

DAYLIGHTING AND VISUAL COMFORT STUDIES OF DESIGN STUDIOS IN INSTITUTIONAL BUILDINGS

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ABSTRACT

Daylighting is an effective method in creating a comfortable visual environment and energy efficiency in university buildings. Not only daylighting create pleasant environment promoting better teaching and learning, it is also energy-efficient. The study aimed to investigate the daylighting performance and visual comfort condition of three design studios in KAED Building, International Islamic University Malaysia (IIUM) and to propose recommendations for creating a comfortable visual environment that saves energy. The objectives were to establish the daylighting performance for visual comfort and achieve energy savings with improved energy-efficient lighting conditions. The study used a case study approach on the three design studios. The methodology simultaneously undertook the daylight measurements using the Lux-Meter and questionnaire survey in the studios. The results showed that the lighting levels were not up to the required standards used in Malaysia (JKR Standard and MS1525). However, the lack of daylight did not hinder the users' visual comfort. The study proposed changing the existing less-efficient Fluorescent-T8 lamps to the more-efficient LED (light-emitting diode) lights for energy efficiency. Calculations on the annual energy consumption yielded a 40% reduction in the lighting bills and a payback period of around five years.

Keywords: Daylighting, energy efficiency, visual comfort, university buildings

1.0 INTRODUCTION

In recent decades, the study of daylighting in institutional buildings has been a subject of interest (Gorgulu, S. & Kocabey, S., 2020 & Castilla et al., 2017). The design of daylighting in educational establishments has proven more important than any other building type. Researches have shown the importance of daylighting in the academic environment on several occasions (Boyce, Hunter, & Howlett, 2003; Plympton et al., 2000; Task, 2000; Mahone et al., 1999 & Nicklas, Michael & Bailey, 1996). For example, the authors stress that daylighting creates a pleasant environment and promotes better health. Plympton et al. (2000) and Mahone et al. (1999) asserted that daylighting enhances academic performance. Michael & Heracleous, (2017) emphasise its potential of energy-saving, especially when combined with other daylighting responsive control systems. Thus, the importance of daylighting in the educational sector has been recognised globally, and it has served as a primary design tool for practitioners such as architects and interior designers. Visual comfort is another essential issue in institutional buildings as it is directly related to the student's wellbeing and learning process (Michael & Heracleous, 2017 & Baker & Steemers, 2014).

Thus, efforts to overcome these problems include the integration of electric lighting with daylighting in saving energy as well as creating a more comfortable visual environment for optimised learning and teaching. Similarly, energy efficiency and its related effects, such as energy generation and consumption cost, are essential. The paper addresses the issues with the primary aim of utilising daylight in establishing the acceptable indoor lighting requirements and satisfactory levels of visual comfort. The study also explored the application of energy-efficient measures, such as the zoning of appropriate electric lighting in

consideration of daylight and the usage of more energy-efficient lamps in conserving energy while improving visual comfort, as well.

2.0 LITERATURE REVIEW

Building sector accounts for nearly 30% of global final energy usage, and its energy demand is expected to keep growing with the increasing population and expanding tertiary industry in the coming decades (Wang, et al., 2018). Thus, there is a need to find a solution to decrease energy usage, influencing global warming. Mahlia et.al (2011) further asserted that the government paid over MYR2.7 billion for electricity bills from government universities and hospitals. On a global scale, 25-40% energy balance of a building is on lighting, reaching 19% on worldwide energy consumption. Lighting thus becomes a key reason for energy efficiency research in various countries (Liu & Ren, 2020 & Elena, 2013). One would see the cost of lighting in those commercial buildings such as universities can amount to more than the budget of computers and books combined, reaching up to 42% of the total electricity supplied (Mahlia et al., 2011).

Harnessing daylight had been a primary architectural strategy in schools to cut the cost further, improve impact on students' and teachers' health, and increase their performance in the learning environment (Olson & Kellum, 2003; Mathalamuthu, Dass & Nik Ibrahim, 2014). Lighting optimisation research thus becomes the target in energy efficiency. The inclusion of lighting control devices has shown good energy savings potential (Elena, 2013). Replacing existing lighting systems with energy-efficient lamps such as Lighting Emitting Diode (LED) has similarly reduced energy cost and GHG emissions (Gorgulu & Kocabey, 2020). However, still lacking, a need to further research on suitable solutions that would reduce energy consumption for lighting to reduce further non-renewable energy consumption leading to GHG emission, which is highly influential towards global warming (Becchio, 2013).

An indoor environment is highly influenced by the quality of installed lighting, especially in learning institutions. Studies have shown how high-quality lighting is crucial to students' mood, behaviour, and ability to focus on learning (Musa, et.al, 2012). Furthermore, lighting is considered essential to the design and operation in all learning environments as its influence on the quality of an indoor environment is enormous (Michael & Heracleous, 2017). The present study investigates the present lighting scenario and visual comfort in three design studios in the Kulliyyah of Architecture & Environmental Design (KAED) in IIUM. Furthermore, this research proposes potential improvements to provide better visual comfort and minimise energy consumption due to artificial lighting usage.

3.0 RESEARCH METHODOLOGY

Three methods were conducted for this study: the first two were data collections in the case study studios, which included daylighting data monitoring and questionnaire survey on assessing daylighting perception and visual comfort (Castilla, et. al, 2017). The third method was the energy consumption analysis where lighting calculations on the annual energy consumption (AEC) and payback period were undertaken. The section first describes the case study studios and their lighting conditions.

3.1 The Case Study Studios

This study concerned design studios in KAED in IIUM, located at Jalan Gombak, Kuala Lumpur, in Malaysia. The building consisted of four floors with two main exits with two courtyards situated at the NW and SE of the building. These courtyards gave indirect light to the surrounding corridors, as shown in Figure 1.

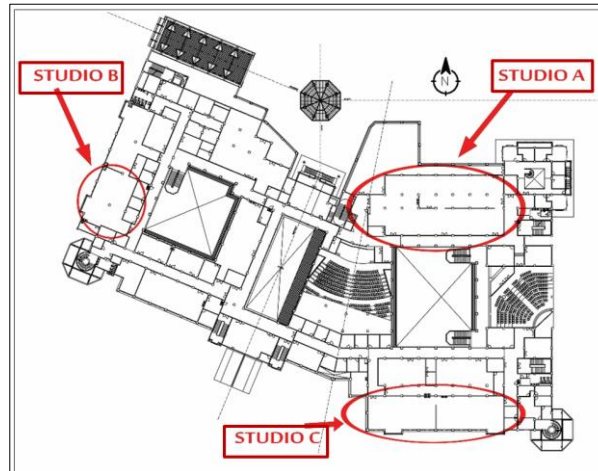


Fig 1: Plan of KAED Building. The red circles are the studios surveyed.

3.1.1 Description of Studio A

Studio A is the biggest of all three studios, with a deep plan of about 35 m x 18 m and a ceiling height of 3 m, totalling an area of 631 m². Studio A was located on the north side of the building. A total of 30 windows (with dimensions of 1.8 x 1.2 m) was located along the two long sides of the studio. There is a courtyard at the exterior of the south side of the windows, separated by a 3 m wide corridor. The north wall of the studio had a 3 m wide corridor and a large balcony with white floor tiles (Figure 2 (a)). The windows had aluminium frames with clear float glass.

Vertical blinds were utilised to control the amount of light entering the space and to eliminate any glare source during the day. The Window-to-Floor Ratio (WFR) of this Studio is 11.13%, which is less than the recommended percentage of 20% (Mathalamuthu & Nik Ibrahim, 2014). The windows in the north were protected from direct light rays by using a horizontal sun shading projection of 1.2m, as in Figure 2 (b). Figure 2 (c) shows the interior of studio A with the north-facing windows.



Fig 2: (a) The plan of Studio A. (b): The shading system of Studio A. (c) The interior on the north part.

3.1.1.1 Lighting Conditions

Studio A has bright spaces near the northern windows and dark spaces for most of the interior. Hence, artificial lighting is required to attain better visual comfort. All three studios use the linear T8 fluorescent (FLT8) tube (36 W cool daylight) to light up the interior spaces. Studio A has a total of 100 luminaires of 0.6 m × 1.2 m housing two FLT8 lamps. The lighting layout followed a matrix arrangement of 14 rows of lamps horizontally by seven rows of lamps vertically. The total lighting load was 7200 kW. Figure 3 shows the electrical lights and switches control diagram.

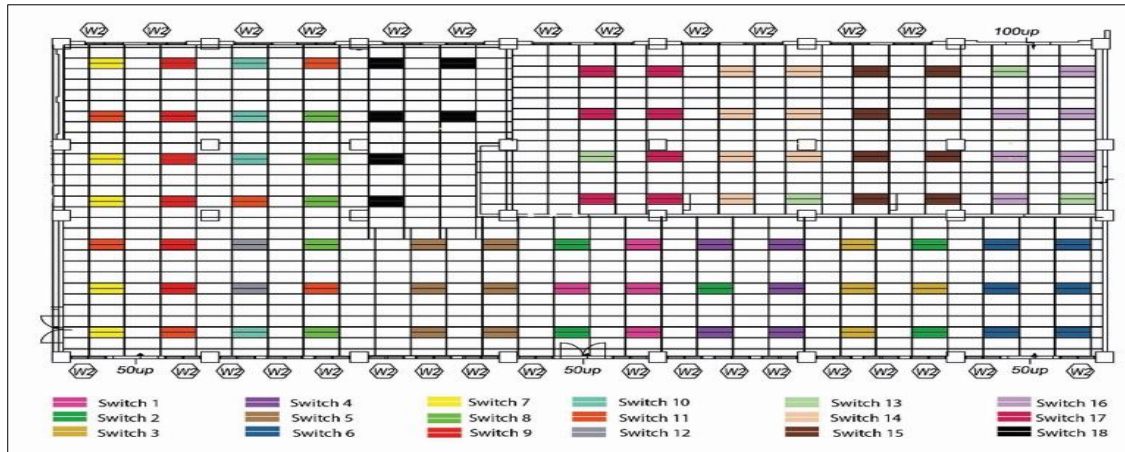


Fig 3: Arrangement of lamps controlled by the switches 1- 18 in Studio A.

3.1.2 Description of Studio B

Studio B is located on the northwest side of the building with a floor area of 176 sqm (11m x 16m) and a floor-to-ceiling height of 3 meters. The layout of studio B is shown in Figure 4 (a). Studio B had seven windows, located on the northwest side with no sun shading on the exterior. The windows and vertical blinds have the same characteristics as that of studio A. Figure 4 (b) is from the entrance looking at the Northerly Windows, and 4 (c) shows the interior view of Studio B. The WFR of this Studio was 9.31 %, which is also less than that recommended (MS1525, 2019).

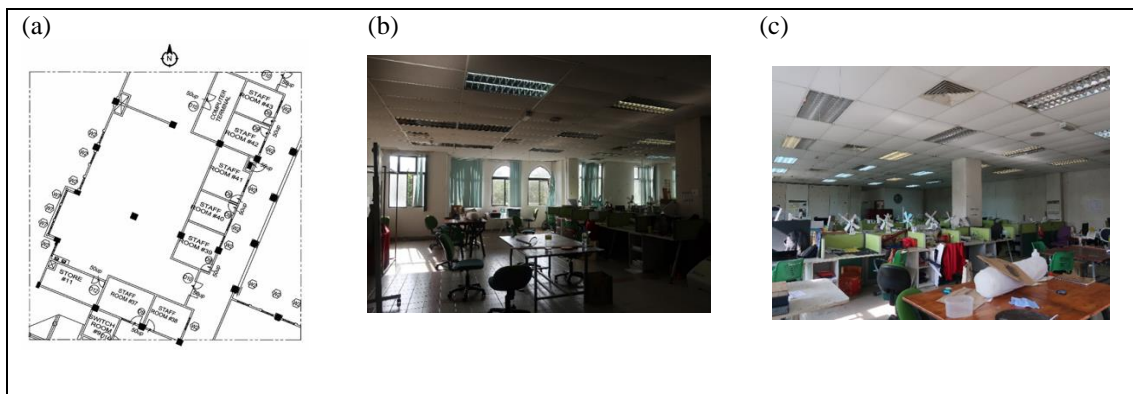


Fig 4: (a) Plan of Studio B. (b) View from the entrance looking at the northerly windows. (c) View of the interior.

3.1.2.1 Lighting Conditions

Studio B was the darkest one of the three studios. It has small bright spaces proximate to the windows in the northwest area. The other spaces have low daylight penetration and got darker deeper into the space. Hence, artificial lighting is required to attain better visual comfort. A total of 26 luminaires were installed in Studio B, with a total lighting load was 1.872 kW. Figure 5 shows the electrical lighting plan of Studio B and the electrical switches control diagram.

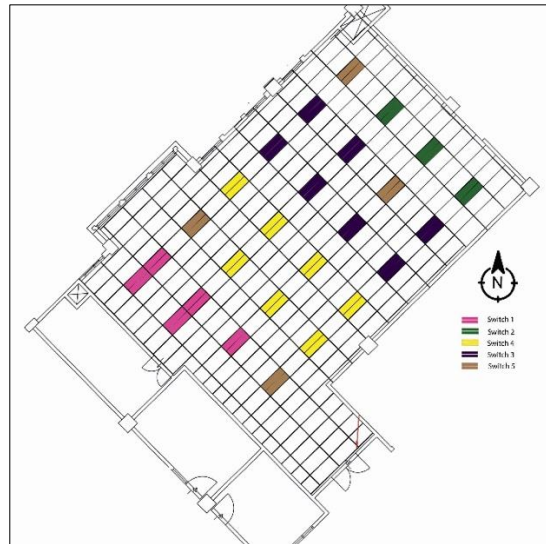


Fig 5: Arrangement of Lamps Controlled by the Switches 1- 5 in Studio B

3.1.3 Description of Studio C

Studio C faces the south with a floor area of 400 sqm (40 m and 10 m) and a floor to ceiling height of 3 meters high, as shown in Figure 6 (a). The windows are located at the south side of the studio facing the exterior. The characteristics of the windows and vertical blinds remain the same as that of Studio A and B. Figure 8 (b) and (c) shows the entrance looking at the northern windows and interior view of studio B, respectively. WFR of Studio C was 10.53 %, which was less than recommended (MS1525, 2019).

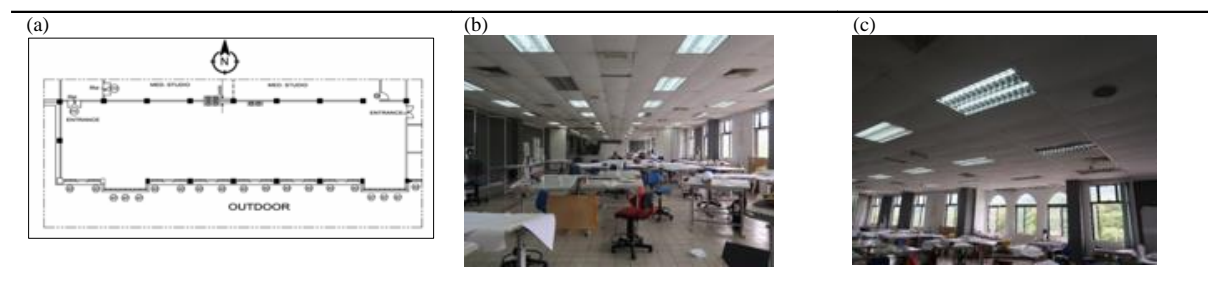


Fig 6: (a) Plan of Studio C. (b) Interior view of Studio C. (c) Interior view of Studio C showing the southerly windows.

3.1.3.1 Lighting Conditions

In Studio C, the areas proximate to the windows have sufficient daylight penetration in the south area. However, the south-facing windows caused much discomfort glare during the

daytime. The other spaces have low daylight penetration and got darker going deeper into the space. A total of 64 luminaires were installed in Studio C, consuming 4.608 kW. Figure 7 shows the electrical lighting plan of Studio C.

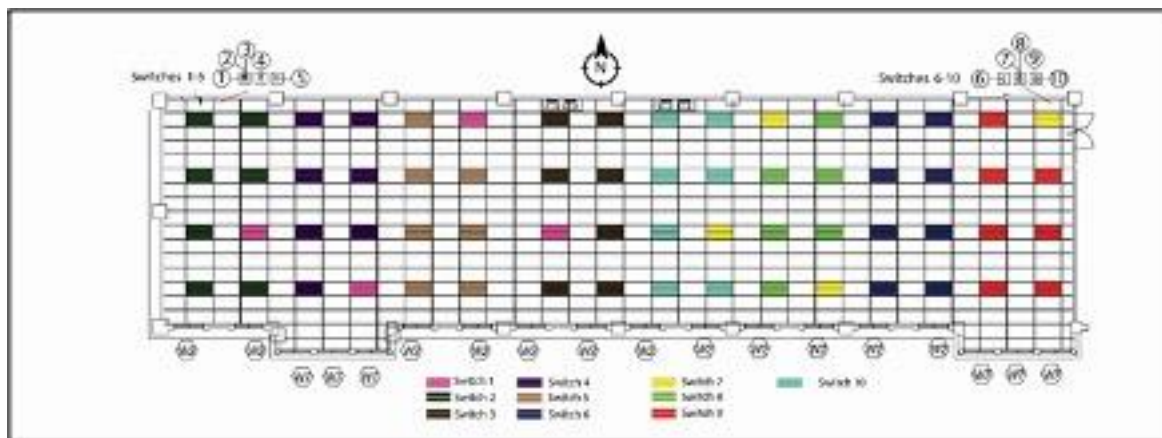


Fig 7: Reflected ceiling plan showing the lights and the control switches plan in Studio C

Data Sampling

a) Field Measurements

The illuminance was measured by a THDL400 Instruterm Digital Lux meter (Ibañez, Zafra, & Sacht, 2017). The instrument was placed at the height of 1 meter to prevent any shading on the lux meter. The readings were compared against the recommendations from MS 1525:2007, which stipulated a standard illumination of 300 - 400 lux for a studio.

b) Questionnaire Survey

The questionnaires on assessing daylighting perception and visual comfort (Castilla, et. Al, 2017) were distributed to the students who were present in the studios during the survey. There were no lecturers present when the questionnaire was distributed, and the students were doing self-study, sitting randomly. A total number of 94 students (58 females (61.7%) and 36 males (38.3%)) participated in the study. According to Sarantakos (2012), 35% of N (total number of populations of the survey are 254) is considered probable for the number to be meaningful for analysis purposes. Therefore, this was sufficient for meaningful analysis because the respondents were more than 35%, and the data can be generalised. Of the students, 39.4% were from Studio A, 22.3% were from Studio B, and 38.3% were Studio C students. The software Statistical Package for the Social Sciences (SPSS) was used to analyse the data from the questionnaire survey. The main aim of the analyses was to establish the relationship between the orientations and achieve visual comfort.

c) Lighting Annual Energy Consumption (AEC) Calculation

Two main calculations for the AEC were undertaken. The first was to calculate the existing AEC of the existing consumption using the FLT8 lights and the other was with the retrofitted LED lights. Both of these calculations were also taking into consideration the number of lamps without daylighting (380 lamps) and with daylighting (330 lamps). The last calculation was establishing the payback period of the LED retrofit.

i. Electricity Consumption

The total daily energy consumption (EC) of lamps is calculated by multiplying the total number of the lamp (N), the power consumed by the lamp (W), and total hours of operation (OH), which is assumed to be 9 hours per day. The annual energy consumption for existing lamps is interpreted in the following equation.

$$\text{Equation 1: } EC = (N \times W \times OH) / 1000$$

Where, N = Number of lamps (N). W = Lamp wattage (W) and OH = Hrs of use per year (Mahlia et al., 2011).

ii. Operating Cost

The operating cost (OC) is the total annual energy consumption (kW per year) multiply the electricity tariff (ET) and the annual operation cost can be calculated by the following equation:

$$\text{Equation 2: } OC = EC \times ET$$

The total energy consumed (kW per year) \times energy cost (RM) per kWh)

iii. Energy savings

Energy-saving (ES) is the difference between the energy consumption of existing (EC_Existing) and retrofit lighting (EC_Retrofitting) system. The following equation was used to calculate energy savings.

$$\text{Equation 3: } ES = EC_{\text{Existing}} - EC_{\text{Retrofitting}}$$

iv. Payback Period

The payback period (PAY) is the amount of time taken to recover the additional investment (increment cost) (ΔCI) on efficiency improvement through lower operating costs. PAY is found by solving the following equation (Mahlia et al., 2011):

$$\text{Equation 4: } PAY = CI / (ABC(\text{old}) - ABC(\text{new}))$$

To calculate the payback period, the following variables must take into consideration: the characteristic of both lamps, lamp cost, lamp lifetime, installation, labour cost, operational hours used and electric utility rate among others.

4.0 DISCUSSION

4.1 Case Study

4.1.1 Daylighting Analysis of Studio A

In the daylighting analysis, the lighting levels monitored were separated into three coloured zones. The Yellow Zone is the highest luminance level received in the studio of > 400 Lux. The Orange zone represents the 300 Lux line, at the maximum level that may not require any artificial lighting. The Blue zone indicated the low daylighting level below the Malaysian Standard. Hence, this promotes artificial lighting usage to supplement daylighting at all hours of the day.

Figure 8 shows the maximum lighting levels of Studio A at 1.00 pm. As observed, ample daylighting comes from the North orientation and could penetrate up to a third of the depth of the studio. However, the rest of the studio space is underlit and would require artificial lighting most of the time.

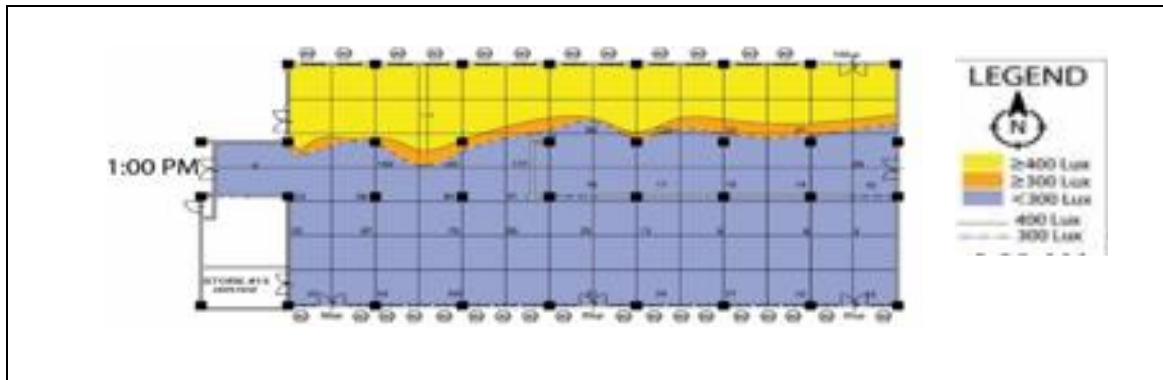


Fig 8: The contour of illuminance levels of Studio A at 1.00 pm

4.1.2 Daylighting Analysis of Studio B

Studio B has the maximum illuminance level later in the day at around 6.00 pm. This level could be due to either the northwest orientation where the sun penetration is most significant or the small number of openings in this studio. The lighting penetration was less earlier in the day, as seen in Figure 9. Therefore, for most of the day, the space needed artificial lighting.

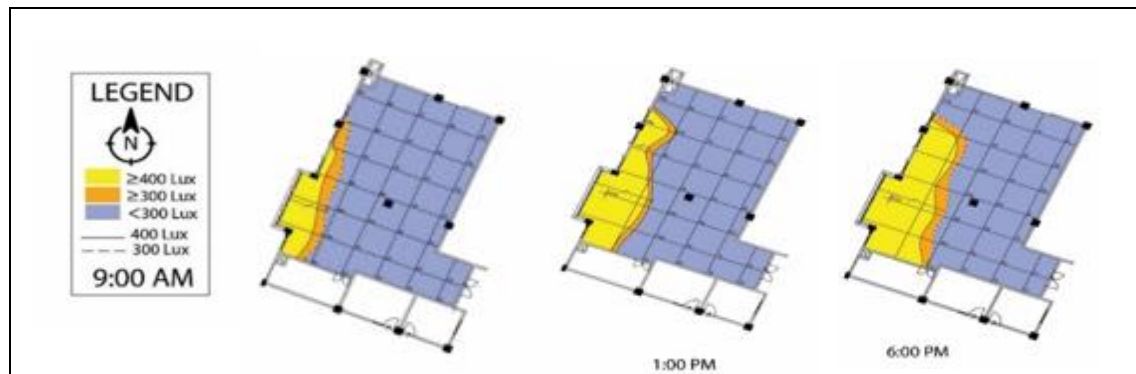


Fig 9: The contour of illuminance levels of Studio B at 9.00 am, 1.00 pm and 6.00 pm

4.1.3 Daylighting Analysis of Studio C

Studio C windows face south and have the most daylighting penetration. The daylight is better distributed than the other two studios under-studied, as shown in Figure 10. Daylight penetration was good during the earlier part of the day and by afternoon reached almost half the depth of Studio C. Thus, the studio does not need the lights for a good part of the day. But the daylighting level drops tremendously around 6.00 pm, indicating the need for artificial lighting.

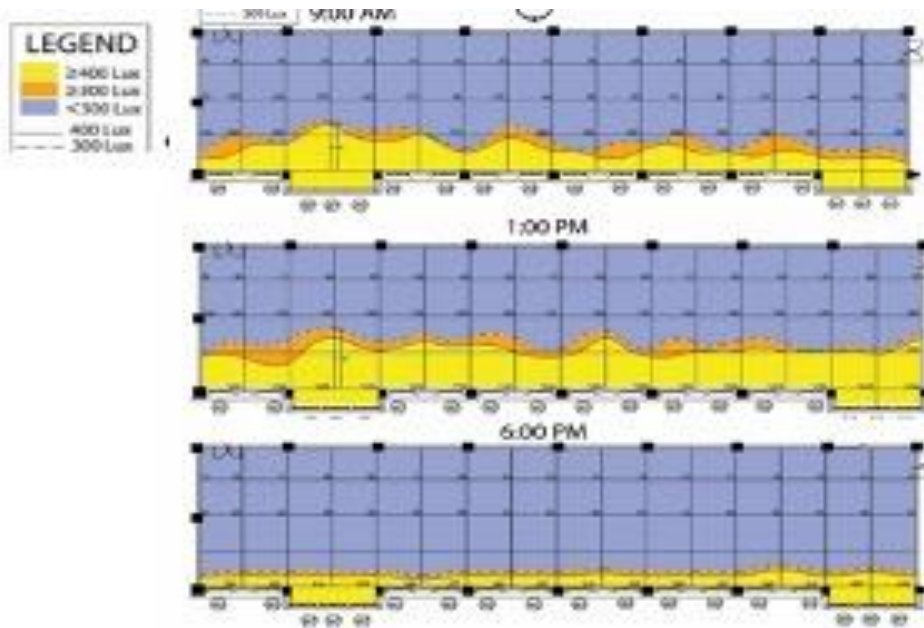


Fig 10: The contour of illuminance levels of Studio C, at 9:00 am, 1:00 pm and 6:00 pm

4.2 Questionnaire Survey Results

The survey was conducted in situ to respondents who were working in the studios independently and not during the teaching time. The studio was not fully occupied. The survey was done to validate the findings of the lighting analysis with the opinions of the users of the space in terms of their visual comfort. Results show that majority of the respondents were comfortable and satisfied with the daylighting inside all studios despite the dim daylighting conditions monitored. This is because most of the respondents taking part in the survey were sitting beside the windows, and none of them used the darker areas.

The majority of respondents from the three studios evaluated daylight availability as average but acceptable. Although glare conditions were present and the uniformity of daylight was uneven, an average of 80% of respondents was generally satisfied with the daylight perception, and most of them evaluated the daylighting uniformity as normal. Therefore, the study can establish that the respondents perceived the overall visual comfort as satisfactory. However, this finding contrasted with the field measurements where most of the areas of the studio measured poor daylight illuminance levels, which did not meet the standards mentioned.

4.2.1 Lighting Energy Consumption Calculations

The energy consumption (EC) calculation was undertaken to establish potential savings in energy consumption of switching to more energy-efficient light bulbs than the existing ones used – from FLT8 to LED tubes (Mahlia et al., 2011). In addition, potential savings was indicated of utilising daylight for areas adjacent to windows that did not need artificial lighting during the day.

Assuming an average of 9 working hours for five days a week for 25 days per month, the total days taken for the calculations was 260 days per year. Four different calculations were assumed and undertaken, as follows:

- Existing fixtures (FLT8 lamps) - without daylight (total of 380 light bulbs).
- Existing fixtures (FLT8 lamps) - with daylight (total of 330 light bulbs).
- Alternative fixtures (LED lamps) - without daylight (total of 380 light bulbs).
- Alternative fixtures (LED lamps) - with daylight (total of 330 light bulbs).

The results are shown in Table 1.

Table 1: Lighting energy calculations for FLT8 and LED

Items	FLT8		LED	
	Without daylighting	With daylighting	Without daylighting	With daylighting
Total number of lamps	380	330	380	330
Lifespan (hours)	13,000	13,000	50,000	50,000
Power consumed per unit (W)	36	36	14.5	14.5
The total power consumed (kW)	13.68	11.88	5.51	4.79
Total energy consumption (kWKwh/year)	32,011	27,799	12,893	11,197
Total energy cost (RM)	11,684	10,147	4,706	4,087

The total AEC predicted for the FLT8 lamps in the studios was 32,011 kWh/yr without considering the daylight and with utilising daylight is approximately 28,000 kWh/yr – a saving of almost 30%. Meanwhile, the total annual energy consumption of using LED light with daylight was predicted at 11,197 kWh/yr. This indicated the potential savings of between 40% in the consideration of without daylighting and up to 65% energy savings when considering daylighting. Further calculations made for the return-on-investment or payback period was found to be around five years, making this a good investment.

5.0 CONCLUSION

The study conceived the notion that energy consumption in faculty buildings has good savings potential. With the recommended illuminance level by MS:1525:2014 of 300 lux to 400 lux illuminations as a base for the study, this level is acceptable for the occupants' visual comfort in the studio. However, this illumination standard was not uniform throughout the entire studio space, warranting the use of artificial lighting almost at all times. Only spaces adjacent to windows have enough daylight, but the lighting fixture arrangements did not consider this perspective.

Studio C has the best daylighting potential among the three studios, as most windows are on the south side. However, this comes with glare conditions, and the windows were shaded with horizontal blinds, limiting the daylighting potential. The same was observed in Studio A with the north-facing windows too. This is the result of inappropriate external shading devices on the studio's windows. The field measurement showed that the lighting levels and uniformity in most of the interior spaces of the three design studios were not within the range of the Malaysian Standard MS 1525:2014. But as indicated in the questionnaire data analysis, most of the students perceived it as acceptable. The reason was deducted because artificial lighting was readily available, and whatever lighting deficiencies happened was made up by it.

The calculation of energy consumption showed savings from integrating daylighting using the FLT8 lamps was found to be 14%. However, better savings from the LED lamps showed

massive potentials of between 40% and 65% savings of using energy without and with daylight, respectively. Lastly, the payback period for using the LED lamps was about five years. This meant that after five years of usage of the LED lamps, even with high initial costs, the less energy consumed will bring profit for the investment.

6.0 RECOMMENDATIONS

The study proposed recommendations on daylighting penetration inside the studios to sustain acceptable lighting levels and reduce artificial lighting usage. Firstly, the switching wiring system should be arranged in a more coordinated strategy into zones in a horizontal mode parallel to the direction of the daylight penetration. The lamps closest to the windows may not be switched on at all times during the day except when the outdoor conditions are darker. Any partitions preventing the flow of the daylight should be rearranged in a vertical manner adjacent to the windows.

Secondly, the studio's wall-floor ratio (WFR) should be not less than that recommended by the JKR standard of 20%. Although large openings allow more daylight, this can also increase the cooling demand in buildings. Therefore, external solar shading devices should be utilised to prevent direct sunlight and solar gains into the interior spaces. The use of suitable internal blinds is also suggested in all orientations in the studios to improve visual comfort and reduce glare. In addition, other daylighting devices like the light shelves can improve the penetration and distribution of daylight to the interior.

Finally, replacing the existing FLT8 lamps with more efficient LED lamps will provide better energy efficiency and savings. However, LED lamps are costly, but the time to return the investment is short, and the benefit is the savings in energy and subsequently, cost.

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