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An Analysis of Variation of Ceiling Height and Window Level for Studio Architecture in Malaysia

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***Abstract*—**This paper investigated the impact of ceiling height and window head heights variation on daylighting inside architectural teaching studio with a full width window. In architectural education, using the studio is more than normal classroom in most credit hours. Therefore, window position, size and dimension of studio have direct influence on level of daylighting. Daylighting design is a critical factor that improves student learning, concentration and behavior, in addition to these, it also reduces energy consumption. The methodology of analysis involves using Radiance in IES<VE> software under overcast and cloudy sky in Malaysia. It has been established that presentation of daylighting of architecture studio can be enhanced by changing the ceiling heights and window level, because, different ceiling heights and window head heights can contribute to different range of daylight levels.

***Keywords*—**Ceiling height, window head height, daylighting, studio architecture, simulation.

I. Introduction

BEFORE 1950, the majority of educational space was utilized by natural lighting [1]. Daylighting is a significant factor in the design of educational building, it does not only affect the consumption of energy by displacing artificial lighting, it also impacts on health, level of stress and performance of students [2]. This is so because, it is complicated to supply the adequate value of daylight throughout a side lit space [3]. Comparison between normal classroom and studio has shown that in formal classroom, a relationship exists between teachers and students only while in a studio, it exists between teachers and students as well as within student to student [4]. In addition, most of the times, it is found out in studios that there exists better cooperation among students, and this brings out the best in them. Quite a number of scholars have reported the use of studio architecture is an outstanding model of education [5].

In architectural school, the studio is used for more than just normal classroom activities; consequently, the lighting plays a very great role in improving the students learning [6]. It has been proven that good daylighting reduces dependence on artificial lighting. It is often preferable for studio architecture to be open and have larger study room than conventional classrooms.

However, the dimension of ceiling heights and window head heights must always be considered in order to achieve the optimum daylighting standard. Gregge and Ander in 1995 stated that the height and size of window are the major variables needed to get the preferred value of natural light [7]. This paper presented an investigation into the determination of the dimension of ceiling height and window head heights with respect to Malaysia’s standard.

II. Studio Space Characterizes

Daylighting creates a more attractive atmosphere quality and provide an appropriate working place where visual tasks can be comfortably carried out during the day [8]. Architectural studios have a history of large open design with natural lighting where each student is allocated a desk for drawing and construction of models manually [9].

Most of architectural school are still utilizing manual drawing techniques; although, computer technology has been introduced to assist in drawing and presentation since the ‘80s but this has not replaced the manual operation [10].

The Requirement of Lighting is the most important value for these type of classrooms, therefore, the recommended components for these type of building must be used to improve the phenomenon of daylighting [11]. Natural lighting should be provided from the student's left side [9], dimension of desk for drawing should be suitable for A0 size of paper (92×127 cm); therefore each space requires 3.5 to 4.5 m^2 per students and clear height should be 2.70-3.40 m [12].

The aim of architecture studio was to design optimum daylighting using different ceiling heights for architecture studio (576 m^2) which can occupy approximately 100 students. It is better to situate classroom on the lower floors to provide better access and support services [13]. The orientation of an educational building should be considered along the east- west axis to optimize a position where south faces the north [14]; since the sun path can have a significant influence on the level of illuminance [11].

The dimension of window head high must be extended for more than 2.1 m above the plane [15]. Researchers believe that ceiling heights must be at least 3 m for the smallest classrooms and normally not less than half of the dimension of the width for all except the largest classrooms.

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PJ Waldram in 1913 [16] explained that the ratio of the glazing area to floor area is one tenth in order to obtain the minimum requirement of daylighting [16].

III. Methodology

For this research, 3 models of architecture studio were simulated with various ceiling and window head heights in Malaysia. The case study used for the objective of this research was 36m width, 16m depth with different ceiling and window head heights. The models were located in the ground floor. The studio received natural lighting from windows in the south wall. As shown in Fig.1 (case study1), the windows' head heights were fixed 2.1 m from the floor and the ratio of window area to floor area through which the simulations were runwas 10%, the range of ceiling heights was from 2.4 m to 10 m. It can be seen in Fig.2 that the range of ceiling heights and window head heights increased from 2.4 m to 10 m and 0.2 m to 7.8 m respectively in Case Study 2. The rule of thumb glazing area to floor similar to Case Study1 and Case Study2 was 10%. Fig.3 showed Case Study 3, the ceiling heights were increased from 3 m to 10 m and the Ratio of glazing area to floor area were greater than the CS 1 and CS2, approximately by 13% , this is so because, CS3 have windows with full width wall and window head 0.5 m and 0.3m from the ceiling.

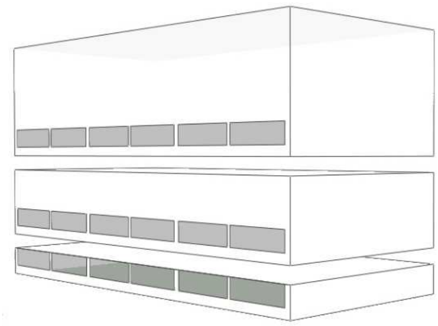

Fig. 1 Case Study 1

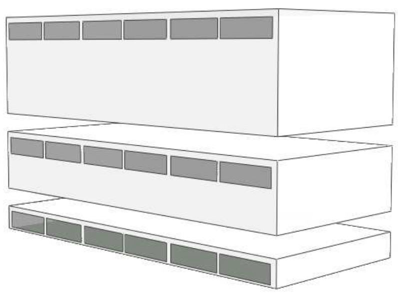

Fig. 2 Case Study 2

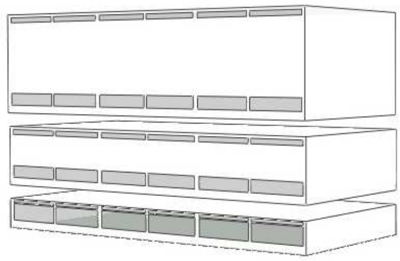

Fig. 3 Case Study 3

A.Simulation

The present study uses Radiance in Integrated Environmental Solution <Virtual Environment> IES<VE> program to evaluate the average daylight factor and illuminance in an architecture studio environment in Malaysia. Radiance is a software package developed by the Lighting Systems Research group at the Lawrence Berkeley Laboratory in California, USA. Radiance was developed as a research tool for predicting the distribution of visible radiation in illuminated spaces. Radiance is internationally recognised as one of the leading lighting simulation tools available. Radiance is a program that can analyse daylighting, it is a collection of program of graphical simulation. Moreover, it has been validated and considered appropriate for calculation of illuminance and prediction of internal illuminance with a high degree of accuracy for various sky conditions [17].

Table shows .1 the condition of simulation in Subang, Kuala Lumpur, it is the nearest to the case studies and it is situated at 3.12° North and 101.55° East longitude and 22° altitude. The CIE standard overcast sky and uniform cloudy sky were assumed for sky condition according to the climate of Malaysia. Most typically, sky used CIE overcast sky for program of simulation as well as standard mathematics recommended for relative luminance. [11] The value of the reflectance of rooms has an important effect on the performance of daylighting. Internal surface reflectance value for ceiling, wall and floor were 80%, 50% and 20% respectively; furthermore, the transmittance of the glazing was 80% in the simulation of the case study according to IES standard. The reflection from ceiling was brighter than from walls and floor. In addition, the reflections from both the walls and floors are also important for daylighting [7]. The calculations for the purpose of estimating day light levels were set on 21st of July at 12 pm on the working plan 85 cm.

TABLE I
RELATED INFORMATION TO THE COMPUTER SIMULATION

Related information to the computer simulation	
Date of simulation	July 21 st
Time of simulation	12 pm
Location	Kuala Lumpur- Subang
Latitude	3.12° North
Longitude	101.55° East
Sky condition	CIE standard overcast sky
Reflected of wall	50%
Reflected of floor	20%
Reflected of ceiling	80%
Transmittance of glazing	80%

IV. RESULT AND DISCUSSION

According to the CIBSE, provision is made for the design of illuminance for types of classroom within the range from 300 to 500 lux.

Malaysian standard code of practice on energy efficiency and use of renewable energy for non-residential buildings had recommended between 300 to 400 lux as range of the illuminance level for drawing office, however, it suggested that for exact drawing, the value must be around 1000 lux (table 2) [3, 18].

TABLE II
ILLUMINANCE LEVEL ACCORDING TO MALAYSIAN STANDARD 1525

Illuminance type	Activity	Illuminance (lux)
Working interiors	General offices, reading and writing,	300-400
	drawing office	300-400
Exacting task	Proof reading	500
	Exacting drawing	1000
	Detailed and precise work	2000

A. Case Study 1

It can be seen in Fig. 6 that the average illuminance increased with increasing ceiling heights and this effect was less under the overcast sky than under the cloudy sky. As ceiling heights were increased beyond 7 meters, the average illuminance increment became more significant according to Malaysian standard under overcast skies.

The range of average illuminance obtained was between 345 lux to 580 lux and 525 lux to 825 lux under overcast and cloudy skies respectively. The linear correlation obtained, R^2 value (i.e. the correlation factor) is more than 0.9 for the mode l of the studio for both skies, its value is close to1and for this reason it is obvious that a high quantity of correlation exists between the two set of outcomes.

The analysis of simulation of studi 1, can be described in various ways. Researchers stated that natural light in the rooms from the aperture received from direct beam illuminance of the sunlight, ground reflected light and illumination from the sky. (Fig. 5)[7, 11, 19]

Robbins suggested that the control and improvement of light from the external ground plane should be analyzed inside the building. These are some of the other reasons why the impact of the reflectance from the surface has a significant effect on the value of daylighting. In addition, the reflection from the ceiling constitutes the most important surface in the rooms[7].

Other researchers believe that highly reflecting walls and ceiling can develop the optimum result of illuminance[16].

Consequently, the design of Case Study 1 was chosen with the large ceiling surface as well as the bright reflection from ceiling which was about 80%.

As ceiling heights increase, there is the possibility of getting more reflected light from the external ground to the depth of of bright ceiling; consequently, the amount of light increased with this simulation as indicated by the result.

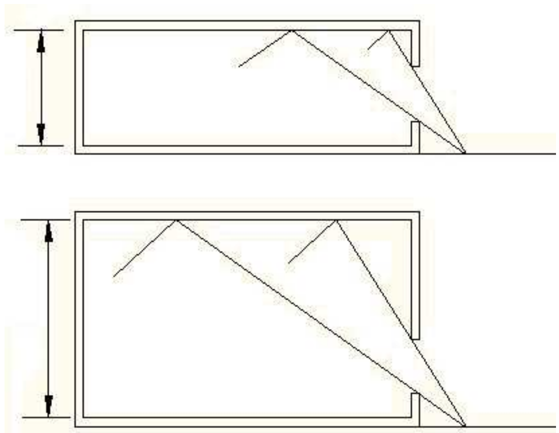

Fig. 4 The effect of reflected from external ground floor on room with higher ceiling

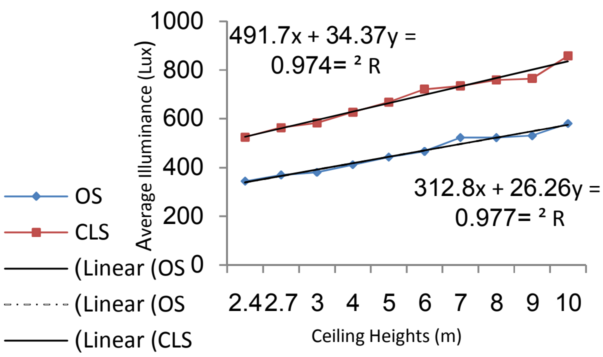

Fig. 5 Average illuminance ratio versus multipactive ceiling heights under an overcast(OS) and cloudy sky (OS)

The linear correlation as shown in Fig. 5 can be presented by the following simple Equation below for rule of thumb:

Equation 1. $E_{avg} = 25 H_c + 310$ (Overcast Sky)
Eq uation2. $E_{avg} = 35 H_c + 490$ (Cloudy Sky)

E_{avg} : Average illuminance
H_c: Ceiling Height

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B. Case Study 2

As shown in Fig. 6, the average illuminance decreased with increasing ceiling heights and window head heights; except if the range of ceiling heights in the Case Study 2 is less than 3 meters for both overcast (OS) and cloudy sky (CLS). In addition, the average illuminance was less under overcast sky than under cloudy sky. Fig 6 Illustrates the average illumination inside the Case Study2 set by Malaysian standard MS1525. However, the required electrical light is below 3 meters, hence, as ceiling heights were increased by more than 4 meters and 6 meters, the average illuminance became less of a considerable value under overcast and cloudy skies respectively.

Fig. 6 indicated that high average illuminance could be achieved inside CS2 with dimension of height ceiling up to 3 meters and window head heights upward to 2.7 meters of the approximate standard dimension of 2.1 meters. Therefore, the result of simulation for ceiling heights was found to reach 3 meters which was highest amount of average illuminance.

Polynomial correlation of simulation for CS2 obtained for R2 was more than 0.8, nevertheless, the average illuminance was plotted against the multiple ceiling heights.

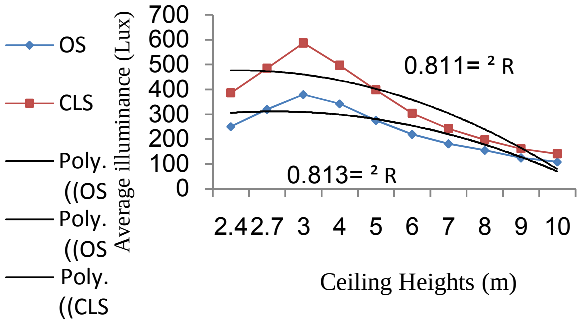

Fig. 6 Average illuminance ratio versus multiple ceiling and higher window hights under an overcast and cloudy sky

The result of the calculation showed that if ceiling height and window level were higher, the result would appear less bright than that of similar room depth because of the smaller value of visible sky. Fig.7 [19].

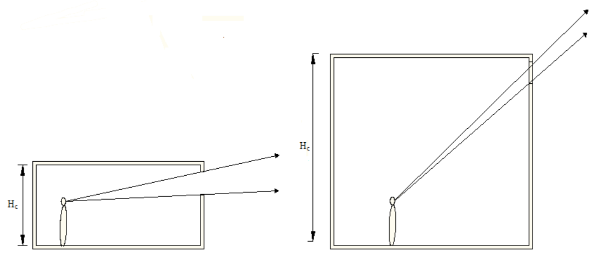

Fig. 7 The comparison room with higher ceiling and higher window level (Source: [20])

However, according to Baker N.V. (1993), high window have a significant influence on the penetration of daylighting in depth [11], a position of aperture in the studio describe the reason for the decreasing average illuminance on the working plane.

C. Case Study 3

The design of case study 3 was such that the ceiling heights increased from 3 m to 10 m; however, the window head heights were according to the standard 2.1 from the floor which also puts the other window close to 0.3 m from the ceiling and window height 0.5m was the fixed area in whole of the series (Fig.3).

According to Fig.8, the result of simulation CS3 obtained showed a model with increasing ceiling heights, which puts the other window near the ceiling and have a better result when compared with CS1 and CS2. In the architecture studio, students require more light when drawing, the details and the floor area of this studio must be known. The window that is close to the ceiling can perform the function of daylight in the back of studio. Several researchers found that the depth of room for useful daylight should be two times the dimension of ceiling heights [19].

According to Fig 8, the average illuminance increased from 430 lux to 635 lux whereas the ceiling height increased from 3 m to 10 m under overcast skies, also, the range of average illuminance increased from 660 lux to 875 lux under cloudy skies, this makes the cloudy skies to be brighter than overcast skies. A better linear correlation can be obtained by this simulation when compared to other case studies.

The reflected sun light from the external ground plane and bright ceiling surface as well as increment in the amount of window area can enable more brightness of rooms [7], hence, the reflections from external ground floor under both skies and enhanced window area can improve the light performance within the studio depth. Moreover, positioning the window near the ceiling can bring better light penetration to the depth of the room.

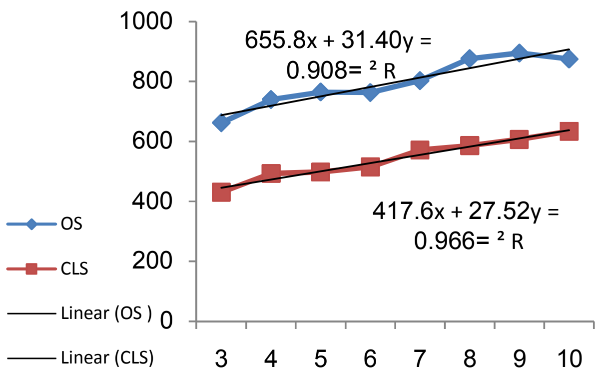

Fig. 8 Average illuminance ratio versus multiplicative ceiling hights under an overcast and cloudy sky

It can be obtained from the linear correlation in Fig.8 by simplifying Equation.3 and Equation.4 for both skies.

Equation 3. $E_{avg} = 27\ H_c + 420$ (Overcast Sky)
Equation 4. $E_{avg} = 30\ H_c + 650$ (Cloudy Sky)

V. Conclusion

Average illuminance increased in case study1 and case study 3, although, the result of case study 2 was against the other conditions examined in this research. In case studies 1and 3, there was variation in the ceiling height while the window head heights were fixed; but, In case study 3, the windows were close to ceiling.

The result of the analysis indicated that the contribution of light from the external ground floor and other exterior reflecting surfaces can be an important component of average illuminance. Furthermore, higher and bright ceiling can provide more area of visible sky and higher amount of average illuminance at a similar depth.

The result of case study 2 indicated that when ceiling height and window level was higher, the result would appear less bright than similar room depth because of the smaller value of visible sky. Since, the diffused light from higher ceiling was less than the lower ceiling.

The result of simulation demonstrated that day light in cloudy skies was brighter than in overcast sky. Finally, the correlation between ceiling heights and the value of illuminance have been found by simple equation according to large architecture studio. Eq.1 and Eq.2 are the simple models that were designed by correlation of in Case Study 1.

Equation 1. $E_{avg} = 25\ H_c + 310$ (Overcast Sky)
Equation 2. $E_{avg} = 35\ H_c + 490$ (Cloudy Sky)

Equation.3 and Equation.4, By linear correlation of Case Study3 were obtained the simple equations in case study 3.

Equation 3. $E_{avg} = 27\ H_c + 420$ (Overcast Sky)
Equation 4. $E_{avg} = 30\ H_c + 650$ (Cloudy Sky)

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