analyzed as follows. The results show that testing difference is acceptable.

Keywords: office building, daylighting, experimental study

NOMENCLATURE

E	Illuminance [lux]
D	Daylight fator
L	Luminance [lumen]
θ	Elevation of testing point
α	Azimuth of testing point
T	Transmittance

1. INTRODUCTION

Daylighting is to bring natural light into buildings, and provide a better indoor light environment than artificial lighting. Daylighting can not only reduce the lighting electricity, but also create a dynamic indoor environment, and a healthy and excited working environment will be produced as follows [1].

Artificial lighting not only consumes a large amount of electricity but also dissipates waste heat into indoor space, which causes the increase of cooling load. However, if effective use of daylight is involved, the decrease of heating, cooling and lighting energy required to condition buildings would come true. Daylighting design [2, 3] cannot only save energy but also lead to a light, airy architecture of great beauty. In fact, daylighting has become a major topic in energy conscious design, next to passive solar heating and cooling, in recent years. Studies [4, 5] in the Southeast Asian regions have shown that the use of daylighting can reduce overall energy consumption by 20% and also reduce the sensible heat load on air conditioning.

2. MODEL SIMILARITY ANALYSIS

In related study [3], the author provided an analysis of the affecting factors of daylighting with numerical simulation, but the results of simulation need to be validated with experiments. Since it is too difficult to do experiments in existing offices, a model of 1:2 is

established for the experiments. However, does the model have the same indoor daylight distribution as that of antetype? Analysis on that from theoretical and simulating aspects is as followed.

2.1 Theoretical analysis

Experimental model of 1:2 is shown in Fig. 1, which has a geometric similarity with antetype, and the same parameters like transmittance and reflectance as that of antetype.

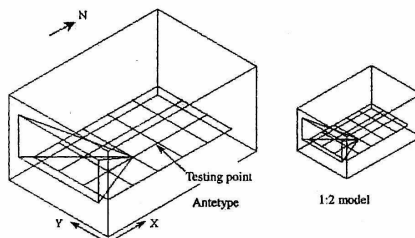


Figure 1: Experimental model of 1:2.

Indoor illuminance of testing point is calculated as followed [6]:

$$E = \int_0^{2\pi} \int_0^{\pi/2} D_{\theta\alpha} L_{\theta\alpha} \cos\theta d\theta d\alpha$$

For both model and antetype, θ and α are the same. The formula $\cos\theta d\theta d\alpha$ is the solid angle of testing point to sky, and it is also obviously the same.

$L_{\theta\alpha}$ is sky luminance with an elevation of θ and an azimuth of α , which is the same for model and antetype. $D_{\theta\alpha}$ is daylight factor of testing point, which can be calculated with the following formula:

$$D_{\theta\alpha} = T_{\theta\alpha} \sin\theta$$

T and θ are equal for model and antetype, so $D_{\theta\alpha}$ is also equal. Therefore, indoor illuminance distribution should be equal for both model and antetype.

2.2 Simulation analysis

RADIANCE software is used for simulation in this paper. The antetype has a size of 6m*4m*3m (length*width*height) with a south external window, which is measuring 3.2m*1.5m, and has sill height of 1m and transmittance of 0.502. The reflectance of ceiling, floor and internal wall are 0.75, 0.35, and 0.7 respectively. Working face is 0.8m high.

Table 1: Indoor illuminance comparison of model and antetype ($|I_{antetype} - I_{model}| / I_{antetype}$).

X/m Y/m	0.25	0.75	1.25	1.75	2.25	2.75
1.75	0.008	0.007	0.009	0.009	0.001	0.008
1.25	0.000	0.008	0.001	0.008	0.006	0.008
0.75	0.000	0.000	0.009	0.002	0.003	0.000
0.25	0.014	0.004	0.020	0.003	0.002	0.006

From Tab. 1 we can see that indoor illuminance is almost equal for both model and antetype. The reason why little illuminance difference is available is that the absolute positions of testing points are not the same. Only two errors are higher than 1%. The maximum error is 2%, that is, illuminance difference will be 20 lux with an illuminance of 1000 lux, which can be ignored. Therefore, both model and antetype have the same indoor illuminance distribution.

3. EXPERIMENTAL TESTING AND ANALYSIS

3.1 Model description

Experimental model is made up of wood. Since no consideration of energy consumption in this experiment, the material of model envelope has no impact on the experiment.

The model with a scaling of 50% is shown in Fig.1. It has a size of 3m*2m*1.5m, and a south window. The model may be considered as an office, or one part of an open office. To ensure the window facing south, a compass is used to help with the establishment of the model, which is located on the roof of No. 16 building in Tianjin University^[5]. The model is decorated with white wall paper and floor leather, and no shading around it.

The reflectance of the floor, wall side and ceiling are 0.3, 0.499 and 0.778 respectively. Four different window transmittances of 0.778, 0.617, 0.44 and 0.22 are involved in the model.

3.2 Daylight factor

Due to the various sky conditions, the sky condition of simulation is not the same as that of experiment. The simulating sky condition includes CIE clear and CIE overcast. To enhance the

experimental reliability, clear sky condition is chose for testing. Even in this case, because of some other affecting factors, the testing outdoor illuminance is not equal to the simulating one, and it has no meaning to use indoor illuminance to validate the simulating results. According to this, daylight factor is involved subsequently.

daylight factor (df) = indoor illuminance / outdoor illuminance

To simplify the study, the average daylight factor of testing points with same distance from external wall is involved for the analysis on its changing rule along axis X.

3.3 Testing conditions

Table 2: Testing conditions.

No	Width (m)	Height (m)	Sill height (m)	Transmittance	Sky condition	Testing time
1	1.0	0.6	0.5	0.778	Clear	9/16 10:40
2	1.2	0.6	0.5	0.778	Clear	9/16 10:49
3	1.4	0.6	0.5	0.778	Clear	9/16 10:56
4	1.6	0.6	0.5	0.778	Clear	9/16 11:05
5	1.6	0.75	0.5	0.778	Clear	8/13 15:45
6	1.6	0.75	0.5	0.617	Clear	8/14 15:45
7	1.6	0.75	0.5	0.440	Clear	8/17 15:45
8	1.6	0.75	0.5	0.220	Clear	8/20 15:45
9	1.6	0.75	0.45	0.778	Clear	8/25 09:20
10	1.6	0.75	0.50	0.778	Clear	8/25 09:28
11	1.6	0.75	0.55	0.778	Clear	8/25 09:35
12	1.6	0.75	0.60	0.778	Clear	8/25 09:43

3.4 Testing and analysis

3.4.1 Window-to-wall ratio (WWR)

Tests of the influence of WWR on daylight factor distribution are carried out at 10:40 on 16 Sep. 2003, which includes a south window with a sill height of 0.5 m, and a transmittance of 0.778. Four different WWR of 20%, 24%, 28% and 32% are involved in the tests.

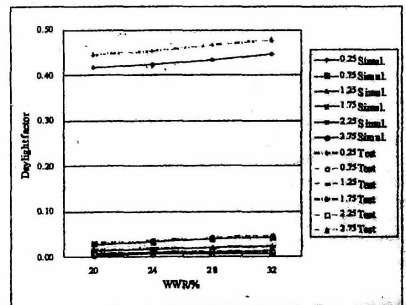


Figure 2: Influence of WWR on daylight factor.

Fig. 2 shows the influence of WWR on daylight factor along room depth. The dashed is corresponded to testing data, and the real line is corresponded to simulating data. From this figure we can see that: 1) daylight factor at the room depth of 0.25m is

obviously higher than that of other depth, which is caused by direct solar radiation; 2) daylight factor goes higher as WWR increases; 3) the closer the testing point is to external window, the more the influence of WWR on daylight factor will be, and the more steep the corresponding curve will be; 4) the closer the testing point is to external window, the more the offset of testing curve from simulating curve will be, and the higher testing error will be. This is because during every testing, we firstly test outdoor illuminance, and then followed by indoor illuminance with the sequence shown in Fig.3. We assume outdoor illuminance as a constant during the testing when we calculate indoor daylight factor, but actually outdoor illuminance is changing all the time as shown in Fig.4. Therefore, the further the testing point is to external window, the higher the testing error will be, and the errors are all plus; 5) testing curve is above simulating curve, and the reasons are the same as that of the above mentioned.

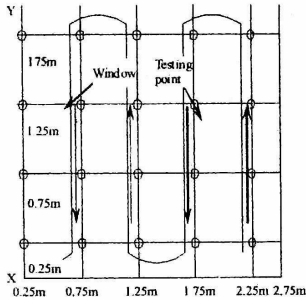


Figure 3: Sequence of testing points.

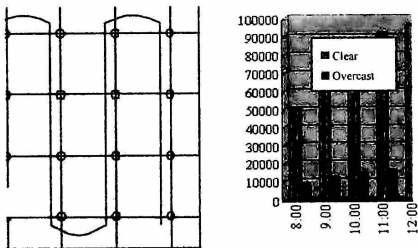


Figure 4: Trend of outdoor illuminance.

3.4.2 Transmittance

Tests of the influence of transmittance on daylight factor distribution are carried out at 15:45 on 13, 14, and 17 and 20 August 2003, which includes a south window with a sill height of 0.5 m, and a WWR of 40%. Four different transmittances of 0.778, 0.617, 0.44 and 0.22 are involved in the tests.

Fig. 5 shows the influence of transmittance on daylight factor along room depth. The dashed is corresponded to testing data, and the real line is corresponded to simulating data. From this figure we can see that: 1) daylight factor is linear with transmittance, and goes higher with transmittance increases; 2) the closer the testing point is to external window, the more the influence of transmittance on daylight factor will be, and the more steep the corresponding curve will be; 3) the closer the testing point is to external window, the more the offset of testing curve from simulating curve will be, and the higher testing error will be. The reasons are the same as that of 4) in 3.4.1; 4) testing curve is below simulating data, and testing data is lower than simulating data.

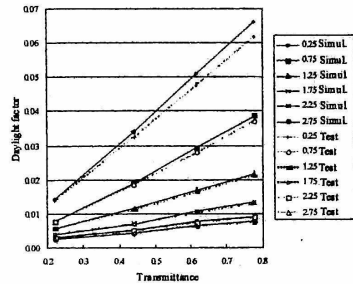


Figure 5: Influence of transmittance on daylight factor.

3.4.3 Sill height

Tests of the influence of sill height on daylight factor distribution are carried out at 9:20 on 25 August 2003, which includes a south window with a transmittance of 0.778, and a WWR of 40%. Four different sill heights of 0.45m, 0.5m, and 0.55m and 0.6m are involved in the tests.

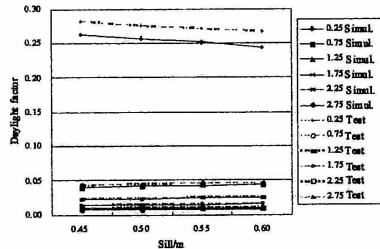


Figure 6: Influence of sill height on daylight factor.

Fig. 6 shows the influence of sill height on daylight factor along room depth. The dashed is corresponded to testing data, and the real line is corresponded to simulating data. From this figure we can see that: 1) daylight factor goes down as sill height increases at a room depth of 0.25m or less than 0.25m, but it goes up as sill height increases at a room depth of more

than 0.25m. That is because, the higher the sill height is, the more the shading of wall to testing points close to external window will be, and the deeper the penetration will be; 2) daylight factor at the room depth of 0.25m is obviously higher than that of other depth, which is caused by direct solar radiation; 3) daylight factor goes up as sill height increases; 4) the closer the testing point is to external window, the more the influence of sill height on daylight factor will be, and the more steep the corresponding curve will be; 5) the closer the testing point is to external window, the more the offset of testing curve from simulating curve will be, and the higher testing error will be; 6) testing curve is above simulating curve, and testing data is higher than simulating data.

4. CONCLUSIONS

- 1) Both model and antetype have the same indoor illuminance distribution
- 2) To reduce the influence of various sky conditions, daylight factor is used for experimental study instead of illuminance. The result shows this idea is absolutely feasible and reliable.
- 3) The experimental study validates the influence of WWR, sill height and transmittance on daylight factor.
- 4) The closer the testing point is to external window, the higher testing error will be because of the sequence of testing points.

- 5) The analysis on changing trend of outdoor illuminance shows that the testing error is plus for tests in morning and minus for tests in afternoon. The testing errors are all acceptable.

5. ACKNOWLEDGEMENTS

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