

Daylighting Performance of the Enclosed Atrium in Zhuhai City International Trade and Exhibition Centre

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Abstract

Zhuhai City International Trade and Exhibition Centre building has an enclosed atrium to facilitate daylighting and natural ventilation of the surrounding rooms. A field measurement of illuminance distribution in the atrium and RADIANCE simulation of daylighting performance of the atrium are presented in the paper. The RADIANCE simulation is validated with the field measurement data for some chosen time and sky conditions. The simulation is then extended to discuss the effect of geometric variations on daylighting performance. The results show that the enclosed atrium's geometric parameters can significantly alleviate or aggravate its performance. A combined geometric parameter, Well Index, is introduced in discussing the relationship of daylighting performance and the atrium's geometry.

Keywords: Daylight, atrium, field survey, simulation, Well Index

1 Introduction

Daylighting has become a major topic for sustainable building design in the last two decades across the world. Atrium as a hybrid architecture aesthetics element and building technique element has been used in subtropical climate area widely. One of the atrium's basic functions is to introduce daylight into the core of the building. Atrium is the main daylight source in buildings. The level for daylight needed in an atrium is determined by the use of the atrium: if the principal requirement is for a pleasant view, then the daylight must be sufficient merely to provide a bright, lively atmosphere (a daylight factor of 5% to 10%) and to sustain the plants (a daylight factor of 5% to 40% [Baker et al. 1993]). It is well known that the geometries of the atrium can influence the atrium daylighting performance, but the correlation between them is not clear, in this paper, several computer models have been employed to simulate a real building and discover the relationship between them. Three combined geometric parameters: Plane Aspect Ratio (PAR), Section Aspect Ratio (SAR) [Bednar, Michael J, 1986] and Well Index (WI) will be used in the analysis of the geometric effect on daylighting performance.

2 Case study

Zhuhai City International Trade and Exhibition Centre (China) is an enclosed atrium building, located in Zhuhai City, Guangdong Province, 22.3° north and 113.52° east. The local prevailing climate is oceanic monsoon subtropical. The centre is a three-storey large scale commercial building with the atrium in the core, which has the plane of 30m (L) by 20m (W) and a height of 3.8m on each floor. Figure 1 shows the interior view and plan view of the atrium space. Figure 2 shows the rendered images of the atrium in RADIANCE simulation. Field surveys were conducted for the overcast sky condition on 22nd August 2006. The grid of measurement points are shown in Figure 3. The grids 5~11 were in the atrium space and the rest were in the adjoining space. The illuminance distribution on the grids and the outside were measured by two Peak Tech 5035 Environment Meters with an accuracy of $\pm 5\%$. The

illuminance values on the grids were also calculated in RADAINCE simulation.

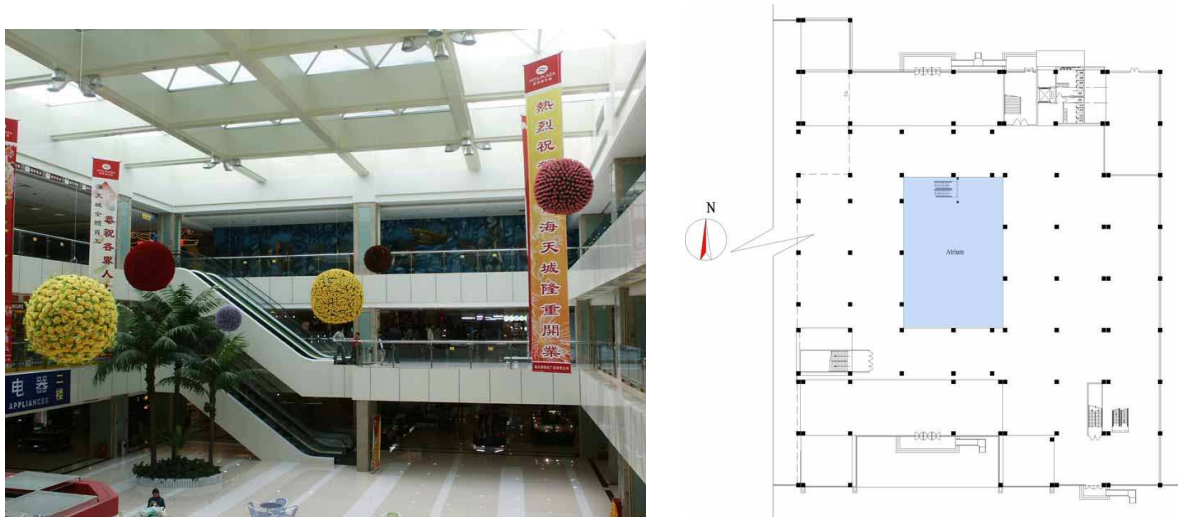


Figure1: Interior view and plan view of the atrium

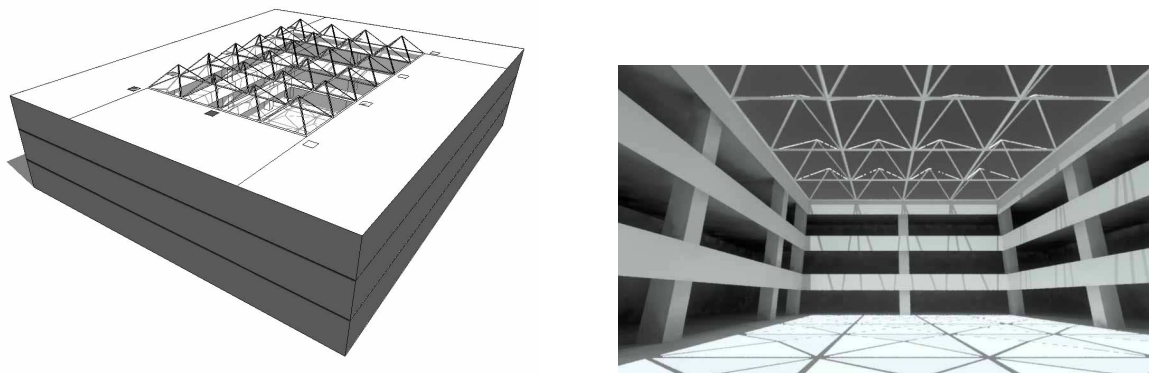


Figure 2: Rendered images of the atrium in RADIANCE simulation

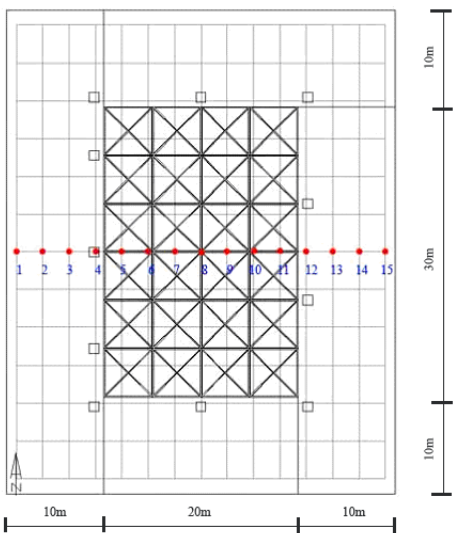


Figure 3: Grids in the field survey and simulation of the atrium

Daylight Factor, which is the ratio of the internal illuminance to the external horizontal illuminance under the overcast sky, is usually used to indicate daylighting performamnce.

Figure 4 shows a comparison of the measured and simulated Daylight Factors for various grids 800mm above each floor. It was found that their deviation were in the range of 16~23%. Considering the computer modelling error, atrium wall and glazing reflectance estimation error, and field survey equipment accuracy, this deviation is acceptable.

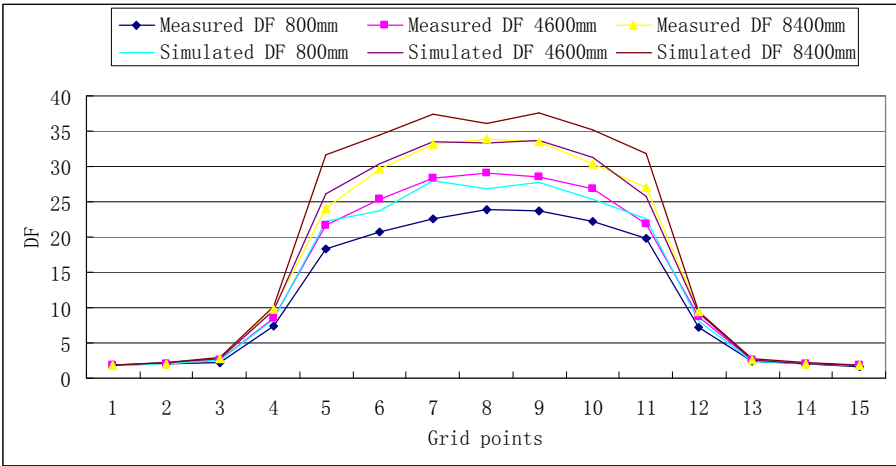


Figure 4 Comparison between field survey and computer simulation results

Figure 5 shows the calculated illuminance for a CIE clear sky condition on 22nd August. The illuminance at Grid Point 1 reaches the peak value 1146 lux at 9:00am and then decreases gradually to 9 lux at 18:00pm. Grid Points 2, 3, 4 are all located in the western adjoining space, and have the same trend. Meanwhile, Grid Points 12 to 15 are all located at the eastern adjoining space, and have a lower illuminance at 9:00am and the peak value at 15:00pm. Grid Points 5 to 11 are all located in the atrium space, the illuminance at these points increase from 9:00am, reaching the peak value at 12:00 am and then decreasing gradually until 18:00 pm.

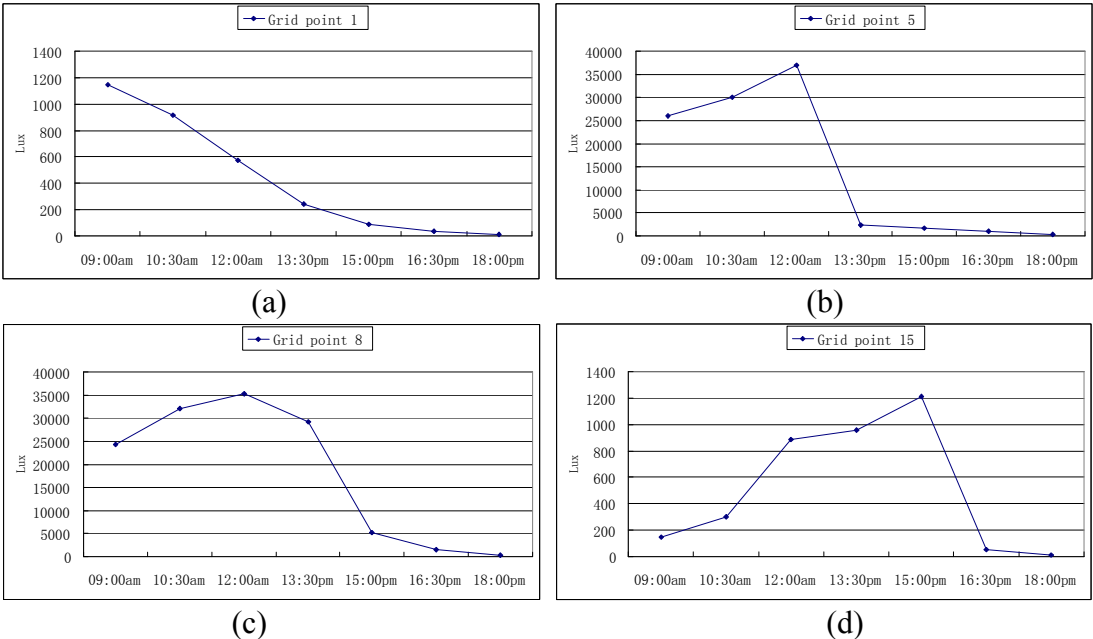


Figure 5 Illuminance level versus time under a CIE clear sky on 22nd August

Figure 6 shows the mean illuminance value between 9:00am~12:00am. It can be seen that the atrium space (Grid points 5 to 11) have much higher illuminance value than the grid points in the adjoining space (point 1 to 4, 12 to 15). The points closer to the centre of the atrium have higher illuminance value.

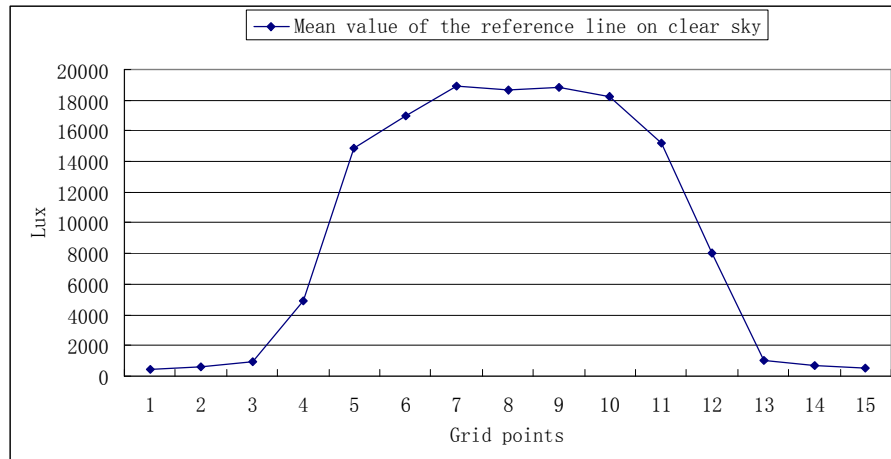


Figure 6 Mean illuminance value between 9:00am~12:00am under a CIE clear sky on 22nd August

3 Parametric study of geometric effect

The daylighting performance of an atrium is strictly dependent on its geometrical aspect. According to Liu et al. (1991), Baker et al. (1993), Kim and Boyer (1986), the shape of an atrium can be described and quantified with a geometric parameter such as the Well Index which represents the relationship between the light-admitting area and the surface area of the atrium. The WI can be also described by the combination of the plane aspect ratio (PAR) and the section aspect ratio (SAR), that is:

$$PAR = \frac{Width}{Length} = \frac{W}{L} \quad (\text{Equation 1})$$

$$SAR = \frac{Height}{Width} = \frac{H}{W} \quad (\text{Equation 2})$$

$$WI = \frac{Height \times (Length + Width)}{2 \times Length \times Width} = \frac{H(W + L)}{2WL}$$

$$= \frac{1}{2} \frac{H}{W} \left(1 + \frac{W}{L}\right) = 0.5 \cdot SAR \cdot (1 + PAR) \quad (\text{Equation 3})$$

Eq. 5-3 indicates that $WI = f(SAR, PAR)$. So the WI can be employed to represent different combinations of PAR and SAR.

Seven variations of the geometry were chosen for this type of atrium, as listed in Table 1. Case 1 is the base geometry same as the case study in the previous section, i.e., $L=30\text{m}$, $W=20\text{m}$, $H=11.4\text{m}$ and $WI=0.475$. In the seven Cases, the atrium's width has been set at a constant value of 20m. So the same grid for illuminance calculation as in Case 1 was used for other six cases.

Table1 1: Variation in the geometries of the enclosed atrium

Enclosed atrium	Length (m)	Width (m)	Height (m)	PAR	SAR	WI
Case 1	30	20	11.4	0.67	0.57	0.475
Case 2	20	20	11.4	1.00	0.57	0.570
Case 3	20	20	19.0	1.00	0.95	0.950
Case 4	40	20	26.6	0.50	1.33	0.998
Case 5	20	20	26.6	1.00	1.33	1.330
Case 6	30	20	38.0	0.67	1.90	1.587
Case 7	20	20	38.0	1.00	1.90	1.900

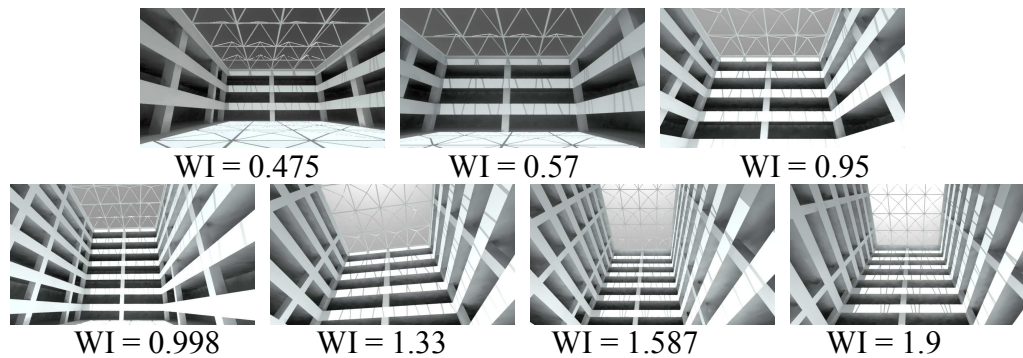


Figure 7 Perspective illuminance image under sunny sky at 12.00am on 22nd August (Case 1 to Case 7 with different Well Index)

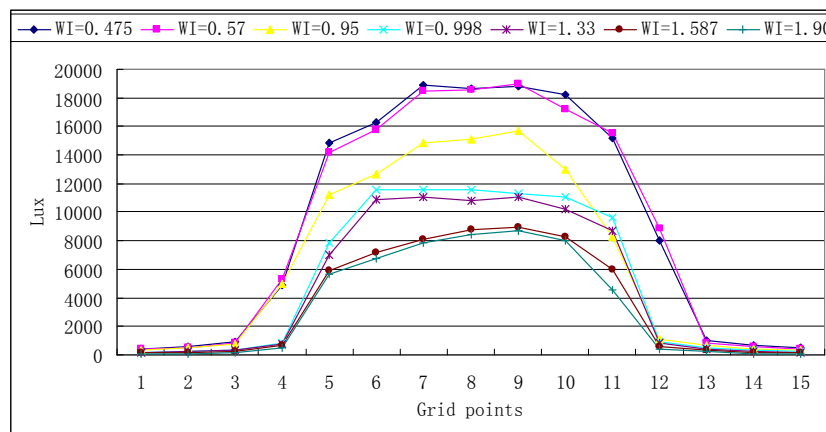


Figure 8 Mean illuminance values on the grid 800mm above the ground floor between 9:00am to 18:00pm under clear sky on 22nd August

The average illuminance values for 9:00am to 18:00pm under a clear sky are given in Figure 5-4. It can be seen that:

- Illuminance decreases as atrium Well Index increases under a clear sky condition.
- Illuminance levels are close when the heights of atriums are the same or close as in Cases 1 and 2, Cases 4 and 5, Cases 6 and 7 even the Well Indexes (WI) have a larger difference. This means that the height or plays a dominant role in the atrium's illuminance level under clear sky conditions. For example, there is a large difference in the illuminance level between Case 3 and Case 4 due to their very different SAR.
- Length or has a very small influence on the atrium's illuminance level. For example, the lengths in Case 4 and Case 5 are 40m and 20m respectively, but they have very close illuminance curves.

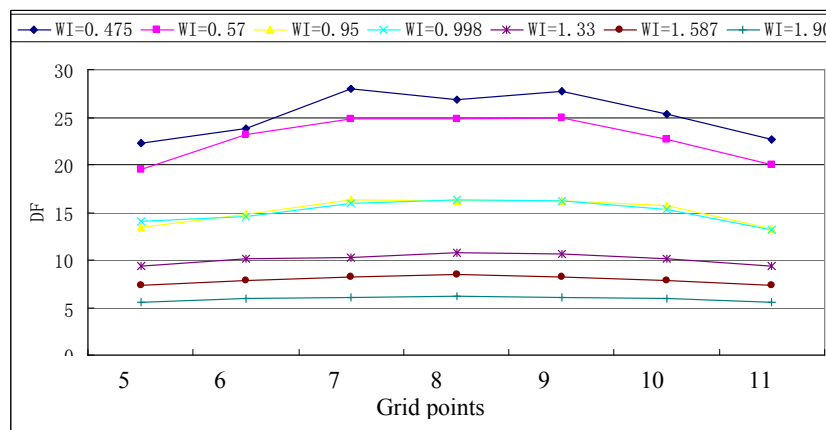


Figure 9 Daylight Factor distribution on the grid 800mm above the ground floor

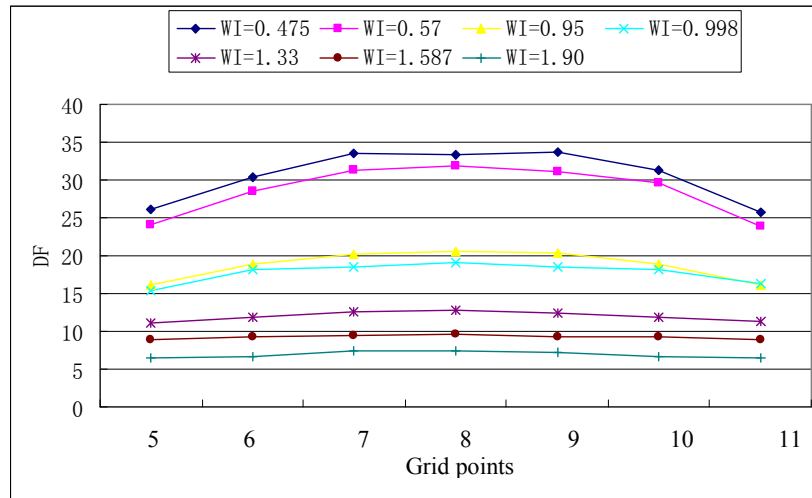


Figure 10 Daylight Factor distribution on the grid 800mm above the 1st floor

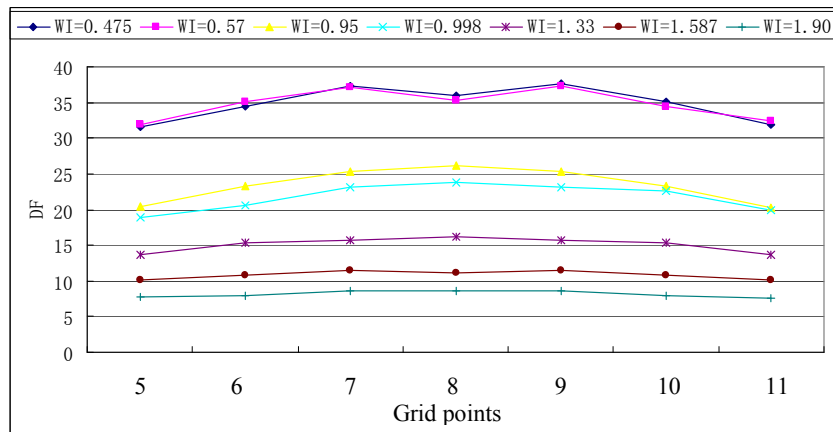


Figure 11 Daylight Factor distribution on the grid 800mm above the 2nd floor

Figures 9~11 give the calculated Daylight Factor distribution under the overcast sky for three floors. Compared with Figure 8, it can be seen that the Well Index has a more obvious effect on the daylighting performance under the overcast sky than under the clear sky. Figure 12 indicates a nearly linear correlation between the average Daylight Factor and the Well Index.

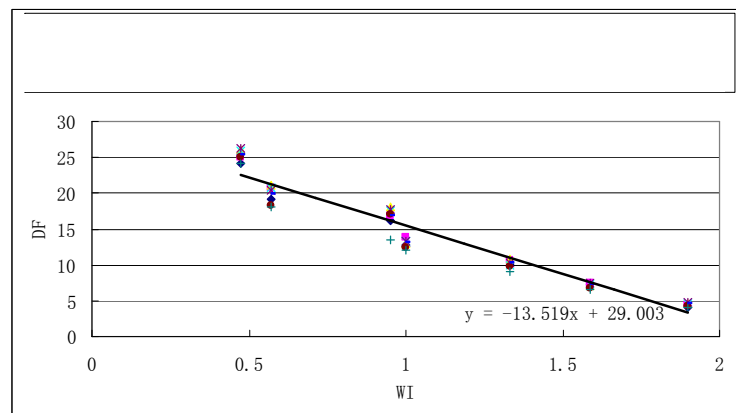


Figure 12 Correlation of average Daylight Factor on the ground floor with the Well Index

4 Conclusions

The field measurement of the enclosed atrium in Zhuhai City International Trade and Exhibition Centre building has been carried out. The measurement data has been used to validate RADIANCE simulation of daylighting performance of the atrium. The overall agreement of the measured and simulated is satisfactory. The RADIANCE simulation has been also carried out to analyse the geometric effect on daylighting performance of the enclosed atrium. It has been seen that there is a nearly linear correlation between the average Daylight Factor and the Well Index of the atrium. The results have indicated that the Well Index no less than 1.8 is necessary to achieve an average Daylight Factor of 5%.

Reference

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