PAPER P3.B

Advanced Daylighting System for Deep-Plan Office

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Abstract

This paper presents a preliminary study on the application of advanced daylighting system for redirecting daylight into deep space of deep-plan office. A system called Anidolic Light Pipe (ALP) has been selected for the analysis. The simulation was carried out in the worst case scenario which used the CIE overcast sky as a reference sky. Four cases i.e. BASECASE and three alternative cases (CASE 1 to CASE 3) have been simulated. The results of simulation show that the use of ALP system increases the illuminance in the rear room as well as the uniformity of illuminance in the whole room.

Keywords: *Advanced daylighting system, anidolic light pipe, computer simulation, window system*

1. Introduction

1.1 The importance of daylight

The importance of daylighting in architectural design is well known. Daylight provides good lighting atmosphere for architectural spaces and offers high possibility in the reduction of electrical lighting energy. It also has the contribution on the increase of workers performance (Boyce, 2004). Another benefit of integrating daylighting in office buildings is to promote more sustainable living environments. Most importantly, daylight offers health benefits by providing biological and psychological effects (Sunlight Direct, 2004).

The visual (psychological) effects of light are relate to the sick building syndrome (SBS) (Guzowski, 2000). A study carried out by Hedge (cited in Guzowski, 2000) "found that the quality of lighting environments correlates directly to the frequency of vision-related symptoms such as headache, eyestrain, and visual discomfort." Another study, The Building Research Establishment (BRE) Review has identified several contributory factors to the SBS which is one of them is poor lighting, particularly little daylight (Health & Safety Executive., 2005). The non-visual (biological) effects of light are due to its impact on the body's circadian rhythm (biological clock). Disturbance to the circadian system may cause behavioral and health problems such as sleep disorder, seasonal affective disorder, Alzheimer's disease, and breast cancer" (Chung, 2005). According to Chung (2005, paper 8, p.5) "… daylight has several benefits on circadian system. First of all, it usually provides much higher illuminance than electric lighting so that it is more effective in entraining the human circadian system. Secondly, it contains a larger portion of short wavelength light which has been shown to stimulate the human circadian rhythm more efficiently than the longer wavelength light. Thirdly, daylight entering the interior (through vertical windows) gives much higher vertical illuminance at the eye than most electrical lighting installation."

However, the use of daylight to illuminate the deepest parts of deep-plan office is inadequate. Because daylight can only illuminates the perimeter zone of the office, which has a distance of about 1.5 times of window height. Beyond this area, artificial light will be required extensively. This will has implication on the increase of energy demand and CO_2 emission. This paper presents a preliminary study on the application of advanced daylighting system called anidolic light pipe (ALP) for redirecting light into rear space of deep-plan office in order to improve daylight quality via computer simulation method.

1.2 Basic Principles of Anidolic

Non-imaging optics principles have been applied to the design of new reflectors forming daylighting systems (Courret et al., 1998, Scartezzini and Courret, 2002). These systems called anidolic systems (an: without, eidolon: image in ancient Greek). In principles, this system uses compound parabolic concentrator (CPC) to redirect lights (diffuse lights).

The properties of anidolic system, according to Scartezzini (2002) are as follows:

- Anidolic based on non-imaging optics (Edge-Rays principles)
- Minimize the number of reflection, by maximizing collection and distribution of daylight flux (Law of conservation "Etendue").
- Accurate definition of admittance sector for incoming light rays (capture of diffuse daylight from sky vault)
- High angular selectivity for exiting light rays ("Beam Projector" for diffuse daylight)

According to Winston et al. (2005), all lights coming from the focus of parabolic will be reflected parallel with the parabolic axis (refers to Figure 1 for more information). By using this principle, all lights in front of the window can be redirected to the inside of the room.

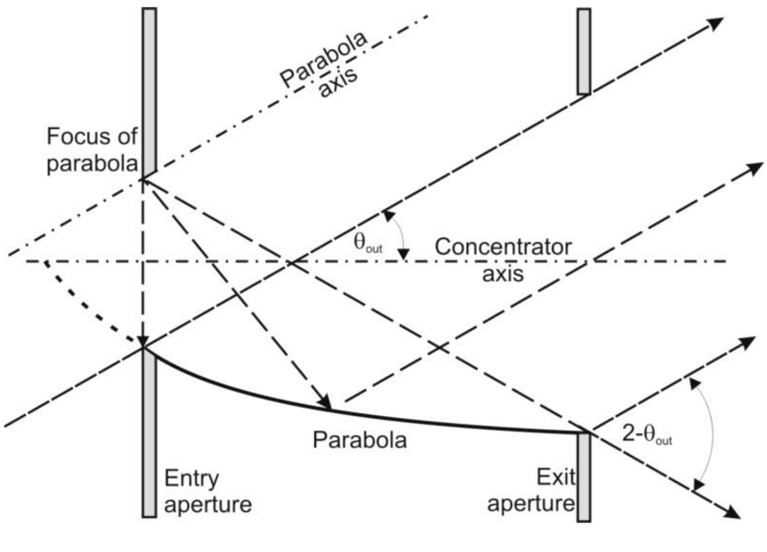

Figure 1: The basic principles of CPC based on edge-rays principles (Scartezzini and Courret, 2002)

The research on the application of anidolic daylighting system has been carried out in several research institutes around the world. The main focus of these researches is the use of non-imaging optics to increase the daylight factor in the rear zone of the deep room. Some of these studies are as follows:

- Design and assessment of an anidolic light-duct (Courret et al., 1998),
- The application anidolic in underground space (Molteni et al., 2001, Scartezzini and Courret, 2002),
- The use of anidolic in deep office in highly luminous city (Ochoa and Capeluto, 2006),
- Comparing anidolic application in the tropics and the temperate location (Wittkopf, 2007, Wittkopf et al., 2006),
- Preliminary investigation of anidolic in the heavily obstructed area (Lau and Baharuddin., 2006).

This system increased daylight factor in the back of the room and decreased DF in the front part of the room in overcast sky condition. It reduces discomfort due to glare or to improve the illuminance uniformity ratio, the upper window has to be equipped with a daylighting system. This system also improves visual comfort probability for a large part of the room (Compagnon et al., 1993).

Anidolic zenithal collector is the first generation design of non-imaging optics in daylighting application system (Scartezzini and Courret, 2002). This system takes advantage of the higher luminance of the sky occurring at high altitudes, an external concentrator can be mounted in front of the vertical opening in the facade. The anidolic concentrator is designed to accept all incoming light from half the sky hemisphere (Compagnon et al., 1993).

2. Methods

2.1 Computer Simulation

This study was carried out using the computer simulation technique called RADIANCE. RADIANCE is a physical based, backward ray-tracing rendering tool that has been developed by Greg Ward at Lawrence Berkeley National Laboratory. RADIANCE is able to simulate internal illuminance and luminance distributions in complex building under arbitrary sky conditions (Larson and Shakespeare, 1998).

RADIANCE is a lighting simulation program that synthesizes image from 3D geometric models of physical spaces. The input model describes each surface’s shape, size, location and composition. A model often contains many thousands of surfaces, and is often produced by separated CAD tool. Beside arbitrary (planar) polygons, RADIANCE directly models spheres and cones. Generator programs are provided for the creation of more complex shapes from these basic surface primitives (Larson and Shakespeare, 1998).

RADIANCE daylight simulation program has been extensively validated. Mardaljevic (1995, 2000) found a good agreement between daylight illuminance in full-scale office model at BRE office and the illuminance predicted by RADIANCE simulation program under real sky conditions.

The parameters used in the simulation are listed in Table 1. The simulation was carried out in the worst case scenario which used the CIE overcast sky as a reference sky.

Table 1: RADIANCE parameter settings

Parameter	*Value*
-ab (ambient bounces)	*5*
-aa (ambient accuracy)	*0.15*
-ar (ambient resolution)	*256*
-ad (ambient division)	*1024*

2.2 Model

For the purpose of studying the capability of ALP to redirect daylight into deepest part of deep-plan office, a model with a width, length and height of 3, 10 and 4 m, respectively have been simulated and analyzed (Figure 2). The reflected material with 95% reflectivity has been used in the anidolic and light pipe parts.

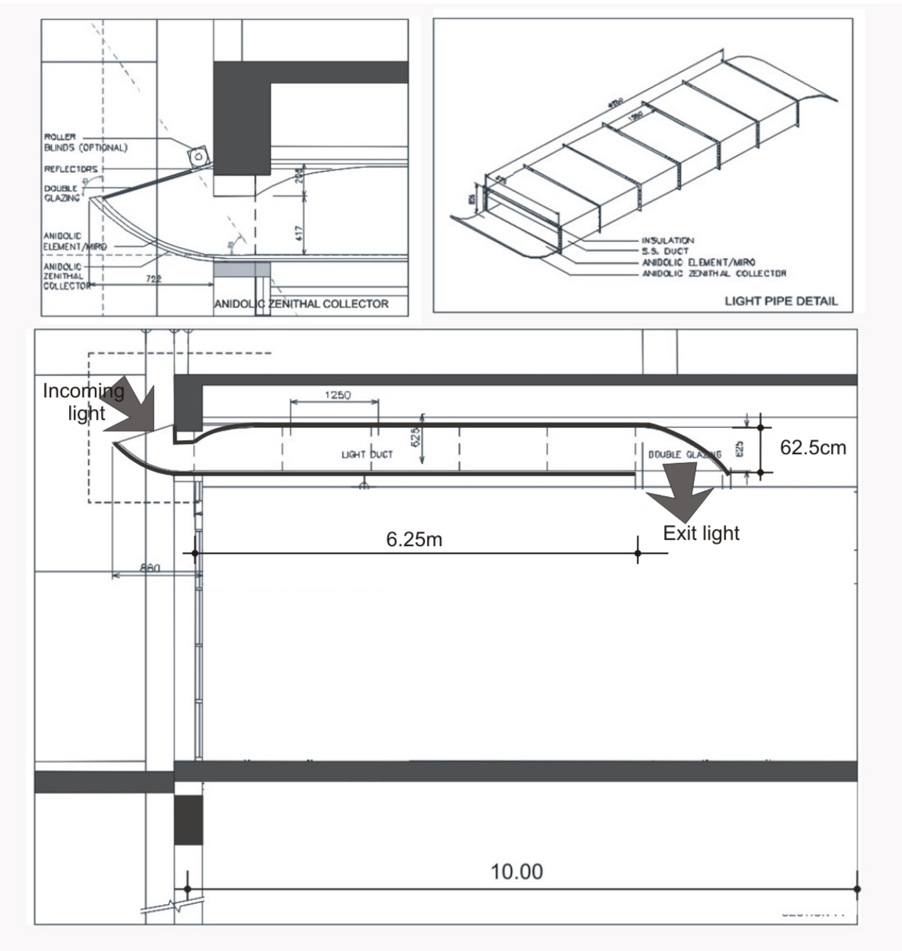

Figure 2: Model descriptions

2.3 Performance criteria

In order to evaluate the daylight performance inside the model for each case, daylight factor (DF), the illuminance level and the daylight uniformity have been used as performance criteria. DF is a ratio of illuminance received by a point inside a room to the unobstructed outdoor illuminance under overcast sky condition (Mardaljevic, 1998), while the illuminance level is the absolute illuminance received by a point inside the room and daylight uniformity is a ratio of minimum illuminance/DF to the average illuminance/DF.

3. Results and Discussion

Daylight factor (DF) performances of the baseline and the three cases are illustrated in Table 2 and Figure 3. These show that the DF of BASECASE is reduced rapidly from 20.16% in the perimeter area (0.5m from window) to below 1% in the rear room (7.5 to 9.5m from window), with minimum DF of 0.57%. This resulted in very high illuminance at window area but very low illuminance at the rear room. By using anidolic light pipe (ALP), the DF performance inside the room has been improved significantly. Among the three ALP systems, the CASE 2 has the best DF performance. In the CASE 2, the DF at the window area has been reduced significantly to 14.02%, while the DF at the rear room has been improved significantly to an average of 2%.

As seen in Table 2, the daylight uniformity of BASECASE is very small i.e. 0.1 which indicates that the distribution of daylight inside the model was worse. However, the used of ALP systems, had improved the daylight uniformity in comparison to the BASECASE performance. Among the three ALP systems, the CASE 2 had the highest uniformity performance i.e. 0.33. The daylight uniformity of CASE 2 was 3.3 times better than the BASECASE performance. This was resulted from the reduction of high illuminance at window area and the increase of illuminance at rear area. The CASE 1 & CASE 3 has improved the daylight uniformity marginally.

Table 2: Daylight Factor (DF) performance of the four cases

Distance from window (m)	*BASECASE - (w/o anidolic light pipe) (%)*	*CASE 1 - Anidolic (light pipe 6.25L, 0.70W) (%)*	*CASE 2 - Anidolic (light pipe 6.25L, 2.30W) (%)*	*CASE 3 - Anidolic (light pipe 3.5L, 2.30W) (%)*
0.5	*20.16*	*17.44*	*14.02*	*14.12*
1.5	*13.91*	*12.09*	*11.11*	*11.25*
2.5	*8.24*	*6.47*	*6.28*	*6.59*
3.5	*4.90*	*3.57*	*3.59*	*4.41*
4.5	*2.98*	*2.05*	*2.14*	*4.11*
5.5	*1.93*	*1.29*	*1.55*	*3.02*
6.5	*1.30*	*1.18*	*1.84*	*1.86*
7.5	*0.94*	*1.23*	*2.66*	*1.51*
8.5	*0.71*	*0.96*	*2.13*	*0.91*
9.5	*0.57*	*0.75*	*1.53*	*0.56*
Min	*0.57*	*0.75*	*1.53*	*0.56*
Max	*20.16*	*17.44*	*14.02*	*14.12*
Average	*5.56*	*4.70*	*4.68*	*4.83*
Max/Min	*35.13*	*23.29*	*9.16*	*25.26*
Min/Ave (Uniformity)	*0.10*	*0.16*	*0.33*	*0.12*

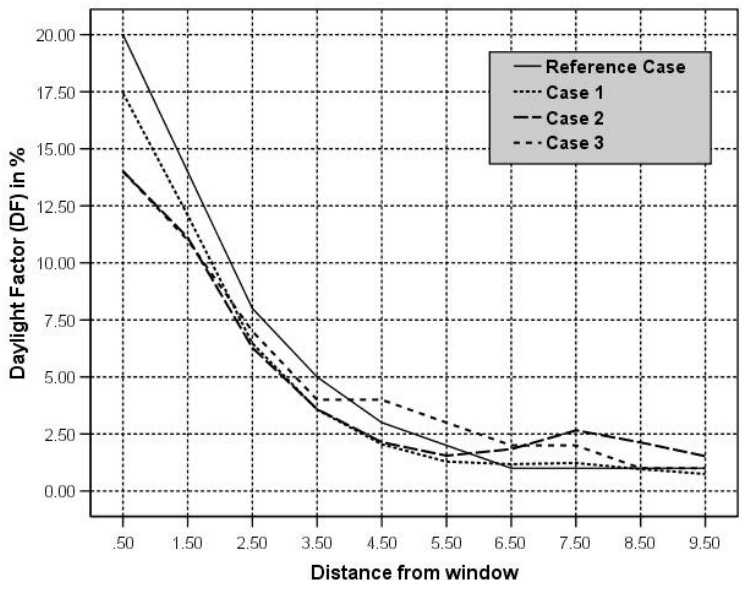

Figure 3: Daylight performance of BASECASE and three ALP systems

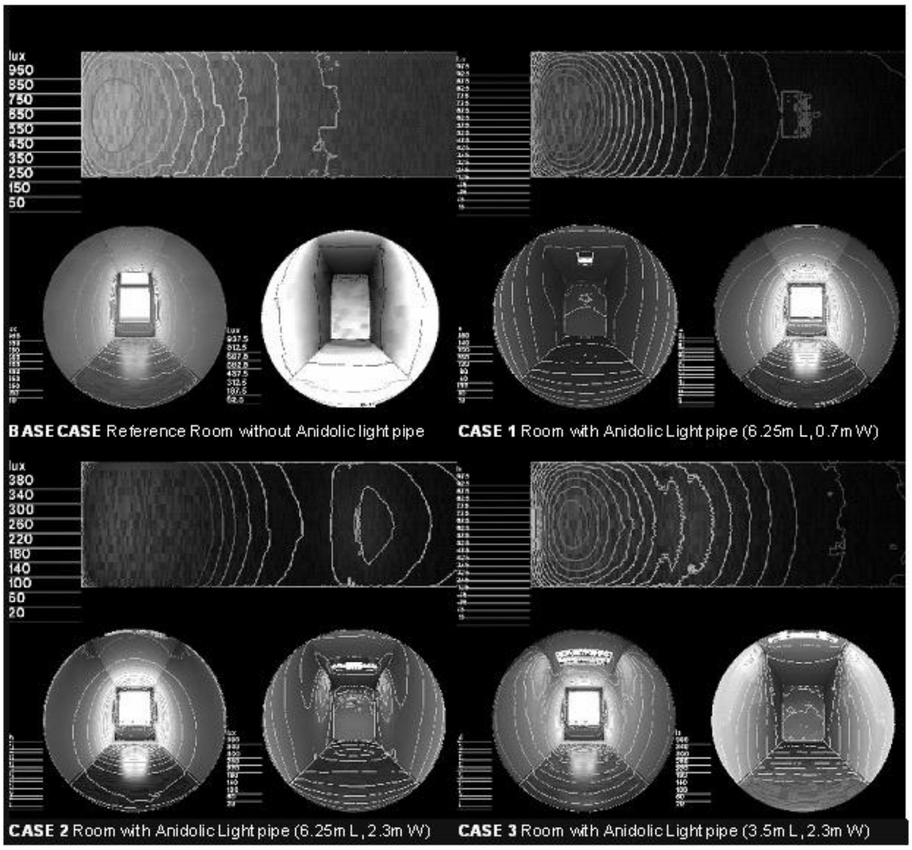

Figure 4: Isolux of BASECASE and the three ALP systems

The illuminance level of the four cases can be seen in the isolux graph presented in Figure 4. As seen in the figure, very high illuminance level was recorded at window area, but low illuminance level at the rear part of BASECASE. The use of ALP systems significantly reduced the illuminance at the window area and improved the illuminance at the rear room. This high illuminance at window area potentially creates glare problem to the occupants and therefore it should be reduced. At window area, Both CASE 2 & 3 reduced the illuminance about 30% of BASECASE value, while CASE 1 only reduced about 13%. The reason for this is that because the width of CASE 2 & 3 were the same (2.3m), which was larger than the width of CASE 1 (0.7m). Therefore, the amount daylight blocked by CASE 2 & 3 that entered the interior area was higher than CASE 1. At rear room, CASE 2 improved the illuminance about 132% of the BASECASE value, while CASE 1 & CASE 3 improved the illuminance about 17 and 38%, respectively.

Based on the above analyses, the use of ALP system, especially CASE 2 would potentially reduce the lighting energy use due to the improvement of DF/illuminance distribution and reduce the cooling load by minimizing heat gains from the window and from artificial lighting. Besides, the reduction of illuminance at the perimeter area and the increase of daylight uniformity improve the quality of light inside the office, which in turn affect the performance of workers. Therefore, the application of this system in the deep-plan office would potentially bring environmental, health and economic benefits.

4. Conclusions and recommendation

Based on the results and discussion, several conclusions can be drawn as follows:

- ALP reduces the illuminance at the perimeter area of the office due to its shading effect.
- ALP improves the illuminance at the rear room by reflecting daylight, especially diffuse light, through light pipe to the back area of the office.
- ALP system improves the daylight uniformity in the deep room area, which improves the quality of light inside the office.

This is a promising system to reduce the energy use and to improve the workers' performance in deep-plan office buildings. However, further study in the real situation by mock-up method is needed to test the real daylight performance of this system. The author believes that the actual performance of ALP system would be better than the simulated one.

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