DAYLIGHTING PERFORMANCE OF MANUAL SOLAR SHADES

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ABSTRACT

The daylighting performance improvement of manual solar shades was compared with two conventional window scenarios. A developed stochastic model for manual solar shades was used for co-simulation by BCVTB. Results show that manual solar shades increase useful daylight illuminance by approximately 160 % compared to conventional windows with less significant daylight illuminance fluctuation. In addition, occupants operate solar shades effectively during the late spring and early summer and the manual control during other periods can be further improved to enhance daylighting performance.

Keywords: manual solar shades, daylighting performance, useful daylight illuminance

1 INTRODUCTION

Daylighting is the controlled admission of natural light into a building in order to reduce artificial lighting energy consumption. By providing a direct link to the dynamic and perpetually evolving patterns of outdoor illumination, daylighting helps create a visually stimulating and productive environment for building occupants. Daylight is considered to be an important factor for workers' satisfaction in an office space, since it provides office workers with psychological benefits in the space where artificial lighting systems create uniform and monotonous visual environment. To maximize daylight utilization, buildings are now designed with large windows or glazing curtain walls, which, in turn, could also increase the cooling load in summer or accelerate heat loss in winter. For example, intense daylight leads to glare problems at the perimeter zone and daylight with excessive solar gains leads to the increase of cooling energy consumption. In addition, direct sun in the eye of a building occupant can cause disability glare, which interferes with the occupant's ability to see and perform work and should be avoided. To have a controlled daylighting performance, solar shading devices are usually used, which can be designed to prevent overheating, to reduce heating losses and cooling loads, and to control the visual environment.

The adoption of movable solar shading devices to reduce the energy consumption and control daylighting performance was reported by researchers. For example, Staziet et al.[1] compared different fixed shading devices in terms of daylighting factors in a Mediterranean climate. Esquivias et al. [2] studied the daylight performance of overhangs and side fins in an open-plan office. These kinds of shading devices are fixed on buildings and thus need to be long enough to block excessive daylight due to the relatively low solar altitude angle in east and west directions. On the other hand, movable shading devices can be adjusted according to changing outdoor conditions in order to achieve minimal lighting energy consumption while at the same time offering a comfortable daylighting environment. Nielsen et al. [3] analyzed the daylighting performance of movable solar shading devices in office buildings. They found that the use of dynamic solar shading dramatically improved the amount of daylight available if compare to fixed solar shading.

However, this research was based on automated shading devices which mean that a complex con-

Table 1. Characteristics of the office room

Parameter	Value
Location	Ningbo city in China, latitude: 30º, longitude: 120º
Room orientation	South
Dimension	Room: 4×4×3m, Window: 3.8×2.8m
Window and shading device	Three window settings for comparison: 1) Clear double-pane window (CL), visual transmittance: 0.89; 2) Low-E double-pane window (LOW-E), visual transmittance: 0.69; 3) Clear double-pane window +manually controlled external shading (Shade), shade material visual transmittance is 0.2.
Daylight illuminance calculation point	Occupant position in Fig.1, 0.75m above the floor

trol system will be required to maintain the frequent change of shade positions or angles and they are more expensive than manually controlled shades. In China, most office buildings only use manually controlled roller shades [4]. Moreover, occupants' shade control is not as efficient as motorized systems since occupants' behavior is stochastic [5–7]. Therefore, the daylighting performance of manual solar shades should account for the stochastic characteristic of occupants' behavior.

2 METHODOLOGY

2.1. Building model

A typical office room model was used in this paper. Its dimensions are 4×4×3m with a 3.8×2.8m window on the south facade as shown in Fig.1. To compare the performance of manual solar shades with bare windows in terms of daylighting, three window settings were considered. The first two scenarios (clear double-pane windows and low-e double-pane windows) are the most popular design measures in this region. The last scenario represents exterior manual solar shading devices. The characteristics of the office room and the three scenarios are shown in Table 1.

2.2. Stochastic model of manual solar shades

To investigate the impact of manual solar shades on daylighting performance, the stochastic model developed in a previous study by the author [4] was used in this paper. The model was constructed based on field measurements on a typical high-rise glazing building in hot summer and cold winter zone of China. The measurement used a TB-2 pyranometer and PC-2 data recorder installed on the building roof to measure the total solar radiation on south facade and the shading adjustment of south facade of a glazing building located in Ningbo (about latitude 30 degrees North) was recorded by photographing the shades manually per hour. According to the previous research [4], considering five shade states is adequate for building simulation. Therefore, occupants' shade control was divided into 5 solar shading states (shade window area of 0 %, 25 %, 50 %, 75 % and 100 %, respectively). The measurement was carried out during the year in 2011. Though many environmental factors (such as daylight illuminance, glare) influence shade control, these factors can be direct-

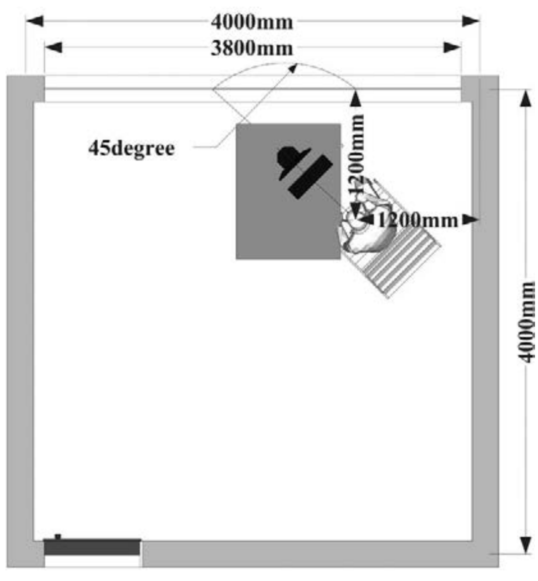

Fig.1. Room model showing the workplace position (upward direction represents South)

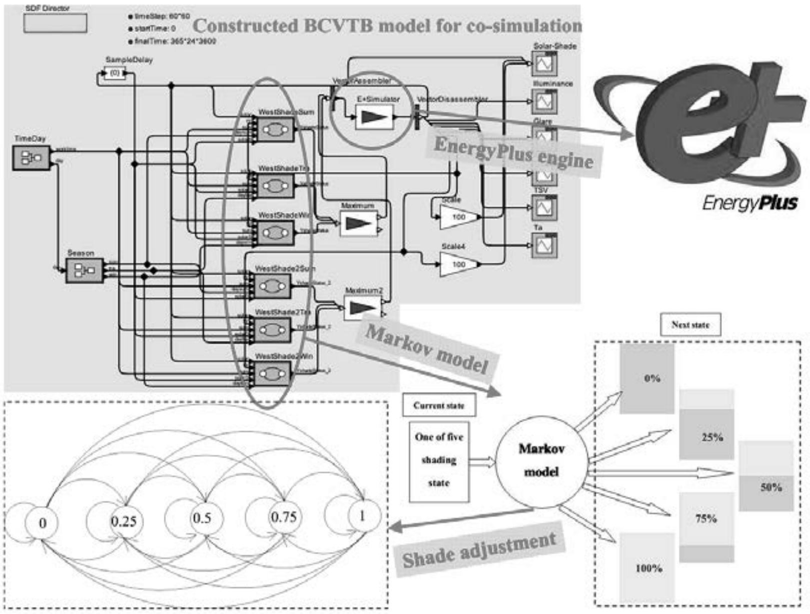

Fig.2. A graphic illustration of the developed method for co-simulation of the daylighting performance of manual solar shades

ly or indirectly linked to solar radiation, and thus daylighting index was not measured. After field measurement, further logistic regression analysis showed that solar radiation is the driving factor (compared to other thermal factors such as outdoor air temperature) of shade adjustment behaviour. Therefore, a first order and time-constant Markov chain method was used to construct the stochastic model of solar shade control based on solar radiation, and the Markov chain transition matrix (the probability of solar shade changes from the current state to the next position) for different sky conditions were calculated and classified. In order to better reflect the occupant behaviour of controlling shades under different sky conditions, the threshold of receiving direct solar radiation (here it is about 300 W/m^2 according to field measurements) was considered as the dividing line to construct transition matrix. After that, the Markov model for solar shades was modelled in BCVTB for co-simulation with EnergyPlus. At each time step, BCVTB will check the solar radiation intensity on external windows from EnergyPlus and then randomly generate a shade position according to the probability distribution and this shade position will then be applied in EnergyPlus simulation. A brief description of how this stochastic model is constructed and the co-simulation is conducted can be seen in Fig.2. More detailed information of this stochastic model and the co-simulation can be found in the previous paper [4].

2.3. Performance index

To have a comprehensive evaluation of daylighting performance, three indices have been adopted to assess the daylighting and glare protection performance. These indices include useful daylight illuminance (UDI), daylight illuminance fluctuation, daylight illuminance distribution. UDI determines when illuminance levels are useful for the occupant, that is, more than 300 lx [8] (not too dark) and less than 2000 lx (not too bright), [9]. Additional electrical lighting may be needed when the daylight illuminance is less than 300 lx, while glare may occur when daylight illuminance is over 2000 lx.

Fluctuation of daylight illuminance is also an important factor in influencing daylighting performance. At present, there is no equation or index for calculating daylight illuminance fluctuation (DIF) and thus the authors have introduced the standard deviation as the evaluation index. This can be expressed as follows:

$$E_\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(E_i - E_{ave})^2}, \qquad (1)$$

where E_σ is the standard deviation of daylight illuminance, N is the number of calculation points for daytime working hours (from 8:00 to 17:00, 10 points: 8:00, 9:00, …, 17:00), E_i is the daylight illuminance for i^{th} calculation point, and E_{ave} is the ave-

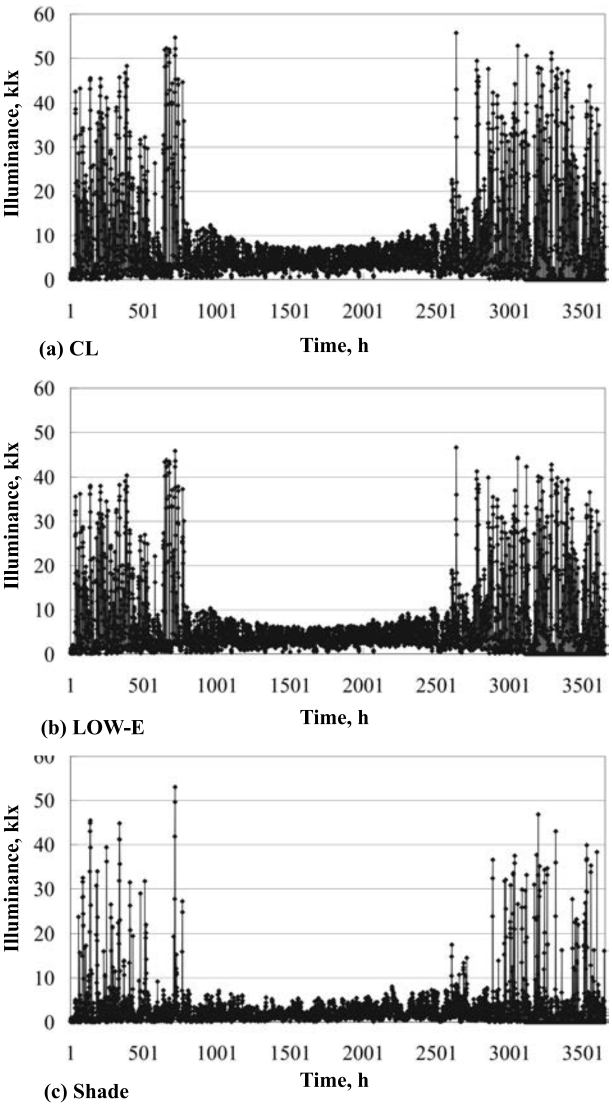

Fig.3 Daylight illuminance for the three measures during annual working hours (calculation point number is (D-1) x 10 + m, where D is the day of the year number and m = 1 for 8:00, 2 for 9:00, …, 9 for 16:00, 10 for 17:00

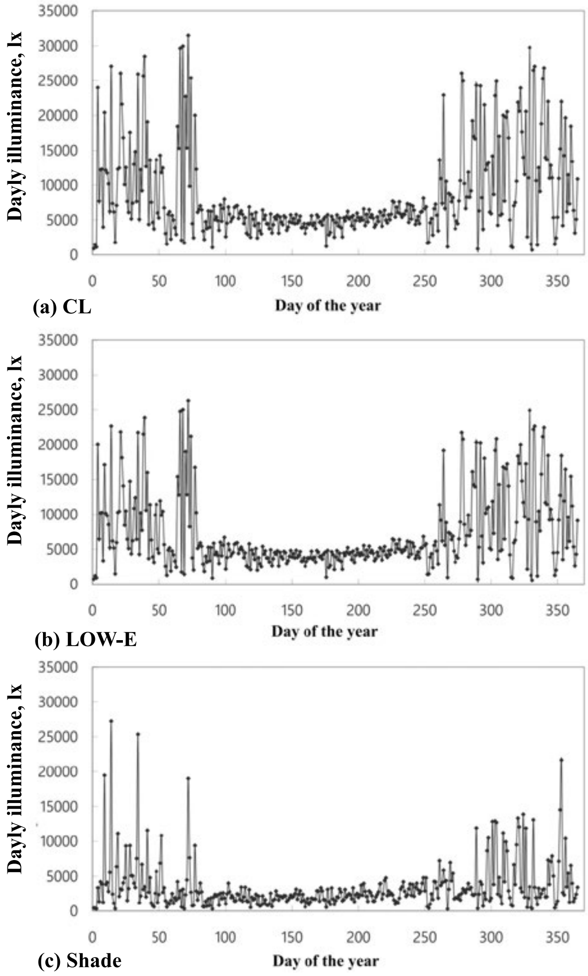

Fig.4 Daily average daylight illuminance for the three measures

rage daylight illuminance of the working hours for a day as shown below:

$$E_{ave} = \frac{1}{N}\sum_{i=1}^{N} E_i. \quad (2)$$

3. RESULTS AND DISCUSSION

3.1. UDI

Daylight illuminance for the three measures during annual working hours is shown in Fig.3. Bare window scenarios (CL and LOW-E) have more hours with high daylight illumimance values compared with Shade. The daylight illuminance was further categorized into three groups, Table 2, according to UDI index. Shade has a total UDI of 1553 h (corresponding to a 42.55 % of working hours), followed by LOW-E (597 h, 16.36 %), and the poorest measure is CL (470 h, 12.88 %). That means manual solar shades perform better than the other two measures by approximately 160 %. Although manual solar shades have a little negative impact with more hours of daylight illuminance less than 300 lx, their positive impact of reducing potential glare risk is more significant with a reduction of daylight illuminance over 2000 lx by more than 1000 h compared to LOW-E and CL.

3.2. DIF

The daily average daylight illuminance for the three measures is illustrated in Fig.4. For this index,

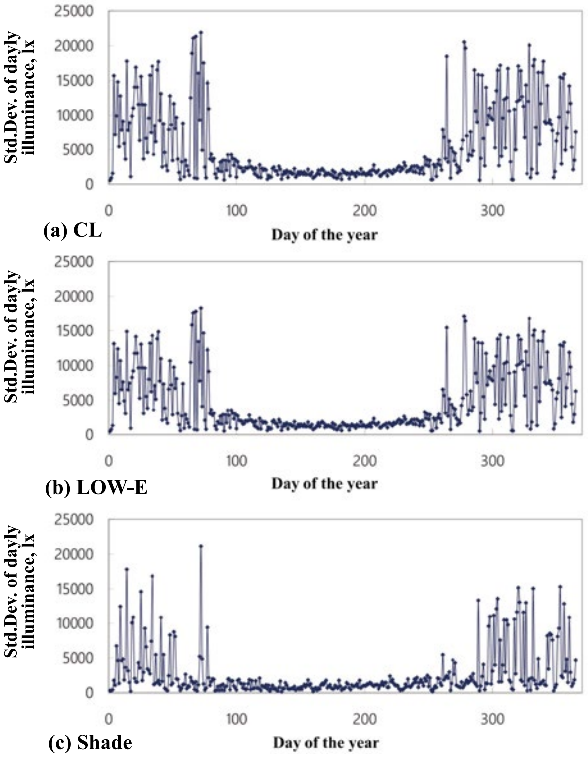

Fig.5 Daily standard deviations of daylight illuminance for the three measures

CL and LOW-E are both higher than 5000 lx, while shade is only about 2500 lx. This means that manual solar shades are more beneficial compared with bare windows (CL and LOW-E) according to the UDI range. On the other hand, the daily standard deviations of daylight illuminance are shown in Fig.5. It can be seen that manual solar shades also perform better with an improvement of about (44–53)%, Table 3, when compared to LOW-E and CL, respectively. This is because solar shades can be manually controlled by occupants in response to changing sky conditions and, thus, daylight illuminance on the working zone will be maintained at a relatively comfortable level.

3.3. Daylight illuminance distribution

Due to the stochastic characteristic of manual solar adjustment by occupants, it is important to understand when shades are adjusted and maintained at a suitable position that daylight illuminance is kept at UDI range (300–2000) lx. Fig.6 presents daylight illuminance distribution during the working hour of the whole year for the three measures. It can be seen that CL and LOW-E have very similar performance with almost the same UDI distribution. This is because they are all transparent windows

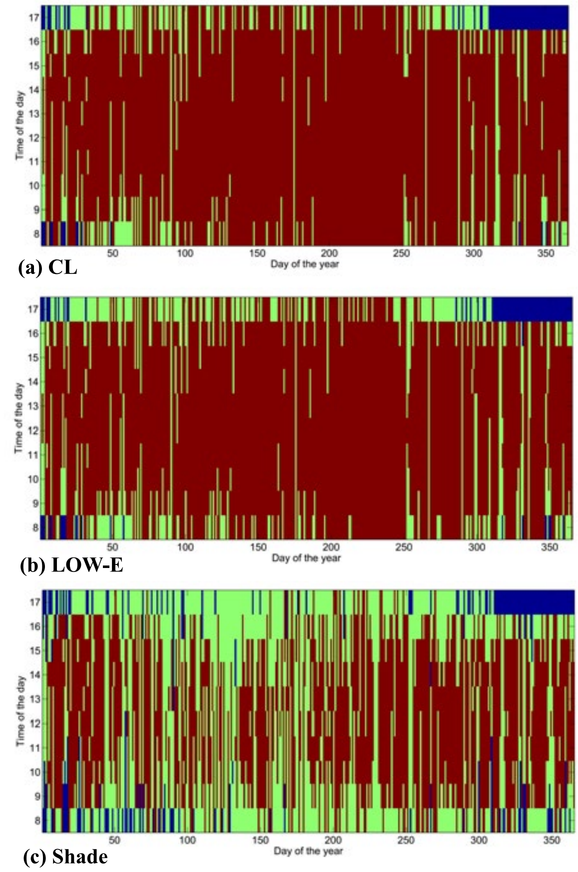

Fig.6. Daylight illuminance distribution during the working hour of the whole year for the three measures (blue:<300 lx, green: (300–2000) lx (UDI), red:>2000 lx)

with only little difference in visual transmittance. And UDI occurs only during early morning and late afternoon when sun light is not very bright. However, shade has more green area during the whole day, especially in late spring and early summer period. This is due to the more frequent use of solar shade compared to other periods. From this figure, it can be concluded that occupants operate solar shades effectively during the late spring and early summer and the manual control during other periods can be further improved to enhance daylighting performance.

4. CONCLUSION

This paper simulates the daylighting performance of manual solar shades and compares its performance improvement with two conventional window scenarios. Results show that manual solar shades increase UDI by approximately 160 % compared to conventional windows with less significant daylight illuminance fluctuation. In addition, occu-

Table 2. Daylight illuminance distribution

	Daylight illuminance, lx	CL	LOW-E	Shade
Hours	<300	89	95	229
	300–2000	470	597	1553
	>2000	3091	2958	1868
Percentage,%	<300	2.44	2.60	6.27
	300–2000	12.88	16.36	42.55
	>2000	84.68	81.04	51.18

Table 3 Annual average of E_{ave} and E_σ for the three measures

Illuminance, lx	Cl	LOW-E	Shade
E_{ave}	8461.48	7081.41	3358.12
E_σ	5341.93	4471.99	2524.83

pants operate solar shades effectively during the late spring and early summer and the manual control during other periods can be further improved to enhance daylighting performance.

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