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Utilization of Natural Daylight in Office Buildings

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Abstract

Daylight utilization in office buildings for creating natural indoor working condition and saving lighting consumption was reported in this paper. An office model was developed for the simulation on the influence of glazing transmittance, sill height and Window-to-wall Area Ratio (WAR) on indoor illuminance distribution and lighting saving. The equations expressing the relationship between the illuminance and the affecting factors were presented. The simulation results indicated that the lighting saving was a quadratic function of glazing transmittance. The increase of sill height by 0.1m produced an increased lighting saving of 0.219 W/m^2 in sunny day as well as 0.225 W/m^2 in cloudy day. The increase of WAR by 0.1 produced an increased lighting saving of 2.719 W/m^2 in sunny day as well as 1.687 W/m^2 in cloudy day.

Keywords: Daylight, illuninance distribution, lighting saving

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 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. Study [4] has shown that the use of daylighting can reduce overall energy consumption by 20% and also reduce the sensible heat load on air conditioning.

2. Fundamental

The simplest example of the radiosity method is that of a spherical enclosure containing a light source. A practical example of such an enclosure would be an integrating sphere used for comparing the light output of light sources.

A single equation [5] can be written representing the energy balance for this situation.

$$F = \frac{F_L}{1-\rho} \tag{1}$$

where F_L is input luminous flux (lumens); ρ is reflectance.

The average illuminance on the inside of the sphere,

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$$E_{av} = \frac{F_L}{A(1-\rho)} \tag{2}$$

where A is room surface area (m^2).

In the case of a room lit by a window, F_L would be the flux that enters via the window. In a room where the room surfaces had different reflectance, it would be necessary to use the average reflectance of all room surfaces in place of ρ. Let this average reflectance be R then the formula becomes

$$E_{av} = \frac{F_L}{A(1-R)} \tag{3}$$

The term F_L now requires consideration.

If F_L is replaced by $TWE_{sky}(\theta/2)$, the formula becomes

$$df = \frac{TW\theta}{2A(1-R)}\% \tag{4}$$

where df is daylight factor; T is glazing transmittance; W is glazing area (m^2); θ is vertical angle in degrees of unobstructed sky measured from the middle of the window

This expression depends upon the fact that the value $\theta/2$ has been found to be a reasonable approximation to the ratio of the illuminance on the vertical face of the window to that on the horizontal from an unobstructed overcast sky, as a percentage.

Thus, $TW\frac{\theta}{2}\times\frac{E_{sky}}{100}$ is equal to the luminous flux passing through the window into the room.

This gives the average daylight factor as

$$\frac{E_{av}}{E_{sky}}\times 100\% = \frac{TW\frac{\theta}{2}}{A(1-R)} \tag{5}$$

The relationship between the illuminance on the vertical window surface and the angle of unobstructed sky was pointed out by Lynes [6].

However, recommendations for daylight factors are usually given in terms of the average daylight factor required on the working plane; that is at desk or work bench height above the floor. Crisp and Littlefair [7] have produced a modified version of the Lynes formula as following to give a better estimate of the daylight factor for the working plane.

$$E_{av} = E_{WP}\left(\frac{1+R}{2}\right) \tag{6}$$

where E_{WP} is the average working plane illuminance. Combined the above two formulas, we can get

$$E_{WP} = \frac{TW\theta E_{sky}}{100A(1-R^2)} \tag{7}$$

3. Simulation and Analysis

Based on the analysis of office configurations, a model measuring 6×4×3m^3 is established with a window facing south and no obstructions. The ground reflectance is given as 0.2. The reflectance of floor, ceiling and sidewall is set to be 0.35, 0.75 and 0.75 respectively. The window wall is an external wall and the other three are internal walls. It can be regarded as an office room or one part of an open office. The working plane is 0.8m above the floor and its required illuminance is 500 Lux. In the case of no daylighting utilization, the room should be installed with 24 18-W fluorescent lamps at 2.8m, 1150 lumens of flux for each one, to meet the required illuminance.

The simulation is carried out based on the climatic condition of Tianjin, China, located at N39.6º with a ranging elevation angle from 27.9º to 73.9º. Sunny and cloudy conditions are employed respectively for the simulation. To simplify the research, the points with the same distance to the external wall are assumed to have the same illuminance. RADIANCE software is used for the simulation and calculation.

3.1. Effect of glazing transmittance

The south-facing window has a configuration of 3.2m in width and 1.5m in height. The sill height is 1m and the Window-to-wall Area Ratio (WAR) is 40%. Four different transmittances of 0.3, 0.502, 0.617 and 0.81 are involved for the simulation.

Fig.1 and 2 show the indoor illuminance distributions on working plane with different transmittances in Sunny and cloudy days respectively. It can be seen that the illuminance decreases sharply within the area with the distance to external wall less than 3.5m and tends to be stable out of the area. The illuminance in cloudy day is much lower than that in sunny day due to no direct solar radiation. It is about 1/10 of that in sunny day within the 3.5m area and 1/4 out of the 3.5m area.

Fig.3 shows the variation of lighting saving with glazing transmittance. It can be seen that the lighting saving increases with the increased glazing transmittance. But the curve of sunny day is steeper than that of cloudy day, which means the glazing transmittance has a more effect on lighting saving in sunny day than that in cloudy day. The lighting saving deference between sunny day and cloudy day ranges from 7.5 to 10 W/m^2.

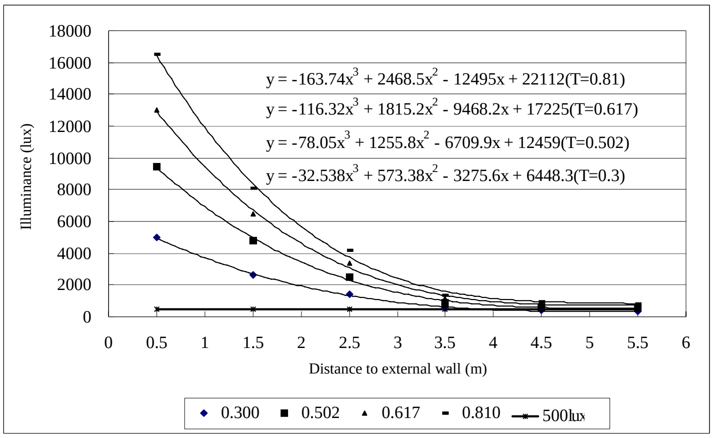

Fig. 1. Variation of indoor illuminance with glazing transmittance in sunny day

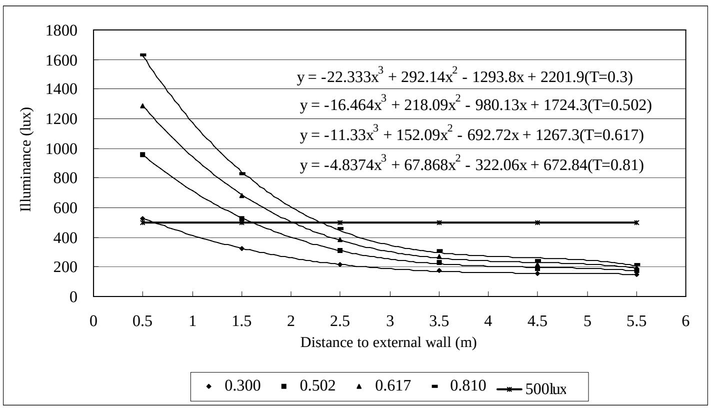

Fig. 2. Variation of indoor illuminance with glazing transmittance in cloudy day

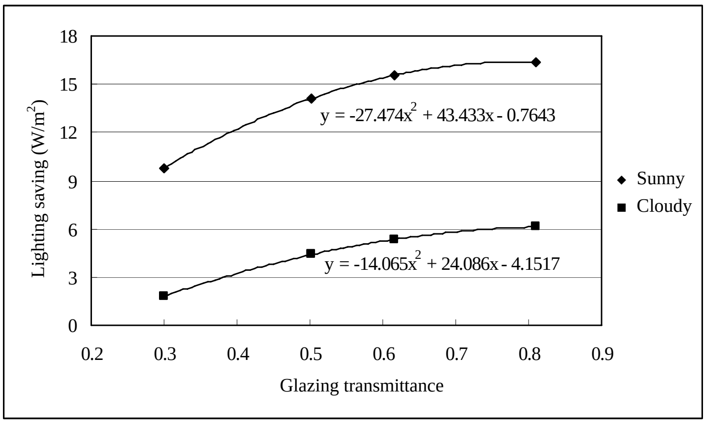

Fig. 3. Variation of lighting saving with glazing transmittance

3.2. Effect of sill height

The south-facing window has a configuration of 3.2 m in width and 1.5 m in height. The glazing transmittance is 0.502 and the WAR is 40%. Four different sill heights of 0.9m, 1m, 1.1m and 1.2m are involved for the simulation.

Fig.4 and 5 show the indoor illuminance distributions on working plane with different sill heights in Sunny and cloudy days respectively. It can be seen that the illuminance decreases with the increased sill height as the distance to external wall is less than 1.5m and increases out of 1.5m.

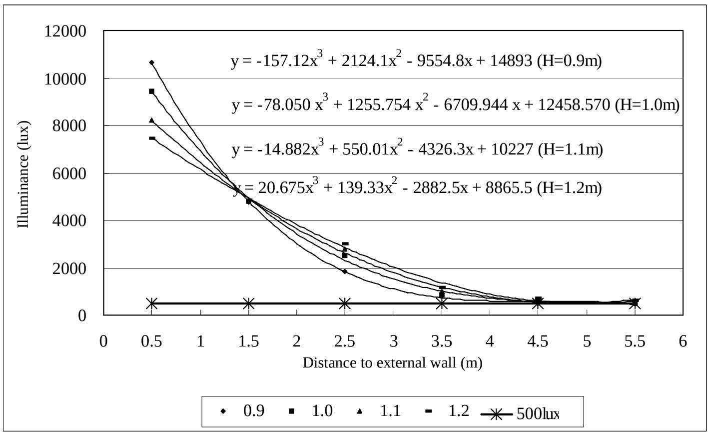

Fig. 4. Variation of indoor illuminance with sill height in sunny day

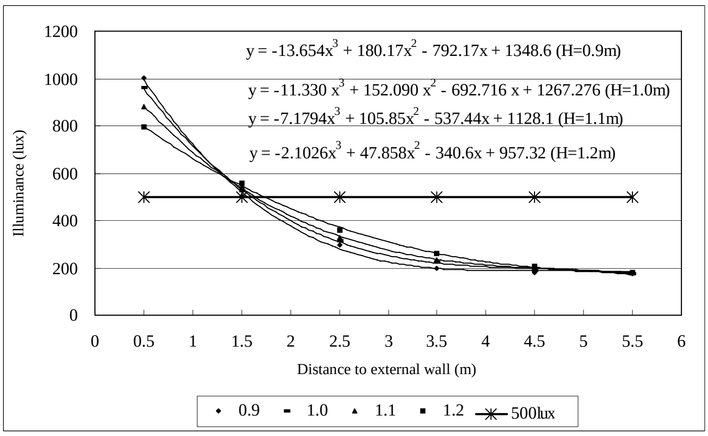

Fig. 5. Variation of indoor illuminance with sill height in cloudy day

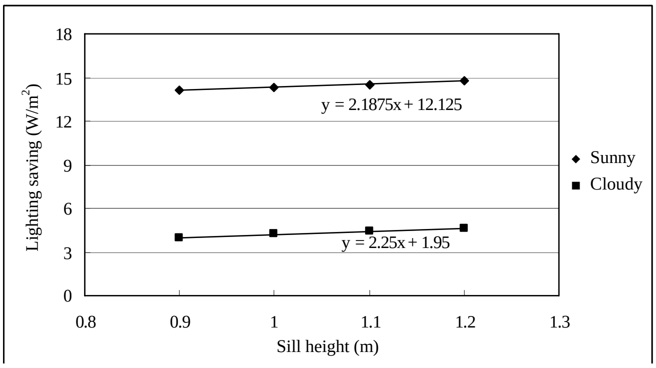

Fig. 6. Variation of lighting saving with sill height

Fig.6 shows the variation of lighting saving with sill height. It can be seen that the higher the sill height is, the more the lighting saving will be. The lighting saving is a proportional function of sill height with similar slope in sunny and cloudy days. In sunny day, the lighting saving increases 0.219W/m^2 with the increased sill height by 0.1m, while 0.225W/m^2 in cloudy day. The lighting saving in sunny day is 10W/m^2 higher than that in cloudy day.

3.3. The effect of Window-to-wall Area Ratio

The glazing transmittance is 0.502 and the sill height is 1m. Four different WARs of 32% (3.2m×1.2m), 28% (2.8m×1.2m), 24% (2.4m×1.2m) and 20% (2m×1.2m) are involved for the simulation.

Fig. 7 and Fig. 8 show the indoor illuminance distributions on working plane with different WARs in sunny and cloudy days respectively. It can be seen that the effect of WAR on the indoor illuminance distribution is very similar to that of glazing transmittance.

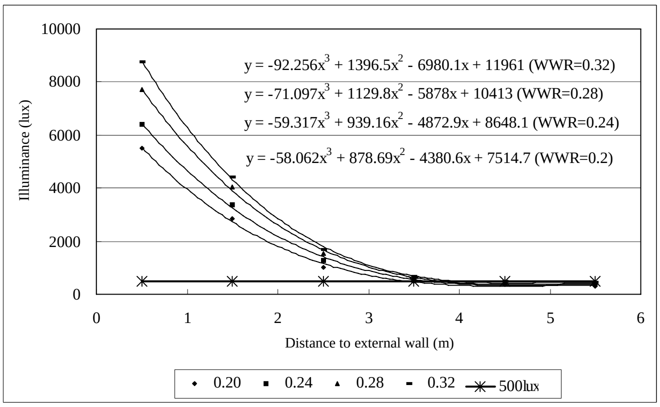

Fig. 7. Variation of indoor illuminance with WAR in sunny day

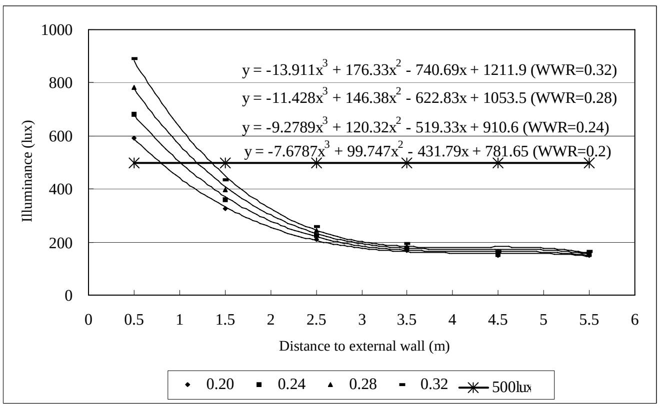

Fig. 8. Variation of indoor illuminance with WAR in cloudy day

Fig. 9 shows the variation of lighting saving with WAR. It can be seen the lighting saving is a proportional function of WAR. The curve of sunny day is steeper than that of cloudy day, which means the WAR has a more effect on lighting saving in sunny day than that in cloudy day. In sunny day, the lighting saving increases 2.719W/m^2 with the increased WAR by 10%, while 1.687W/m^2 in cloudy day, 40% lower than that in sunny day.

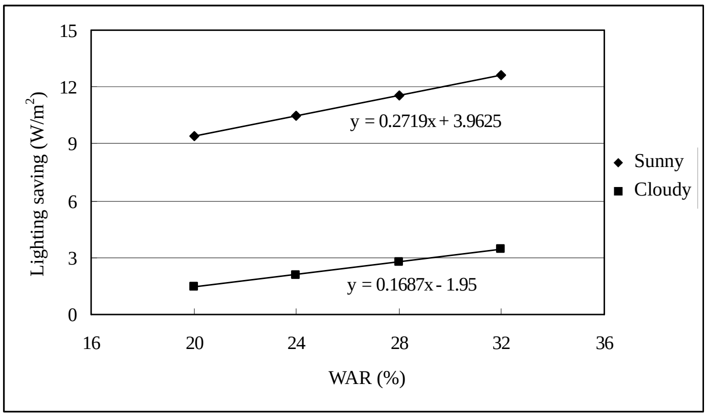

Fig. 9. Variation of lighting saving with WAR

4. Conclusions

An office model is established for the study on the effect of glazing transmittance, sill height and WAR on the indoor illuminance distribution and lighting saving. The following results can be concluded.

(1) With the simulation and calculation, the equations expressing the relationship between indoor illuminance and glazing transmittance, sill height and WAR are given.

(2) The lighting saving is a quadratic function of glazing transmittance. The lighting saving in sunny day is 7.5~10W/m^2 higher than that in cloudy day under the same transmittance.

(3) The lighting saving is a proportional function of sill height with similar slope in sunny and cloudy days. The lighting saving in sunny day is 10W/m^2 higher than that in cloudy day.

(4) The lighting saving is a proportional function of WAR. The WAR has a more effect on lighting saving in sunny day than that in cloudy day. In sunny day, the lighting saving increases 2.719W/m^2 with the increased WAR by 10%, while 1.687W/m^2 in cloudy day, 40% lower than that in sunny day.

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