Civil Engineering and Architecture 10(7): 3165-3172, 2022 http://www.hrpub.org
DOI: 10.13189/cea.2022.100728

Investigation of Various Window Orientation in Daylighting Performance in Hot-Humid Climate of Subang, Malaysia

Seyedehzahra Mirrahimi[1,2,*], Nik Lukman Nik Ibrahim[2], Mohammed Hadi Nahi[3], Arezoo Shirazi[4]

[1]Department of Architecture, School of Fine Arts, University of Tehran, Tehran, Iran
[2]Department of Architecture, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia
[3]Al-Yarmouk University College, Baghdad, Iraq
[4]School of Built Environment, University of Technology Sydney, Sydney, Australia

Received January 31, 2022; Revised August 29, 2022; Accepted September 19, 2022

Cite This Paper in the Following Citation Styles

(a): *[1] Seyedehzahra Mirrahimi, Nik Lukman Nik Ibrahim, Mohammed Hadi Nahi, Arezoo Shirazi , "Investigation of Various Window Orientation in Daylighting Performance in Hot-Humid Climate of Subang, Malaysia," Civil Engineering and Architecture, Vol. 10, No. 7, pp. 3165 - 3172, 2022. DOI: 10.13189/cea.2022.100728.*

(b): *Seyedehzahra Mirrahimi, Nik Lukman Nik Ibrahim, Mohammed Hadi Nahi, Arezoo Shirazi (2022). Investigation of Various Window Orientation in Daylighting Performance in Hot-Humid Climate of Subang, Malaysia. Civil Engineering and Architecture, 10(7), 3165 - 3172. DOI: 10.13189/cea.2022.100728*

Abstract This paper discusses the effect of window orientation on the quality of daylight in order to obtain optimum visual comfort in a lecture room in Subang-Kuala Lumpur Malaysia. Visual comfort in buildings is a vital factor to be taken into consideration and has become a priority. Research work is required in order to recognize the limitations, prospects, and challenges of orientation based on working times for daylighting strategy. The lecture room is associated with outdoor and indoor parameters including geographical location, outdoor illuminance, type of sky, orientation, room size, window to floor area, the position of window, reflectance from floor, wall and ceiling and glazing transparent. It is estimated that the window to floor area ratio in a typical lecture room is 20 percent. The investigation was carried out via Radiance in IES(Virtual Environment) for estimating the evaluated daylighting. The hourly and monthly daylight hours have simulated four cardinal orientations windows because students spend most of the daytime in the lecture room. The average amount of the outdoor illuminance in various months and selected hours of 10am, 12pm and 3pm are simulated under overcast sky and intermediate sky condition according to the Subang-Kuala Lumpur Malaysia condition. The research found that the amount of daylight reaching strongly depends on the orientation, month and time of the working hours in a lecture room. The findings in the lecture room indicate that under an intermediate sky without sun, the north-facing window can provide the best daylight throughout the year during working hours. Consequently, the paper offers to designers and building engineers as a guideline to use guidelines for determining the best orientation instead of a simulation program based on orientation, month and time.

Keywords Daylighting, Simulation, Orientation, Hot-Humid Climate

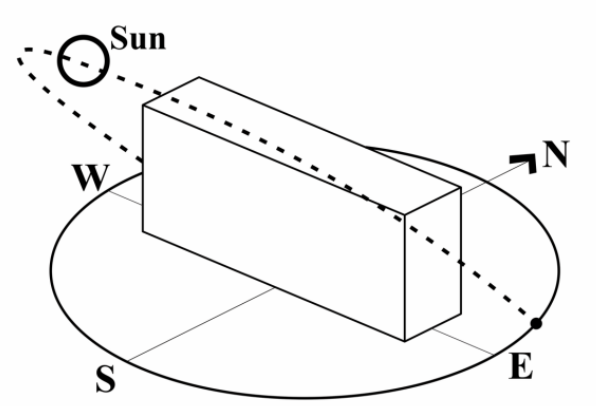
1. Introduction

The term ‘Orientation’ refers to the main façade's direction. This is still ambiguous, with the exception of situations in which the primary facade can be determined by the amount of glazing it contains [1]. Daylight has been a key component of building design in tropical climates. It is the most efficient method of daylight illuminance value for a building throughout the day [2]. The orientation of daylight openings should be such that it is possible to manage the amount of direct sunlight that enters the building while also allowing access to sources of daylight that are of a high quality and offer a lot of illumination. The importance of orientation in a building must be considered from the start, when the architect is determining the location of the building's site. The objective is to ensure that the space receives optimal amounts of useful daylight and sunlight [3]. Based on latitude, sky conditions, and building orientation, daylight can take the form of skylight or both sunlight and skylight. The geographical climate also affects the amount and quality of light that can be used to illuminate a building [4]. As a result, savings from daylight will differ based on the regional climate and sky conditions [5]. The climate condition information provides a more precise illustration of the potential influence of the building on human comfort inside the building.By utilizing the sun as a natural process, it is possible to identify design strategies [6]. If daylighting is properly utilized in accordance with the room's design, it can enhance occupant satisfaction as well as their mental and physical health [7]. Consequently, research should be conducted to improve the daylighting efficiency of lecture rooms. The daylighting performance could be utilized to improve the amount of lighting and reduce glare discomfort in tropical regions, according to the findings of researchers [8,9]. In a lecture room, enough lighting is necessary for reading and writing tasks. It is crucial for students' health and comfort, and it can promote people productivity and lower absenteeism [4, 10]. Daylighting has been shown to improve academic performance. Furthermore, people benefit from a sense of safety and orientation when exposed to natural light indoors [11].

The appropriate range of illumination for a specific area can generate a pleasant indoor environment, which can significantly influence the productivity of the occupants.The quality of the daylight in which a building is located and the external outdoor illuminance in accordance with an area's climate and geographical information should be taken into account by architects and designers.This research aims to the optimum of daylighting in the lecture room with regards to direction at various times of the day and year in Kuala Lumpur-Subang. The hourly value of daylight is required by designers for visual comfort for students in the lecture room. The architect will have to optimize flexibility to get the orientation of building design where the sun path has provided the best availability of natural light in the classroom [3]. Reinhart. C., et al researched that most architects choose to use handbooks as well as guidelines rather than simulation tools [12].

2. Previous study

The influence of daylighting on the interior of the space should be investigated thoroughly, and the local climate should be taken into account more. In the northern hemisphere, for example, the best daylighting is achieved with a south orientation, and a building that is not compass cardinal oriented can interfere with the early morning and late afternoon sun path, requiring a more detailed evaluation. Consequently, the most challenging orientation for daylight openings is toward those regions of the sky when the sun is at its lowest point of the day, generally to the east and west, but the precise orientation varies with location and season. Consequently, buildings oriented in the east-west direction and planning designs that maximise exposure to the northern and southern sky, as seen in Figure 1, are preferable [13].



Source: Allen &Iano 2017

Figure 1. Building orientation

Robson [14] emphasized the necessity of natural illumination in lecture rooms. In the northern hemisphere (UK) climate, he proposed that lecture room windows should never face south or south-west; nonetheless, some sunny windows should always be installed. Furthermore, daylight from the north is sustained and provides an excellent light source in the UK lecture room [15]. Researchers believe that a north-facing window can be more efficiently designed to provide adequate lighting than other window orientations in lecture rooms [16]. Nonetheless, increased sunlight can generate uncomfortable glare in hot weather, particularly in south-facing windows [17]. According to Baker and steemers [1], lecture rooms that face either the north or the south receive 30% more natural light than those that face the east or the west. Windows that face north are classified as north-facing windows with low illuminance levels. While south-facing windows have high illuminance values and slightly changeable illumination, east and west-facing windows provide average levels of illumination, so the quantity of illumination is constant throughout the day. In a cold climate, the west-facing facade provides the greatest amount of light in the afternoon, whereas the east-facing front provides the greatest amount of light in the morning [1].

3. Methodology

The IES<Virtual Environment> computer simulation tool was utilised in this study to evaluate the lecture room's daylighting characteristics. The IES<VE> simulation software is a comprehensive technical design and environmental analysis tool that can be used to simulate and analyse a wide range of building functions. The 3D geometry model is built using the IESVE> models used for this research.

Radiance in the IESVE> programme was used to simulate daylight in order to show study findings on lecture room model settings. In terms of available light-simulation software, Radiance is among the most powerful options [18]. Daylight analysis and Radiance IES<VE> are program keys that have been verified as conforming with the ANSI/ASHARRE standard based on globally acknowledged 'BESTEST' diagnostic tests.The Lawrence Berkeley National Laboratory (LBNL), in the United States, presented Radiance, a graphical simulation application for lighting evaluation [19]. It also includes strong ray-tracing software for calculating daylight, daylight factors, illuminance, and luminance values. Radiance IES is a lighting simulation analysis software and Sun cast is a solar shading analysis software [8]. Ossen claims that as compared to other computer simulation tools, the Radiance-IES in the IES Virtual Environment (IESVE>) computer simulation tool offers greater modelling capabilities with photo-realistic graphics and a more accurate illuminance counter than other software [20]. Using available technology, the advancement of design tools can assist architects and designers in designing improved buildings [21]. Researchers have found that the Radiance result and method performance in actual daylight environments are equivalent [22], and also, Radiance has validated the daylighting calculation for various sky conditions [19]. In the tropical climate, researchers state that Radiance is extremely precise at simulating daylight under an overcast sky without external obstruction [19].

As can be seen in Figure 2, the simulation sets were divided based on the indoor and outdoor lecture room parameters. In accordance with Kuala Lumpur's geographical location and climate, the outdoor parameters consist of the outdoor luminance, kind of sky condition, and orientation. Figure 2 illustrates how indoor parameters are set up into opaque and transparent structures. The basic parameters of an opaque building are the dimensions of the floor and the height of the ceiling. According to Baker and Steemers [1], a room is composed of a floor plan, walls with window openings, and a ceiling. The amount of daylighting in a room is influenced by the transparency of the windows as well as the reflectance of the space's floor, ceiling, and walls. At the end of the simulation the lecture rooms were exported to a spreadsheet in Microsoft Excel for analysis. Figure 2 presents the overview of the computer simulation process.

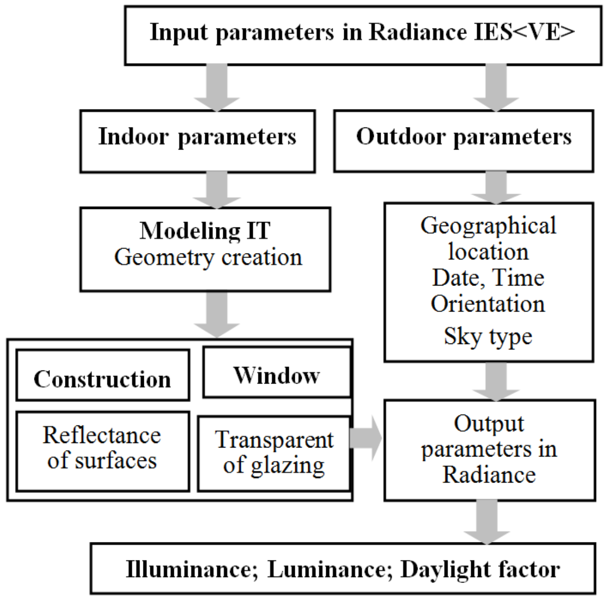


Figure 2. Input parameters in Radiance IES<Virtual Environment>

3.1. Case Study

The lecture room was used as a case-study model for simulation purposes, representing a typical lecture room in Kuala Lumpur-Subang, Malaysia. The impact of various window orientations on the value of daylighting in lecture rooms throughout various months and hours of the day is simulated. Kuala Lumpur is located at latitude 3° 10' N and longitude 101° 42', whereas Kuala Lumpur -Subang is located at latitude 3° 7' N and longitude 101° 33' in Malaysia.

The simulations were done at 10 a.m., 12 p.m., and 3 p.m. since this parameter significantly affects daylighting performance. The time was chosen depending on the position of the sun path during working hours. The influence of various orientations on the daylight value within lecture rooms was determined by simulating data and estimating the average illuminance inside a lecture room on a monthly basis, as well as during various selected working hours.

According to Szokolay [23], natural light is affected by sky conditions, and a totally overcast sky works as a source of diffused light. Commission International de l'Eclairage (CIE) adopts the overcast sky condition known as the CIE sky as the standard design for determining daylight [24]. The minimum level of daylight is represented by the CIE Standard overcast [25]. Since sunlight is completely blocked from making contact with any components under an overcast sky, the range of daylight can be increased under other skies. Research shows that rainy days are greatly contributed to an overcast sky [26].

Zain-Ahmed et al. [9] claimed that the kind of sky condition in Subang can be determined by measuring the nebulosity index (NI). Table 1 presents the Malaysian sky condition classifications by NI values. According to the study, Malaysia's sky is typically an intermediate sky that is neither clouded nor clear. In Kuala Lumpur - Subang, the conditions that were observed included an overcast sky and an intermediate sky without the sun.

The Lecture Rooms feature $64m^2$ (8m'8m) of floor space and 2.7m high ceilings. The daylighting rule of thumb was applied in these rooms, with a 20% window-to-floor area ratio, window head heights of 1.15m and 0.45m and windowsills of 0.9m and 2.05m. The optimal orientation in Malaysia was determined by simulating the four cardinal directions (north, south, east, and west) throughout different months and times of day. The surface of the materials for the floors range between 20% and 30%, the walls range between 50% and 55%, the ceilings range between 90% and 100%, the teaching walls range between 45% and 50%, the doors range between 40% and 50%, the furniture ranges between 40% and 50%, and the equipment ranges between 40% and 50%. Additionally, the average reflectance for a typical lecture room ranges between 40% and 60% [27]. In the lecture rooms, the modeling of the reflectance of inner surfaces was performed using a reflection percentage of 20% for the floor, 50% for the walls, and 80% for the ceilings.

Table 1. Nebulosity Index indicates various sky types in Subang Jaya, Malaysia

Classification of the Sky	Nebulosity Index (NI)	Frequency (%)
Overcast sky	0.00<0.05	14.0
Intermediate overcast	0.05<0.20	2.3
Intermediate mean	0.2<0.70	66.00
Intermediate Blue	0.70<0.95	17.3
Blue / Clear sky	0.95<1.00	0

Source: Zain-Ahmad et al (2000)

Table 2. Input information of the computer simulation

Input information for computer simulation	
Location	Kuala Lumpur- Subang
Latitude	3.12° North
Longitude	101.55° East
Sky condition	CIE standard overcast sky Intermediate sky without sun
The size of lecture room	$64m^2$ (8m´8m) and 2.7m high ceilings
Reflections from the walls	50%
Reflections from the walls	20%
Reflections from the ceiling	80%
Transparency of the glazing	80%

4. Result and Discussion

4.1. Lecture Rooms Facing Various Orientations under Overcast Sky

Figure 3 shows that under an overcast sky, the illuminance of lecture rooms facing different directions was about equal. However, the monthly and daytime simulations for Kuala Lumpur and Subang obtained different findings for the average illuminance value. It is evident that the maximum average illuminance estimate was observed around 12 o'clock in the afternoon with an overcast sky, while the least average illuminance was found at 10 o'clock. The average illuminance value was estimated to be highest in April, March, and September, and it was estimated to be lowest in December and January.Additionally, June and July saw the highest illuminance levels. The average illuminance levels in these lecture rooms were between 300 and 500lux.As a result, according to Malaysian standards, these levels are appropriate for reading and writing activities [28].

4.2. Lecture Rooms Facing Various Orientations under Intermediate Sky

Figure 4 illustrates the estimated monthly average illuminance on horizontal surfaces for the north-facing windows at 10 a.m., 12 p.m., and 3 p.m. in Kuala Lumpur, Subang, under intermediate sky conditions. As shown in Figure 4, the average quantity of illumination for the north orientation was higher at 10 a.m. than at 12 p.m. and 3 p.m. However, for intermediate sky, the average illuminance inside the lecture rooms at 12 noon was lower than at 3pm throughout the year. One possible reason for this could be the path of the sun over Kuala Lumpur. The average illuminance is 450lux at 10 a.m., 350lux at 12 p.m., and 400lux at 3 p.m. The illuminance was at its highest in June. The north-facing figure shows that the average illuminance is highest on the 21st of May, June, and July.

Figure 5 shows that the average illuminance for the southern orientation was between 250lux and 480lux at 10am, 170lux and 480lux at 12pm, and 200lux and 480lux at 3pm. The average illuminance was at its maximum at 10 a.m, while it was estimated to be at its lowest at 12 p.m.However, the average illuminance levels at the three chosen times were roughly the same in January and December. In addition, the minimum monthly average illuminance values from May to July were approximately 250lux at 10am. As well as the average illuminance was below 200lux at 12pm and about 200lux at 3pm between April and August.

Under an intermediate sky, the lecture rooms facing north, south, and west can achieve a maximum average illuminance of approximately 450lux, with the exception of those facing east, which can achieve approximately 650lux for the majority of the year at 10am, and a minimum amount of average illuminance for 5 months of approximately 100lux at noon time 12 pm and less than 200lux in the west orientation. The Malaysian Standard (MS: 1525: 2007) recommends a range of illumination between 300lux and 500lux for reading and writing. Consequently, the daylighting rule of thumb stated is nearly optimal for the north, south, and east orientations [28].

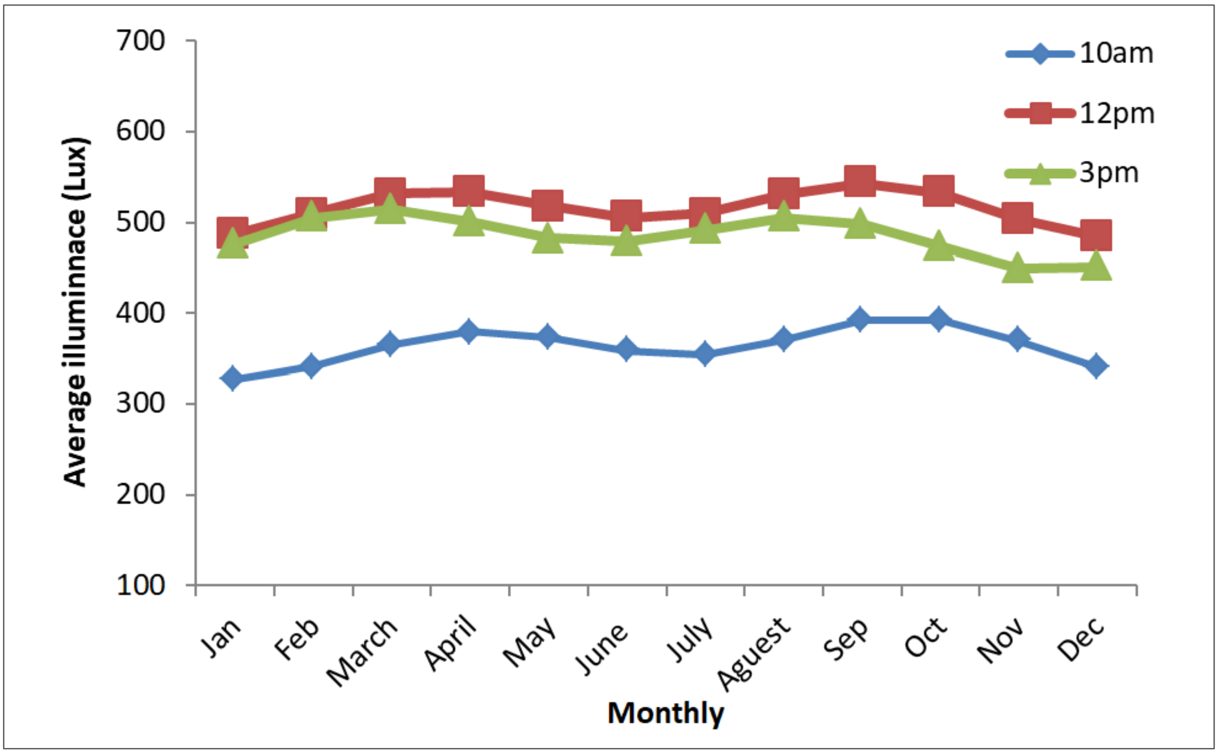


Figure 3. Under an overcast sky, the average illuminance of four cardinal orientations of lecture rooms

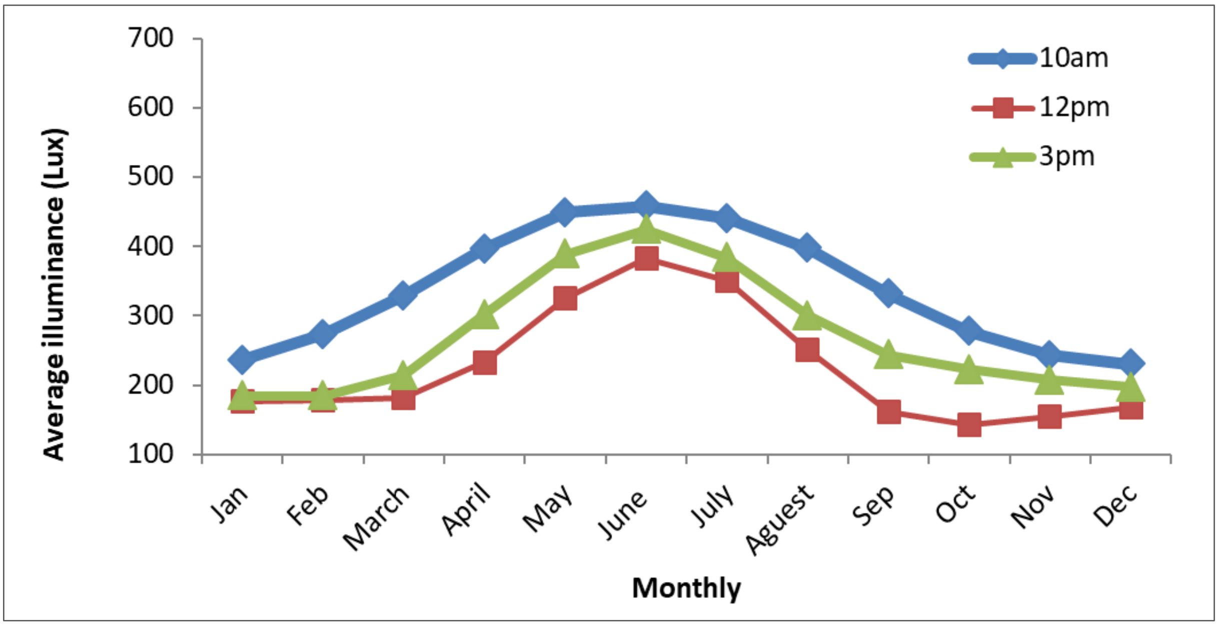


Figure 4. Average illuminance of north-facing Lecture Rooms under an intermediate sky without the sun

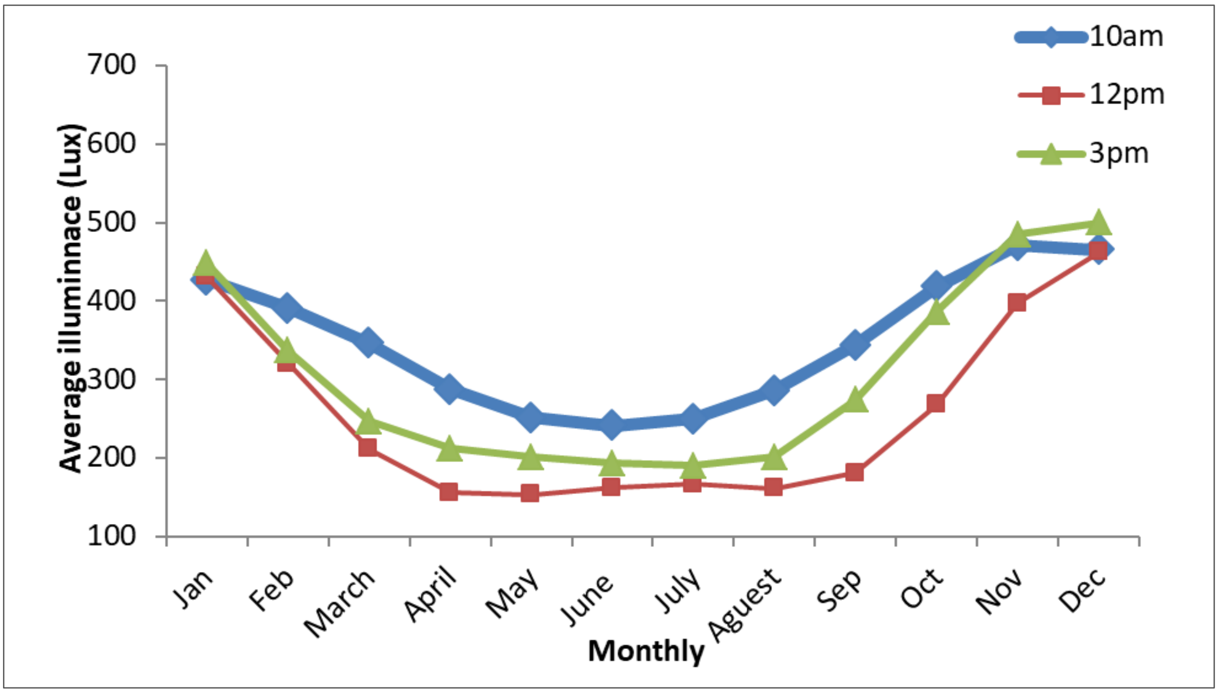


Figure 5. Average illumination of south-facing lecture rooms under an intermediate sky without the sun.

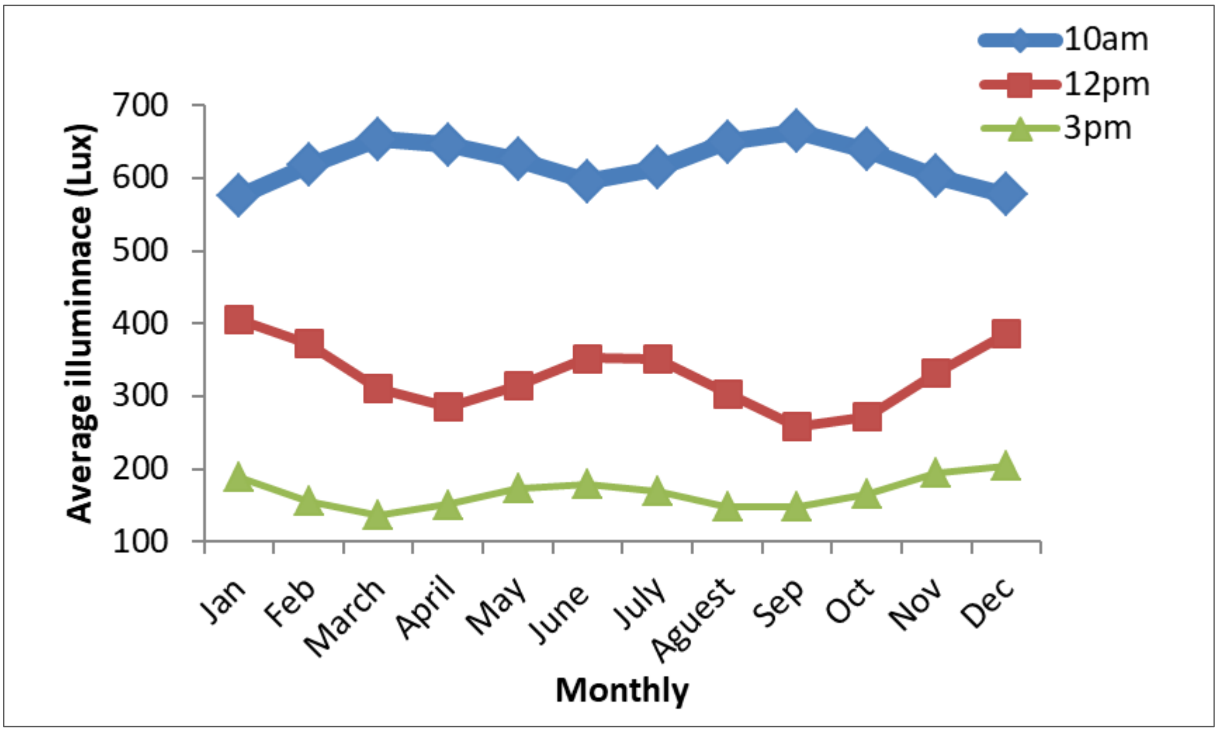


Figure 6. Average illuminance of east-facing lecture rooms under an intermediate sky without the sun

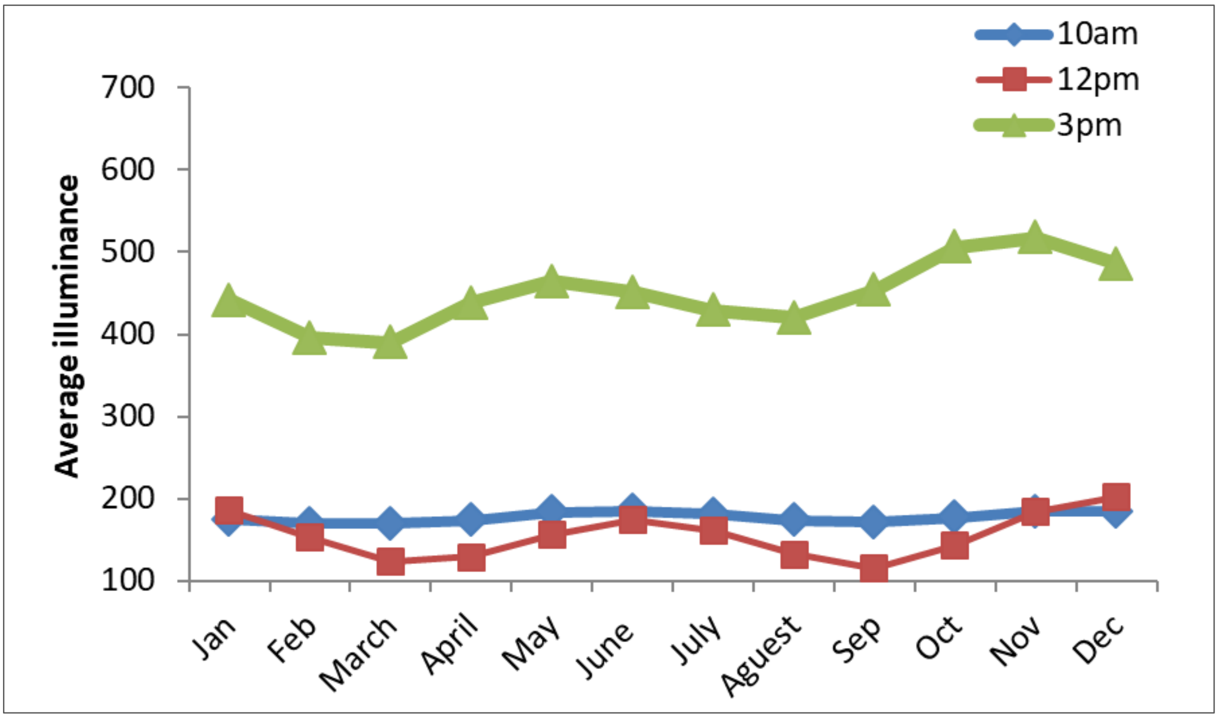


Figure 7. Average illuminance of west-facing lecture rooms under an intermediate sky without the sun

Figure 6 shows that at 10am, the eastern façade's hourly average illumination was higher than at 12pm and 3pm. One explanation could be that the altitude angle is higher at 3pm than it is at 10am and 12pm.At 10 am, the average illuminance value was somewhere above 580 lux, whereas at 3 pm, it was below 200 lux. At 12 o'clock, however, the average illuminance levels ranged approximately between 280 and 400 lux. As a result, according to Malaysian standards, the amount of daylight at 3 p.m. is insufficient for lecture room functions.

The 21st of March and September at 10am under an intermediate sky had the highest average illuminance values, while the 21st of April and September at 12pm had the lowest average illuminance values. The east orientation had the highest illuminance value at 12pm and the lowest illuminance value in January, June, and December.

Figure 7 shows that the west-oriented windows' hourly illuminance value was higher at 3pm than it was at 10am and 12pm. This is primarily due to the location of the sun in relation to the lecture rooms. For all months of the year, the average illuminance under intermediate sky conditions within the lecture rooms with west façade windows is actually dark, with less than 200lux at 10am and 12pm. However, the achieved average illuminance at 3 p.m. was between roughly 350 and 500 lux. As a result, under the intermediate sky condition, sufficient daylight may be provided each month.

5. Conclusions

Daylighting from different cardinal-oriented windows in Malaysian lecture halls was simulated in this research using the IES<VE> Radiance in IES simulation tool, as well as the evaluation of the hourly performance of natural lighting in various orientations under intermediate and overcast sky. North and east orientation have great performance, 20 percent of the ratio of glass area to floor area in classrooms under intermediate sky in Malaysia. The results of the method were the optimum daylighting under north oriented window under intermediate sky on 21st of July. During the morning, the value of illuminance was less than during the afternoon in the north and west orientation window, while, the amount of illuminance in morning was higher than the period time of afternoon in east oriented classroom. The result of simulation under overcast sky among the different orientations was similar, since sky in Malaysia is intermediate sky most of the time. The findings of this study can also be used by researchers of educational building energy efficiency to estimate the lowest and greatest levels of lighting during the day. In conclusion, despite the fact that Kuala Lumpur sky is intermediate most of the time, it has a high amount of illuminance in the north oriented between March to September.

Acknowledgement

The authors would like to express gratitude to the Universiti Kebangsaan Malaysia (UKM) for the allocated research grant GUP-2018-095 on habitable building's indoor environmental quality which had prompted this article.

REFERENCES

[1] Baker, N. and K. Steemers, Daylight design of buildings: a handbook for architects and engineers. 2014: Routledge.

[2] Djamila, H., C.C. Ming, and S. Kumaresan, Estimation of exterior vertical daylight for the humid tropic of Kota Kinabalu city in East Malaysia. Renewable energy, 2011. 36(1): p. 9-15.

[3] Phillips, D., Daylighting. 2012: Routledge.

[4] Egan, M.D. and V. Olgyay, Architectural lighting. 2002: McGraw-Hill New York.

[5] Alshaibani, K., Potentiality of daylighting in a maritime desert climate: the Eastern coast of Saudi Arabia. Renewable energy, 2001. 23(2): p. 325-331.

[6] Salmon, C., Architectural design for tropical regions. 1999: John Wiley & Sons.

[7] da Graça, V.A.C., D.C.C.K. Kowaltowski, and J.R.D. Petreche, An evaluation method for school building design at the preliminary phase with optimisation of aspects of environmental comfort for the school system of the State São Paulo in Brazil. Building and Environment, 2007. 42(2): p. 984-999.

[8] Ibrahim, N., A. Zain-Ahmed, and U. Commercialisation, A simple prediction tool for energy savings due to daylighting in Malaysia. Journal Science & Technology Vision, 2006. 2(1): p. 25-29.

[9] Zain-Ahmed, A., et al., The availability of daylight from tropical skies—a case study of Malaysia. Renewable Energy, 2002. 25(1): p. 21-30.

[10] Hopkinson, R.G., P. Petherbridge, and J. Longmore, Daylighting. 1966: Heinemann.

[11] Lam, W.M. and C.H. Ripman, Perception and lighting as formgivers for architecture. 1977: McGraw-Hill New York (NY).

[12] Reinhart, C. and A. Fitz, Findings from a survey on the current use of daylight simulations in building design. Energy and buildings, 2006. 38(7): p. 824-835.

[13] Allen, E. and J. Iano, The architect's studio companion: rules of thumb for preliminary design. 2017: John Wiley & Sons.

[14] Robson, E.R., School Architecture: Being Practical Remarks on the Planning, Designing, Building, and Furnishing of School-houses. With 300 Illustrations. 1877: J. Murray.

[15] Wu, W. and E. Ng, A review of the development of daylighting in schools. Lighting research & technology, 2003. 35(2): p. 111-124.

[16] Plympton, P., S. Conway, and K. Epstein, Daylighting in Schools: Improving Student Performance and Health at a Price Schools Can Afford. 2000.

[17] Gugliermetti, F. and F. Bisegna, Daylighting with external shading devices: design and simulation algorithms. Building and Environment, 2006. 41(2): p. 136-149.

[18] Freewan, et al., Interactions between louvers and ceiling geometry for maximum daylighting performance. Renewable energy, 2009. 34(1): p. 223-232.

[19] Ng, E.Y.-Y., et al., Advanced lighting simulation in architectural design in the tropics. Automation in Construction, 2001. 10(3): p. 365-379.

[20] Ossen, D.R., Optimum overhang geometry for high rise office building energy saving in tropical climates, 2005, Universiti Teknologi Malaysia.

[21] Ander, G.D., Daylighting performance and design. 2003: John Wiley & Sons.

[22] Mistrick, R. and F. PE, Advancing the Art & Science of Daylighting Design. 2002.

[23] Szokolay, S., Introduction to architectural science. 2012: Routledge.

[24] Grondzik, W.T. and A.G. Kwok, Mechanical and electrical equipment for buildings. 2019: John wiley & sons.

[25] Shahriar, A.N.M. and M.A. Mohit, Estimating depth of daylight zone and PSALI for side lit office spaces using the CIE Standard General Sky. Building and environment, 2007. 42(8): p. 2850-2859.

[26] Li, D.H., A review of daylight illuminance determinations and energy implications. Applied Energy, 2010. 87(7): p. 2109-2118.

[27] Brubaker, C.W., Planning and Designing Schools. 1998: ERIC.

[28] Standard, M., MS 1525: 2007: Code of Practise on Energy Efficiency and Use of Renewable Energy for Non-residential Buildings. Cyberjaya Selangor,Departmen t of Standards Malaysia, 2007.