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ADJACENT OFFICE SPACES IN CIRCULAR ATRIUM WELL: ANALYSING DAYLIGHT QUALITY AND OCCUPANT VISUAL SATISFACTION

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Abstract:
An atrium is believed to be benefited from natural light. However, they have been least successfully as the adjoining spaces has been unable to utilize daylight successfully. Top floor's room is often over-lit and suffer from glare, while lower floors can be dark. This study aims to analyse daylight quality brought in through circular atrium well to the adjacent office spaces, to identify the interior's physical affecting factor, and the occupant's visual satisfaction on work performance. The study began by determining sample floor of upper and lower level each, and workspace adjacent to the East and West of atrium well on the selected floor. The physical characteristics of each works station is identified. Field measurement was carried out by placing HOBO data loggers on the selected occupants' work plane. Structured interview was held to understand occupants' satisfaction on daylight for computer and paper task. The findings were analysed by connecting and comparing the data. The results showed a significant difference of daylight intensity on upper and lower floor.

Keywords: *circular atrium well, adjacent space, office, daylight, visual satisfaction*

I INTRODUCTION

Malaysia has tropical climate that receive sunlight throughout the year. Thus, daylight is an important readily available resource. Daylight can help office buildings in tropical weather to achieve energy efficient as high rise buildings consumed a huge amount of energy to provide sufficient lighting (Yeang, 1996).

Daylight is defined as being the volume of natural light that enters a building to provide satisfactory illumination of internal accommodation between sun rise and sunset. Daylighting design is employed by most of the green building to obtain efficient lighting (Kristensen, 1991). It benefits occupants' productivity, comfort, satisfaction and well-being besides the financial (Allen, 1982; Veltch & Gifford, 1996). The energy audits studied by Pusat Tenaga Malaysia, PTM (2009) on Malaysia's office building concluded that most of them fell in the BEI range of 200 - 250 kWh/m2/yr. Lam (2000) also agreed that daylighting provide more luminous compared to artificial lighting which agree by Evyatar, Eran & Yaakov (2010) on the later year.

Tregenza & Wilson (2011) defined daylight factor as a way of quantifying the daylight in a room. Daylight factor is defined by $DF= \frac{Ei}{Eo} \times 100\%$, where Ei is the internal illuminance on the horizontal plane, and Eo is the external unobstructed illuminance in the horizontal plane (Nick and Koen, 2002). Malaysian Standard 1525:2007 has outlined the average daylight factors obtained by simulation on architectural modelling of a building design as shown in table 1 below.

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Table 1
Daylight factors and distribution. (Source: MS1525, 2007)

Zone	DF (%)	Distribution
Very bright	>6	Very large with thermal and glare problem
Bright	3-6	Good
Average	1-3	Fair
Dark	0-1	poor

"The satisfaction of the visual system and the absence of glare" (Vincent, 2012). Visual comfort is usually defined in terms of illumination level, with the consequent disparity of values found in publications (Judit, Carlos, Isabel, Rafael & Helena Coch, 2012). It is important to utilise daylight in the building interior by considering the intensity, penetration and distribution to avoid glare that reduce visual comfort and work performance (Abdou, 1997; Heschong Mahone Group, 2003).

In addition, several POE studies carried out by Abbaszadeh, Zagreus, Lehrer & Huizenga (2006) and Doulos, Tsangrassoulis & Topalis (2007) concluded that the main cause for visual discomfort come from computer screen's glare and ceiling's reflection. Effective daylight design and systems can help to increase occupant's satisfaction in the same time cutting down artificial light usage (Hua, Oswald & Yang, 2011). Fontoynont (1999) looked into Daylight quality where it can be judged by its ability to satisfy the requirements of occupants at their work space; in terms of:

- Sufficient light on the work plane: (200- 600 lux)
- Glare control using adaptable shading devices, with typical transmittances of awing below 20%
- Reduction of disturbing reflections ('veiling reflections') on computer screens, avoiding daylight coming from behind the terminal user.
- Balanced illuminance in the field of view near the work plane, with surrounding illuminance not exceeding 10 times the one of the task illuminance.

Aizlewood (1995) stated that the fourth out of the four lighting objectives of atrium is the hardest objective that is to provide sufficient daylight to reduce the use of artificial lighting in the adjacent space of the atrium well, which is also the key of atrium components (Sharples, 2007) and the most potential for saving energy (Aizlewood, 1995).

Sufficient daylight levels in the atrium well does not guarantee the same in the adjacent spaces as daylight intensity is very different for every floor. Cole (1990)'s study on a 5-storey well indicates that the opening percentage of the top floor (20%) increases towards the ground (100%) is the most effective. Few similar researches on the daylight in spaces adjacent to atrium well strengthened Cole (1990) findings where increasing the size of glazing towards the ground (100%) is found to be optimal as it helps to maintain the daylight penetration at the lower floor (Aschehoug, 1992; Szerman 1992; Matusiak et al., 1999; Fontoynont, 1999; Sharples & Lash, 2007; Samant 2011; Chow, Lee & Lam 2013).

Baker and Steemers (2002) summarised that useful daylighting in the rooms adjacent to an atrium consists of light from the sky, light reflected from the walls of the atrium, and light reflected from the floor. Fontoynont (1999) found that the reflectance of the floor of the atrium is a significant factor in the daylighting of the two lower floors surrounding the atrium. Samant (2011) stated that there is 5 aspects that affect the daylight performance (quantity and distribution) of an atrium, namely the sky conditions, roof configuration, atrium type, enclosing surfaces and

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design properties of the adjacent spaces. Yunus, Ahamd& Zain- Ahmed (2010) found that light-coloured walls reflect more light downwards the atrium floors and help in increasing daylight to the lower part of adjacent floors. This is proven by Iyer-Raniga (1994) and Chow, Lee & Lam (2013) in their studies.

II PROBLEM STATEMENT AND RESEARCH GAP

From the previous studies, it is understood that efficient atrium well does not guarantee sufficient daylight in the adjacent space, and the distribution of daylight is varies on upper and lower level. Most of the study focused on the atrium and the space underneath. Hence, there is a lack of studies and information on the adjacent space of the atrium well. The use of existing atrium building as a study is very restricted due to security and access reasons (Sharples & Lash, 2011). Besides, most of the studies did not consider the perception of end user, where Ng & Zainal (2011) explained their perception could further improve the building performance from time to time.

III AIM

This studies is aimed to investigate the upper and bottom level of office spaces adjoining to atrium well, on the aspects such as the characteristics of office physical environment, daylight quality and its occupants' visual satisfaction on work performance.

IV METHODS

4.1 The Building of Study

Malaysia Energy Commission Sustainable Building or Diamond Building (Figure 1) is selected as the case study. It is a 7-storey government office located in Putrajaya, Malaysia. It is a milestone in Malaysia to demonstrate the reduction of energy usage due to green design strategies and the achievement of ZEB (Hew & Rao, 2012). It is also the first in the country that obtained GBI Platinum rating by Malaysia's Green Building Index Sdn Bhd and Green Mark Platinum Rating by Singapore's Building and Construction Authority. Diamond Building is the only office building with circular atrium well in this country. Its atrium allowed daylight penetration into the adjacent office space. However, there is a lack of information on this adjacent space till today.

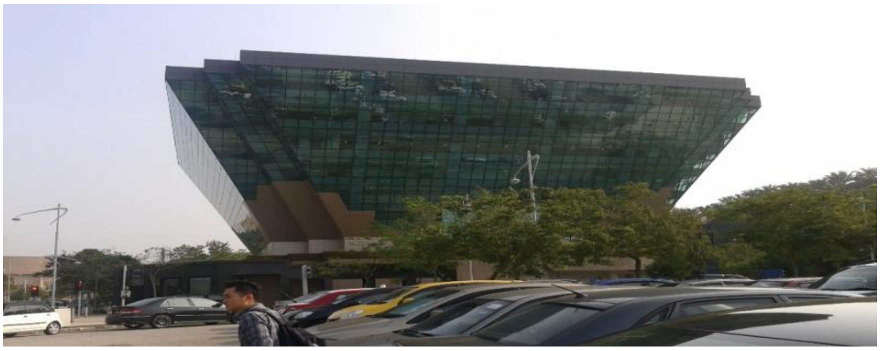

Fig.1. Exterior view of Diamond Building

4.2 Research Design

This study is carried out through a concurrent triangulation design which quantitative and qualitative data are collected and analysed in parallel (Manfred Max Bergman, 2008).

4.3 Workspaces & Participants

Out of 7 levels, only level 3 to 6 have office space adjacent to the atrium well. Thus, it is suggested and restricted by the office management that only level 3 and 6 could be studied, which it fits this study's objective that is to determine the daylight quality on the most top and bottom floor. Non-probability quota sampling is used in this study. Sampling area and population is only focus on office space adjacent to the circular atrium well, orientated at East and West. 3 occupants were selected from level 3, 4 from level 6. Out of the total, 5 have been working at their current workspace up to 5 years since the office start to operate while 2 have less than 6 months. All of them spend their office hours at their workspace.

All of the workspace are located directly next to the circular atrium well and arranged in a similar layout fixed by the office management since this building is completed. Each of the workspace width is defined by the width of 4 unit of window on each floor. The workspace next to next is the mirror of one another. Same set of furniture are installed in each workspace. Each of workspace is provided with a ceiling-hung florescent light with auto sensor right on top, a desk lamp and window shade on the atrium windows upon request.

4.4 HOBO data loggers Calibration test

I. 4 units of HOBO data loggers is placed near to each other as much as possible in the work plane.
II. Each of the data logger was previously set with same date, time and interval of recordings.
III. The recording of work plan illuminance started and ended at the same time.
IV. The data logger is connected to the computer with Onset-supplied USB interface cable to extract the data.
V. The result showed a significant correlation between the data collected by 4 equipment.
VI. The data loggers is reset to a recording interval of 5min, starting from 8.30am on 9th Oct to 5.30pm on 22th Oct. The red blinking lights at the side of the equipment indicated that the battery life is in good condition.

4.5 Data Gathering Procedure

On the 1st days of field measurement which is 12th Oct 2015, weather was sunny. Workspaces on selected sample floors (level 3 and 6) are observed, physical characteristics identified and measured according to the pre-prepared office physical assessment checklist. All occupants were approached at their workspace during work and agreed their workspaces to be the sample of this research and to take part in the interview later on.

Due the lack of equipment where there was only 4 HOBO data logger, field measurement was carried out in 2 phase: phase one (12th – 16th Oct 2015) and phase 2 (19th – 23th Oct 2015), both from Monday to Friday. One HOBO data logger is installed at each workspace. The position to place the data loggers is determined by the occupant on the spot of the work plane where they spending most of their time during work. Occupants were reminded not to remove or cover the data logger in order to ensure the accuracy of the data collection. The starting date and time and 5-min interval between each recording were pre-set. Spot measurement of light intensity at the atrium base and building exterior were measured by KIMO LX100 lux meter at 9am, 12pm and 3pm on 12th Oct 2015.

On the next working day, which is a partly cloudy day, interviewed were carried out with Phase 1 occupants one by one at their workspace. The condition of ceiling light, desk lamp and window shade are observed. None of the artificial light is turned on during and none of the window shade is fully rolled up. The interview started off with occupant’s basic workspace details followed by the perception on the daylighting in their workspace, satisfaction on the daylighting for both computer and paper task, and the frequency of using artificial lights and window shades. Photographs were taken at each workspace in their natural state as how they were occupied.

After a week, data loggers in Phase 1 work plane were removed and data is extracted. 3 of the HOBO data loggers are then installed on Phase 2 occupants work plane with the similar procedure and setting up as Phase 1, followed by interview. The weather on the interview day was overcast sky. Similarly, none of the artificial light is turned on and none of the window shade is fully rolled up. One week later, HOBO data loggers were removed from the workspace. Data is extracted into laptop using the similar method.

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V ANALYSIS AND RESULTS

1) Interior Physical Characteristics of Office Space

Workspace description is as per Table 2 and Table 3 below:

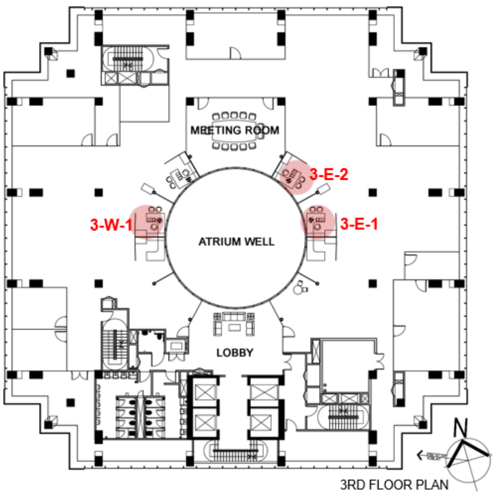
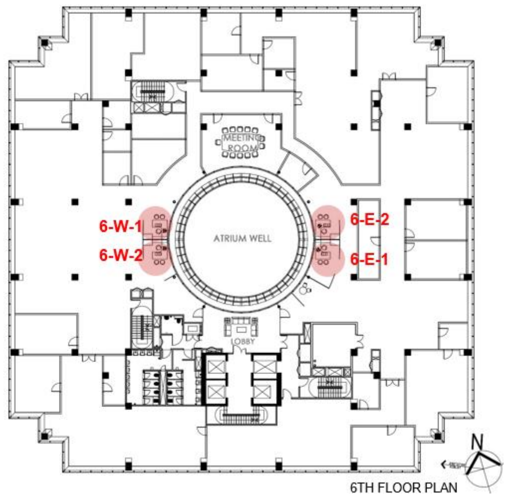
Floor	Level 3	Level 6
Description	Workspace location are highlighted in Red. 	Workspace location are highlighted in Red. 
Type of Personal	Cubicles with low partitions, (H) 1.5m	Cubicles with low partitions, (H) 1.5m
Sitting locatio	(a) Computer work: Facing window (b) Paper task : Next to window	(a) Computer work: Facing window (b) Paper task : Next to window

Table 2

Workspace description of level 3 and 6.

Floor	Level 3	Level 6

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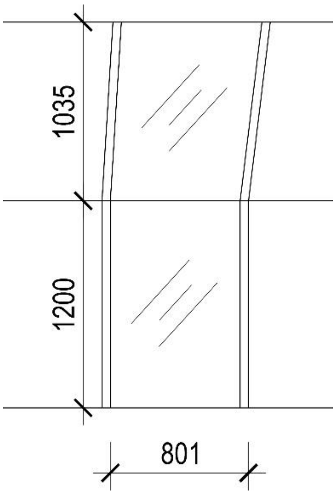
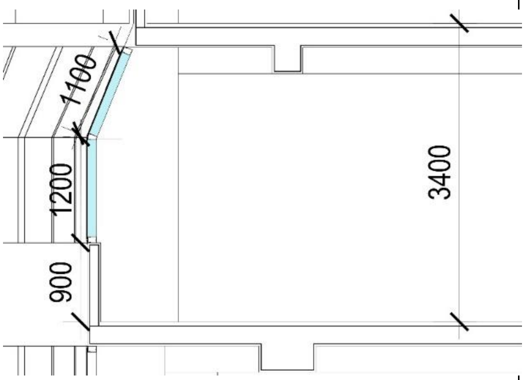
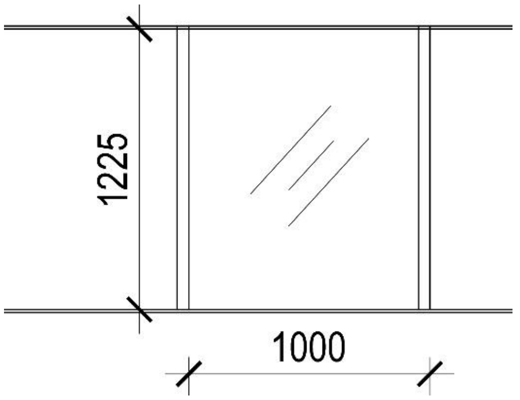
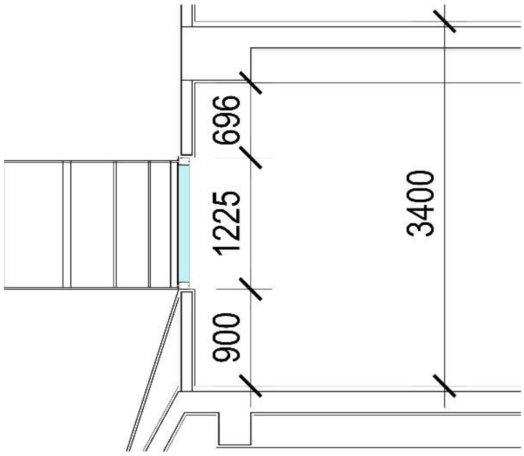
Atrium Well Window Size	Elevation:  Section: 	Elevation:  Section: 
Type of window	Vision window (801mm x 1200mm) Daylight window (801mm x 1100 mm)	Vision window (1000mm x 1225mm)
VLT of Glazing	Single pane clear with VLT of 70%	Single pane clear with VLT of 70%
Workspace geometry	Rectangular	

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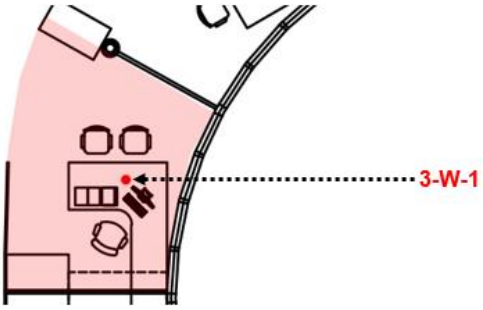
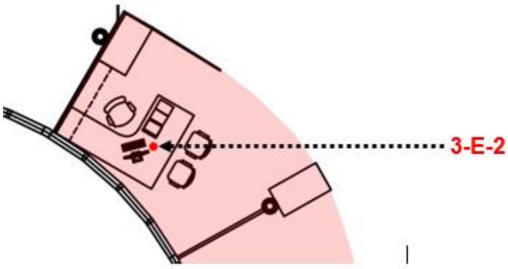
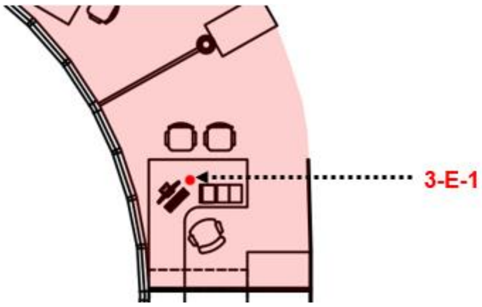
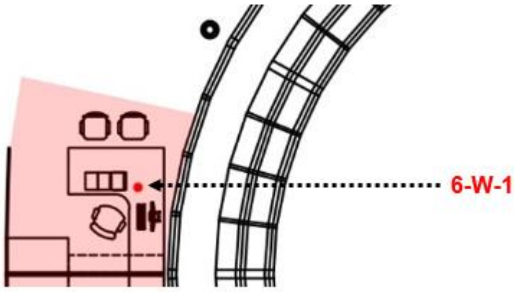
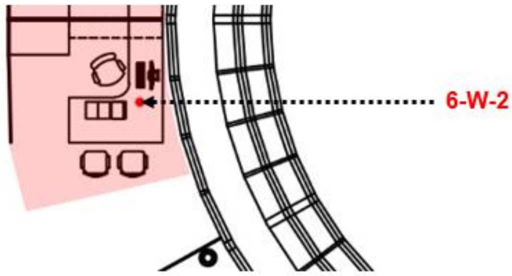
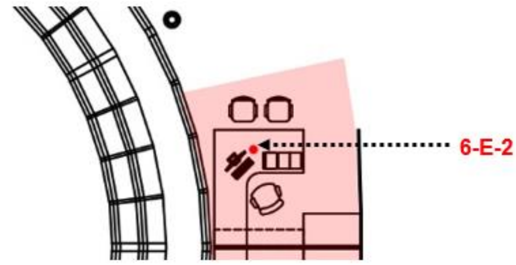
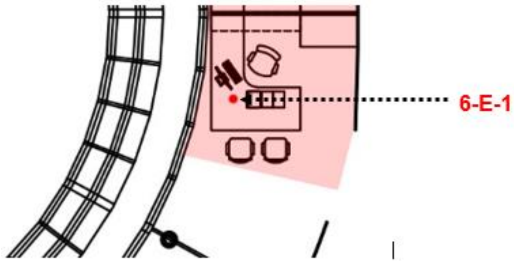
Layout of the workstation	- HOBO point (red dot)   	- HOBO point (red dot)    

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Type of surface finishes & colour

NO.	OBJECT	FINISHES SURFACE	COLOUR
1	Desk	Matte	White
2	Chair	Matte	Black
3	Cabinet	Matte	White
4	Partition	Glossy	Translucent white
5	Ceiling	Matte	White
6	Wall	Matte	White
7	Floor (carpet)	Matte	Brown
8	Window shade	Matte	Brown
9	Atrium well - wall	Matte	White
10	Atrium well - glass	Glossy	Transparent
11	Atrium well – reflective panel	Glossy	White

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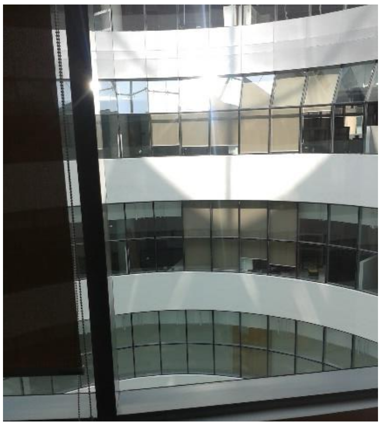
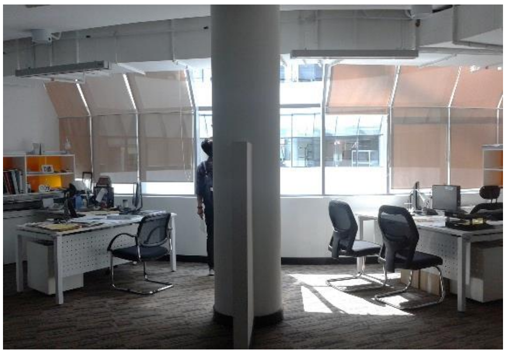
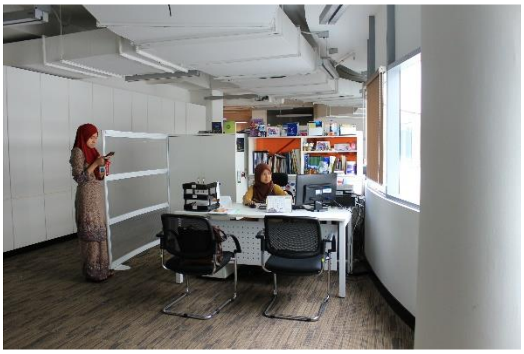
Photos	 Atrium well viewed from level 3.	 Atrium well viewed down from level 6.
	 Workspace 3-W-1 on the right.	 Workspace 6-W-1.
	 Workspace 3-E-2.	 Workspace 6-E-2.

Table 3 Characteristic of Workspace in level 3 and 6.

It is noted that Level 3 has a higher WWR values as compared to level 6 as Level 3 has both vision and daylight window to allow higher daylight penetration into the adjacent office space while level 6 only has vision window. The size of the openings from the well adjacent to office space increased towards the ground floor to avoid the space on level 6 to be over exposed with glare, in the same time to allow sufficient daylight to penetrate into level 3. Besides, this can overcome huge disparity of daylight between level 3 and 6.

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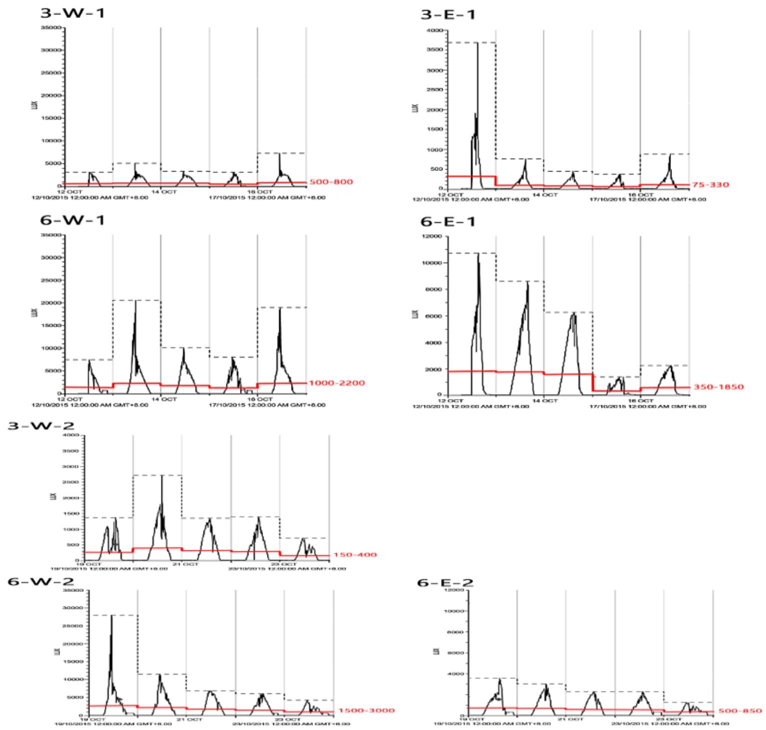

Fig. 2. Work Plan Illuminance (WPI)

2) *Daylight Quality in Workspace*

According to the WPI value obtained from HOBO Data Logger, it concurs with Fontoynont (1999), Sharples and Lash (2007) and Samant (2011) statement on the difference of daylight level on top and bottom level. The average WPI in adjacent office space of level 6 went up to 2200 lux and 3000 lux respectively in Phase 1 and 2 while level 3 only reach 800 lux and 400 lux. Based on the average illuminance level recommended by MS1525, daylight intensity on level 6 often exceed the ideal range of 300-400 lux for a general office. However, level 3 managed to bring in illuminance that achieve the ideal lux range more often. As stated in Dubois (2001), daylight intensity on level 6 in both phase is suitable for paper work but too bright for computer work, this may cause glare for the occupants during computer work. Moreover, intensity on level 3 is more preferable for computer work.

3) *Illuminance Uniformity on Work Plane*

The highest and lowest illuminance during working hours (8.30am – 5.30pm) in each of the workspace are shown in Table 4.

Table 4
Illuminance Uniformity on Work Plane.

Phase 1			
Sample	Highest Illuminance (lux) A	Lowest illuminance (lux) B	WPI Ratio B / A
3-W-1	2613	117	0.044
3-E-1	445	43	0.097
6-W-1	8936	496	0.056
6-E-1	6240	477	0.076
Phase 2			
3-E-2	1785	279	0.156
6-W-2	11388	1312	0.115
6-E-2	3032	547	0.180

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According to Dubois MC (2001) none of the sample workspace achieve acceptable illuminance uniformity with WPI > 0.5 on the work plane. This may cause occupants eyes to adapt the changes of WPI quite often.

4) *Occupant's Visual Satisfaction*

Interview results are summarized in Table 5 below. From the interview, all the occupants noticed the presence of daylight in their workspace. They are satisfied with the presence and quality of daylight in their workspace provided that window shade is given for them to control the amount of daylight based on personal preference. Most of them rolled the nearest window shade with their workspace partly or fully down for both shading and privacy purposes, only leave the one on the furthest open.

Occupant 6-W-2 who suffers from high astigmatism felt that the presence of daylight caused her workspace to be too bright and the unstable illuminance make her eyes suffered. None of the occupants use artificial light besides 6-W-1 who used the desk lamp to suit her mood instead of the insufficient of daylight provided. Only 2 out of 7 occupants encountered glare from the white and glossy atrium well surfaces. However, both of them are suffering from astigmatism without wearing lens. Thus, for normal user, there is no glare problem for them.

All of the occupants were satisfied with the presence of daylight for computer and paper work except for occupant 6-W-1 due to the her personal eye sickness as mentioned before. On the other hand, occupant 6-E-2 mentioned that she personally think that blind helps to control daylight better than the dome shutter as each user can adjust the amount of daylight entering based on their personal need. Furthermore, weather condition change all the time, the dome shutter may not be able to response precisely according to the each occupants need.

In addition, occupants 6-W-2 claimed that she did not rolled down the blind fully although her eyes suffer from the glare due to astigmatism because she found out that as she rolled the blind down, the office space in between the atrium well adjacent space and building perimeter will become dark.

	PHASE 1				**PHASE 2**		
Occupant	3-W-1	3-E-1	6-W-1	6-E-1	3-E-2	6-E-2	6-W-2
Sky condition	Over-cast sky	Sunny	Sunny	Sunny	Overcast sky	Sunny	Overcast sky
Workspace details							
Duration in current workspace	5 years	5 years	5 months	5 years	5 years	5 years	2 months
Working hours	8 hours	8 hours	8 hours	8 hours	8 hours	8 hours	8 hours
Daylight quality							
Presence of daylight	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quality of daylight in general	Satisfactory *	Satisfactory *	Satisfactory *	Satisfactory *	Satisfactory *	Satisfactory *	Too bright
Like the presence of daylight	Yes*	Yes*	Yes*	Yes*	Yes*	Yes*	The illuminance is unstable
Control of daylight with window shade	Yes. Fully rolled down.	Yes. 90% is rolled down.	Yes. 50% is rolled down.	Yes. 90% is rolled down.	Yes. 90% is rolled down.	Yes. 75% is rolled down.	Yes. 90% is rolled down.
Use artificial light when	No	No	Use desk lamp	No	No	No	No

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there is daylight							
Visual satisfaction							
Glare							
Presence of glare	No*	No*	No*	No*	Sometimes	No*	Sometimes
Source of glare	-	-	-	-	Glazing on atrium well	-	Glazing on atrium well
Computer work							
Daylight for computer work	Yes*	Yes*	Yes*	Yes*	Yes*	Yes*	Yes*
Presence of reflection on screen	No*	No*	No*	No*	No*	No*	Yes
Source of reflection	-	-	-	-	-	-	Daylight reflection on atrium well
Paper work							
Daylight on desk for paper task	Yes*	Yes*	Yes*	Yes*	Yes*	Yes*	Too bright when daylight enter directly
Reflection on paper	No*	No*	No*	No*	No*	No*	Yes
Reflection on desk	No*	No*	No*	No*	No*	No*	Yes
Source of reflection	-	-	-	-	-	-	White surface of table

* with the condition window shade is given to control based on personal needs.

Table 5 Summary of result from interview.

VI CONCLUSION

In conclusion, the physical characterise of the atrium well and the adjacent office space will affect the daylight quality. Large openings, white and glossy surfaces on the atrium well allow more daylight entering into the adjacent office space. The white colour of the office furniture acts as internally reflected components (IRC) which helps to improve the light intensity in the adjacent space.

The difference in amount of daylight entering into the adjacent spaces on top and bottom floor is very significant. The increased of the atrium well opening size towards the based help to improve the daylight quality in the lower level.

Occupants who does not suffer for astigmatism are satisfied with the daylight quality in the workspace. Although the WPI is too high for computer work, however due to the advanced technology in computer screen, the matte surface help to prevent glare and reflection. However, everyone treat the amount of daylight differently, thus some problem raised by the occupants on the function of dome shutter and the in between dark space can be further develop into a new study in the future.

Outcome of this study can be a reference for counties under tropical sky conditions as a guide to produce design alternative and typical configurations for commercial offices with circular atrium space, in terms of daylight performances and enable more office building in Malaysia to be energy efficient. In addition, the study on daylight quality in adjacent spaces which in-cooperating the end users perception is found to be lacking of till today. Thus, this study will be

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one of the significant guide for future interest of study in this area.

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