Analysis of Anidolic Daylighting System Parameters in Tropical Climate

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Abstract: Utilizing available daylight in buildings is a crucial issue for reasons of energy-efficiency as well as improvement of occupant's health and well-being. Anidolic Daylighting System (ADS) is a type of daylighting system that provides daylight in areas far from windows. This device concentrates daylight in a collector and transfers it to duct situated between collector and distributor, which then spreads this daylight to the inside of the building. The aim of this research is to determine optimum Anidolic duct shape and width which increases daylight illuminance into the interior of office buildings. The simulation model was designed in Integrated Environmental Solution IES<VE> software to perform daylight simulation experiments. Therefore, three configurations of designed duct shape with two duct lengths (12 and 20 meters) were simulated as duct shape variables. Three different duct width sizes were also evaluated. Results indicated that a rectangular shaped Anidolic with three meter duct width offers higher illuminance than the other simulated cases. For future study, other parameters can be carried out such as depth of duct, size of anidolic, collector and distributor of device.

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1. Introduction

Reducing energy load, especially artificial lighting load is a critical step towards sustainable and energy-efficient buildings. Previous researches were stydied that office buildings consume more than 40% of the over electricity with artificial lighting and reduction of that is particularly notable in these places (Mohammadi et al. 2014; Jenkins et al., 2007; Li et al., 2006; To D. W. T. et al., 2002). Preparing available daylight in buildings is not only desirable for energy efficiency reasons, but also provides a healthy and comfortable environment for the occupants (Veitch, 2006). Windows on vertical façades provide the aperture for daylight, but this light can only penetrate a limited distance from the windows (Tregenza, 1980). Designing higher and longer aperture to provide more daylight at the back of the room leads to an unavailable area near the window and increases cooling load and solar gain, discomfort glare (Santiago, 2011; Li, 2010; Koo et al., 2010).

Therefore, it is necessary to use daylighting and reflector systems that have been shown to be more effective in bringing daylight into deeper interior spaces.

2. Anidolic Daylighting System

Methods to solve the above problems include employing some form of daylighting system to transfer daylight to areas deep within the building. Aimed at that goal non-imaging optics which concentrate daylight were used to set-up a new design technology for daylighting systems. This novel device is an Anidolic daylighting system (ADS) (Figure 1). In this system, daylight is collected from the sky vault through the Compound Parabolic Concentrator (CPC) type collector and is transferred by the duct. A distributor situated in the end of the duct spreads light to the building interior (Welford et al., 1989). The ADS performance under different sky conditions in tropical, subtropical and tempered skies have been simulated (Kwok, 2011; Page et al., 2007; Kunjaranaayudhya, 2005). These results have shown that ADS is of particular interest for tropical areas with predominantly overcast skies like Singapore (Wittkopf, 2007; Wittkopf et al., 2006). Howevr, this device has not been studied sufficiently in tropical climates. Performance of anidolic under tropical climate is different than other climates because of sky conditions which are mainly intermediate and overcast (Scartezzini and Courret, 2002). Therefore, this research attempts to study Anidolic components variables such as duct shape and duct width under tropical climates which the affect the daylight performance of interior offices.

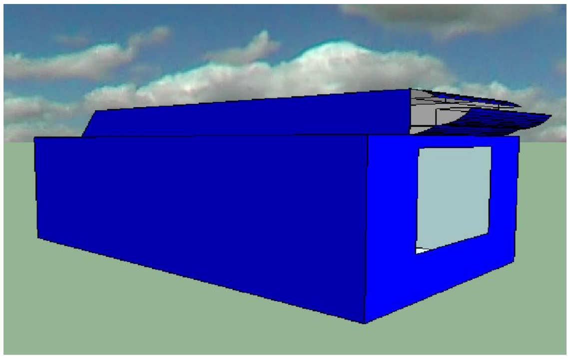

Figure 1. Simulated anidolic model

2.1. Components of ADS

The anidolic system includes three main components: a collector installed in the façade of building, a rectangular light duct in interior rooms and a distributing element (distributor) at the end of the duct which extends into the internal space (Figure 2)

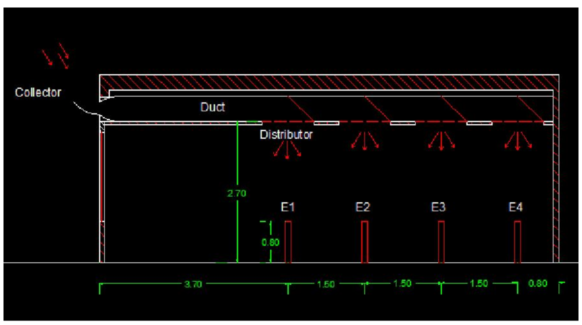

Figure 2. Components of Anidolic Daylighting System

ADS duct is located between the collector and distributors and transfers daylight from collector to distributor. It can change in shape and width and their modifications can affect the amount of daylight in office interiors which is tested during this study. Summary of the objectives to investigate optimum duct configuration is shown in Figure 3.

As is shown in this figure, variables are simulated under intermediate and overcast sky conditions as these are dominant conditions in a tropical climate. Previous research (Roshan, et. al, 2013a) has shown that south and east orientations have better daylight performance than other orientations, so this research simulates using these orientations.

3. Method

Recently, use and interest in daylight simulation tools have increased (Ander, 2003; Loutzenhiser et al., 2007). Simulation tools are the best opportunities for improving a building's energy performance before design, and these are feasible for predicting and improving the building daylight design (Lim et al., 2010)

In this research the simulated model was designed in IES<VE> software to perform daylight simulation experiments (Roshan et al. 2013b; Ghasemi et al. 2013). All items were measured under intermediate and overcast tropical sky conditions in Malaysia while their orientations were south and east.

An open plan office was designed with 5m width and 2.7m ceiling height with different depths. Moreover, the ADS has 3×0.5 m width and height respectively, also with different depth. The window has glazing, and the window-wall-ratio was 25% (Zain-ahmed et al., 2002b; De Nadel, 2005; Wong et al., 2012; Athienitis and Tzempelikos, 2002). The surface properties and material type used in the computer simulation were modelled as shown in Table 1 (Lim, 2011; Linhart et al., 2010). The simulation model was designed in Singapore, and located Latitude 1.37 N; Longitude 103.98 E.

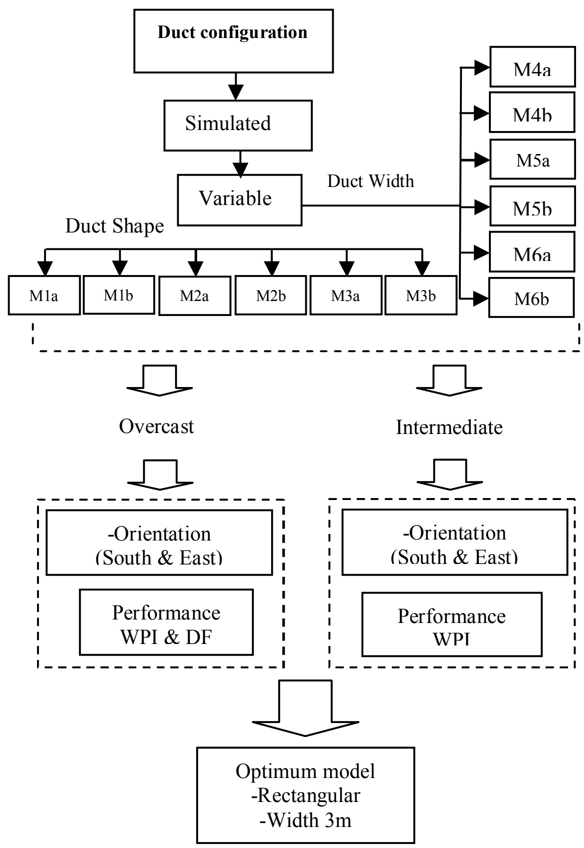

Figure 3. Summary of the objective to investigate optimum duct configuration

To assess the performance of the IES software, Absolute Work Plan Illuminance (WPI) and Daylight Factor (DF) were employed under intermediate and overcast skies, respectively.

Table 1. Parameters in the model

Parameters		
Room geometry	Width	5 m
	Length	9 m
	Height	3.5 m
Window geometry	Width	4m
	Height	1.70 m
	WWR	30% (2.5m*1.7m)
Anidolic	Wall	50%
	Floor	20%
	Ceiling	80%

3.1 Duct Shape

The aim of this study is to determine which duct shape can best improve the daylight performance in the interior of an office building. Three configurations of duct designs with two duct lengths (12 and 20 meters) were studied in this experiment. The first design was a rectangular and the second a trapezoid with larger (3m) duct in front and back (2m). The third design is a reverse of the second design (front duct 2m and back duct 3m). The properties of the shapes are summarized in Table 2.

These variables were assessed under overcast and intermediate skies. This is because overcast sky is the worst condition for daylight availability, and Malaysian sky is predominantly intermediate sky around 85.6-90% (Zain-ahmed et al. 2002a).

These cases have been designed using two different lengths, 12 and 20 meters, which have been evaluated in south and east orientation with the performance criteria WPI and DF.

Table 2. Sub-variables plan of duct shape for simulation

Sub-Variables – Duct Shape			
Shape	Rectangula r	Trapezoid	Trapezoid
Model	M.1a	M.2a	M.3a
Shape plan	12m, 3m	12m, 3m, 2m	12m, 2m, 3m
Model	M.1b	M.2b	M.3b
Shape plan	20m, 3m	20m, 3m, 2m	20m, 2m, 3m

3.2 Duct Width

Another factor that can affect the daylight performance of the device is duct width. To this aim different ducts with the width sizes of 1 m, 2 m, and 3 cases of 1 m, in two different sizes of duct length, 12 and 20 meters, have been designed and simulated.

As shown in Table 3, the Anidolic width in M.4 and M.5 is 2 meters and 1 meter, respectively, while M.6 shows 3 cases of 1 meter.

Table 3. Sub-variables plan of duct width for simulation

Sub-variables	Shape plan	Sub-variables	Shape plan
M.4a	12m, 2m	M.4b	20m, 2m
M.5a	12m, 1m	M.5b	20m, 1m
M.6a	12m, 1m, 1m, 1m	M.6b	20m, 1m, 1m, 1m

4. Results

4.1. Duct Shape in Overcast Sky

In the first stage, these cases have been simulated in the overcast sky condition. As external illuminance daylight in an overcast sky is the same in different directions, it is not necessary to identify the orientation of the building. According to Figure 4, the illuminance value of case M.1 in 12 and 20 meter dimension is 72 lx and 9 lx, which has higher illuminance value than other cases.

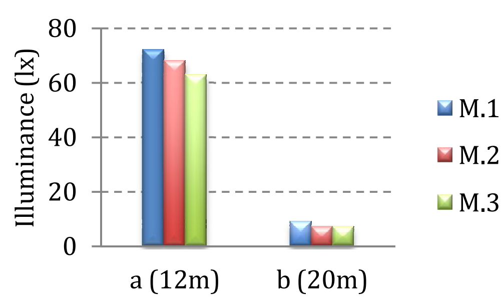

Figure 4. Illuminance value of variables in points E7 (12m) and E12 (20m) of simulated models

4.2. Duct Shape in Intermediate Sky

In the second stage, these cases have been tested in the intermediate condition, and have been evaluated in both south and east orientations on 21 March (appropriate time for simulation because of the sky condition during equinoxes) at 9:00 a.m., 12:00 p.m. and also 15:00 p.m., through performance criteria WPI.

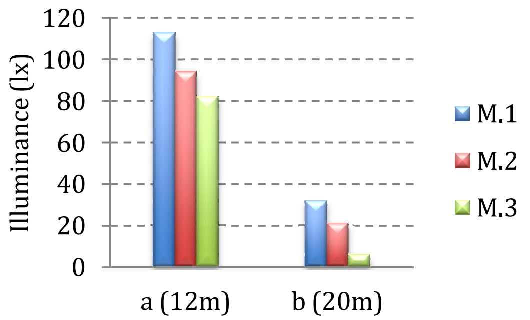

Figure 5. Mean illuminance value of variables in points E7 (12m) and E12 (20m) in the south orientation on the 21th March

Results of the current study show that the illuminance value in case M.1 in 12 and 20 meters in the south orientation is 113 lx and 32 lx respectively, and these values are greater than the other cases (Figure 5). Additionally Figure 6 shows these amounts in the east direction where the WPI in case M.1 in 12 and 20 meters are 140 lx and 92 lx respectively, which has the same result as the previous simulation.

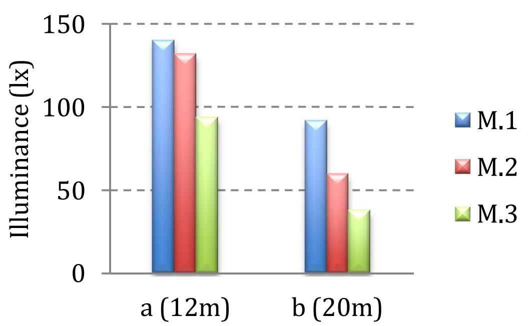

Figure 6. Mean illuminance value of variables in points E7 (12m) and E12 (20m) in the East orientation on 21 March

4.3. Duct Width in Overcast sky

Several cases with different Anidolic duct width sizes are simulated. They are evaluated under overcast and intermediate sky conditions. In the first stage, these cases have been tested in the overcast sky. As the daylight in the overcast is the same in different directions, it is not necessary to identify the orientation of the building. According to the Figure 7, the illuminance value of case M.1 in 12 and 20 meter dimension is 72 lx and 9 lx respectively which offers higher illuminance value than other cases.

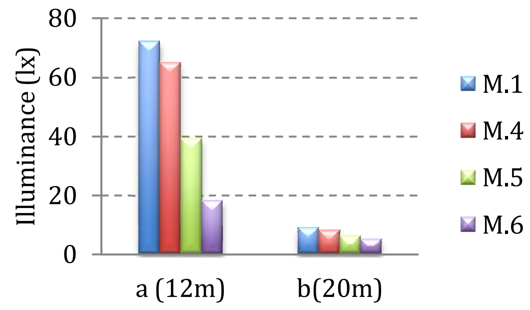

Figure 7. Illuminance value of variables in points E7 (12m) and E12 (20m)

4.4 Duct Width in Intermediate sky

In the next stage, these cases have been simulated in the intermediate condition sky, and they have been evaluated in south and east orientations on 21 March at 9:00 a.m., 12:00 p.m. and also 15:00 p.m. through performance criteria WPI.

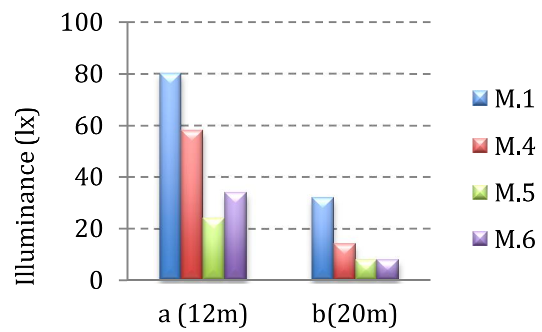

Figure 8. Mean illuminance value of variables in points E7 (12m) and E12 (20m) in the South orientation on 21 March

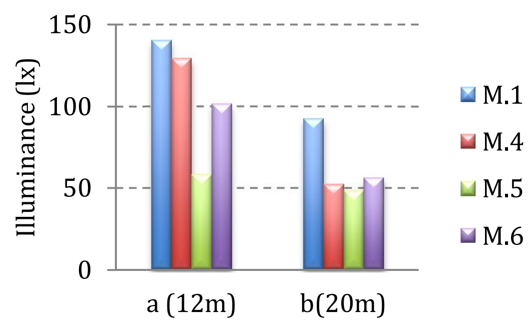

Figure 9. Mean illuminance value of variables in points E7 (12m) and E12 (20m) in the East orientation on 21 March

The results illustrate that the illuminance value in case M.1 in 12 and 20 meter sizes in the south orientation is 80 lx and also 32 lx, and these values are greater than the other cases (Figure 8). Additionally, Figure 9 shows the amounts in the east orientation where the WPI in case M.1 is 140 lx and 92 lx which is the same result as the previous simulation

5. Disscusion

Duct configuration has been considered as one of the affecting criteria that effect light transference in the anidolic. To this aim duct configuration has been analyzed in two sections namely, duct shape and duct width in two sizes, 12 and 20 meters, under overcast and intermediate sky conditions. According to the results case M.1 is the best duct configuration among the cases in this study (Table 4).

Table 4. Illuminance value of variables at points E7 (12m) and E12 (20m) in simulated models

Variable	Orientation	Sky condition	Length	M.1	M.2	M.3	M.4	M.5	M.6
Duct shape & Duct width	South	Overcast	12m	72	68	63	65	39	18
			20m	9	7	7	6	6	5
		Intermediate	12m	113	94	82	58	24	34
			20m	32	21	6	14	8	8
	East	Overcast	12m	72	68	63	65	39	18
			20m	9	7	7	6	6	5
		Intermediate	12m	140	132	94	129	58	101
			20m	92	60	38	52	48	56

6. Conclusion

Results indicated that the anidolic in rectangular shape with three meters under overcast and intermediate sky conditions in 12 and 20 meter sizes are better than other cases in transfering daylight to rear areas in an office building. In addition, in the next step, results showed that case M.1 with three meters width has better illuminance value under overcast and intermediate sky conditions in 12 and 20 meters width in comparison with other cases.

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