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Field Validation of IES-VE for Daylight Assessment in Tropical High-rise Low-cost Housing: Effects of Building Height, Layout Depth, and Façade Design

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ABSTRACT

Daylight is an important component of indoor environmental quality, yet its distribution in tropical high-rise low-cost housing is often uneven due to variations in building height, façade orientation, and unit depth. This study aims to validate the Integrated Environmental Solutions – Virtual Environment (IES-VE) simulation software for assessing daylight performance in tropical high-rise low-cost housing in Kuala Lumpur. A quantitative approach was adopted, combining field measurements and simulation modelling. Field measurements were conducted at different floor levels and room depths to investigate horizontal and vertical daylight distribution within residential units. The Daylight Ratio (DR) was used to represent actual daylight conditions under tropical sky environments, while simulation results were evaluated using the Daylight Factor (DF). The comparison between field measurements and simulation results showed differences ranging from 15% to 20%, which fall within the commonly accepted validation threshold. Statistical validation using Mean Bias Error (MBE) and Root Mean Square Error (RMSE) indicated small deviations between measured and simulated values, while correlation analysis demonstrated a strong agreement with a coefficient of determination (R^2) of 0.9917. The findings confirm that IES-VE can reliably simulate daylight performance in tropical high-rise residential buildings. The validated simulation model provides a reliable platform for future climate-based daylight modelling and visual comfort assessments, including the evaluation of daylight availability, solar exposure, and glare performance. The

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outcomes of this study contribute towards the development of evidence-based daylight design recommendations and support future improvements to daylighting guidelines for tropical high-rise residential buildings.

Keywords: Daylight performance, daylight ratio, IES-VE, radiance, residential

INTRODUCTION

Daylight plays an important role in human life and indoor environmental quality. It contributes to energy efficiency by reducing the reliance on artificial lighting while also improving occupants' well-being and mood (Du et al., 2022; Tanveer et al., 2023). Effective daylighting strategies, therefore, enhance indoor environmental quality and support human comfort, particularly visual comfort (DiLaura,2021).

Building regulations, standards, and rating systems are important tools used to evaluate daylight performance in buildings. Various countries adopt daylight assessment methods that correspond to their climatic conditions and technological capabilities. For instance, the static daylight metric known as the Daylight Factor (DF) has been widely applied, particularly in contexts where technical expertise and simulation resources are limited. In contrast, more technologically advanced countries such as the United Kingdom, the United States, and Japan increasingly employ dynamic daylight metrics through Climate-Based Daylight Modelling (CBDM), which allows daylight performance to be simulated using real climatic data.

However, the Daylight Factor (DF) assumes a uniform overcast sky, which may not adequately represent daylight conditions in tropical climates where sky conditions are highly variable (Dahlan et al., 2009). In tropical regions such as Malaysia, sky conditions change rapidly due to dynamic cloud formation. Studies by (Zain-Ahmed et al., 2002) indicate that approximately 85.6% of the sky conditions in Subang are classified as intermediate skies, while (Djamila et al., 2011) reported that around 70-90% of sky conditions in Kota Kinabalu fall within the intermediate sky category. These findings suggest that tropical daylight conditions are dominated by fluctuating cloud patterns rather than stable overcast or clear skies.

In addition, outdoor global illuminance levels in tropical regions are significantly higher than those in temperate climates. Measurements show that global illuminance may exceed 80,000 lux at noon and occasionally reach values above 100,000 lux. During typical daytime working hours (9:00 a.m. to 5:00 p.m.), outdoor illuminance commonly exceeds 20,000 lux (Lim & Heng, 2016). Because of these characteristics, daylight studies in tropical climates often employ measurements derived from actual indoor and outdoor illuminance ratios, commonly referred to as the Daylight Ratio (DR), which provides a more representative indicator of daylight availability under real sky conditions.

In Malaysia, several regulations incorporate daylighting requirements, including the Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings (MS 1525:2019), the Energy Efficiency and Use of Renewable Energy for Residential Buildings (MS 2680:2017), and the Uniform Building By-Laws (UBBL) 1984. These regulatory standards primarily rely on descriptive recommendations such as a minimum opening area of 10% for daylighting and ventilation, window-to-floor ratio (WFR), and the use of static daylight metrics such as the Daylight Factor (DF). However, such approaches may not fully capture daylight performance in tropical climates where solar exposure is intense, and sky conditions are highly dynamic (Mirrahimi et al., 2022). Consequently, discrepancies may occur between simulated daylight performance and actual daylight behaviour in buildings.

Low-cost housing developments often face additional design constraints. Limited technical input during the design stage frequently results in simplified façade configurations, the absence of shading devices, and compact floor plans (Al-Ashwal et al., 2024; Gonzalez-Longo, 2019). These architectural characteristics may lead to uneven daylight distribution, where spaces close to windows receive abundant daylight while deeper interior areas receive significantly less daylight. Furthermore, building height also affects daylight availability. Lower floors may experience reduced daylight penetration due to surrounding obstructions, whereas upper floors may receive excessive direct sunlight that could cause glare and visual discomfort (Kalaimathy et al., 2023; Syed Fadzil et al., 2009) .

In 2015, the Malaysian government introduced a large-scale affordable housing initiative known as the People's Housing Programme (PPR), implemented by the National Housing Department under the Ministry of Urban Wellbeing, Housing and Local Government (Gonzalez-Longo, 2019). According to the UHLG annual report, 169 PPR projects were proposed nationwide, providing approximately 102,896 housing units (Ministry of Urban Wellbeing, 2016). Nearly 47% of these housing units are in Kuala Lumpur and are predominantly constructed as high-rise residential buildings (JPN, 2016; KPKT, 2017).

Given the increasing reliance on simulation tools in building design, accurate simulation models are required to predict daylight performance and guide design decisions. Integrated Environmental Solutions – Virtual Environment (IES-VE) is one widely used platform capable of simulating both static and dynamic daylight conditions. However, before simulation outputs can be reliably applied in tropical housing contexts, the simulation model must be validated against empirical field measurements.

Previous validation studies have reported simulation–measurement deviations of up to 20%, depending on building type and sky condition (Elsiana et al., 2023; Li et al., 2017). In addition to evaluating percentage differences, statistical indicators such as Mean Bias Error (MBE), Root Mean Square Error (RMSE), and correlation analysis are often used to assess the agreement between measured and simulated daylight data.

This paper, therefore, presents a combined fieldwork and simulation study aimed at validating the performance of IES-VE for daylight analysis in tropical high-rise low-cost housing. Field measurements of indoor illuminance were conducted across multiple floor levels and room depths within selected residential units, and the same conditions were replicated in IES-VE using the Radiance simulation engine. The comparison between field measurements and simulation outputs was carried out using static daylight indicators, where the Daylight Ratio (DR) derived from field measurements was compared with the Daylight Factor (DF) obtained from simulation.

The comparison between field measurements and IES-VE simulation results indicates differences ranging between 15% and 20%, which fall within the acceptable validation threshold reported in previous daylight simulation studies. In addition to percentage difference analysis, statistical validation methods, including Mean Bias Error (MBE), Root Mean Square Error (RMSE), and correlation analysis, were applied to evaluate the level of agreement between measured and simulated daylight conditions. Accordingly, this study focuses on the empirical evaluation of daylight performance in tropical high-rise low-cost housing through field measurements and simulation modelling. By comparing measured indoor daylight conditions with simulated outputs, the research validates the predictive reliability of the IES-VE simulation platform under tropical climatic conditions. This integrated approach establishes a methodological framework for evaluating daylight performance in real residential environments, which can support future research employing advanced dynamic daylight metrics such as Useful Daylight Illuminance (UDI), Spatial Daylight Autonomy (sDA), and Annual Sunlight Exposure (ASE).

LITERATURE REVIEW

Daylight in High-rise Housing Buildings

Daylighting is an important element to optimise the indoor environment quality by improving visual comfort and well-being (Sallan et al., 2025). For residential buildings, a good daylight design supports smooth daily activities, harmonises human mood and at the same time fosters productivity, while poorly designed daylight may cause glare and visual discomfort (Al-Ashwal et al., 2024; Al Horr et al., 2016; Hassan & Al-Ashwal, 2015). Artificial lighting can cause stress and eye strain; thus, a good daylight design can avoid this effect and, at the same time, can reduce the reliance on artificial lighting (Knoop et al., 2020; Wirz-Justice et al., 2021).

Previous studies have shown that daylighting was influenced by window characteristics such as size, placement and type of glazing as shown in Table 1. In terms of size, window ratios such as Window-to-Floor (WFR), Window-to-Wall (WWR), and Carpet Area to Window Ratio (CAWR) are important in determining the daylight performance.

Table 1
Previous study on daylighting in residential buildings

Author Location	Daylight Metric	Objective	Method	Key Finding
(Wong et al., 2004) Singapore	Daylight Factor (DF)	To assess the impact of external shading devices on daylighting and glare	Field measurements LIGHTSCAPE simulations	Use shading devices with adjustable angles to balance daylight and glare; avoid direct sky views.
(Syed Fadzil et al., 2009) Penang, Malaysia	Daylight Factor (DF)	To assess the effect of orientation and WWR on daylight levels	Field measurements Simulation	Reduce WWR to 10% or less in tropical climates to avoid glare and overheating.
(Dutta et al., 2017) Kolkata, India	-	To evaluate how window orientation and dynamic external shading affect cooling loads	TRNSYS and ECOTECT simulation	Use dynamic external shading aligned with sun path on south-facing windows.
(Achsani et al., 2018) Bandung, Indonesia	-	To evaluate daylight technologies for high-rise residential buildings in tropical climates	Literature review	Use diffuse light-guiding systems, especially anidolic systems, for deep floor plans in tropical climates
(Syed Husin & Hanur Harith, 2018) Selangor, Malaysia	Daylight Factor (DF)	To analyse the impact of window types and glazing on daylight performance	Field measurements	Use casement windows with obscure glass for privacy and balanced daylight; avoid fixed louvres with clear glass.
(Dabe & Adane, 2019) Nagpur, India	Useful Daylight Illuminance (UDI)	To evaluate daylight performance by floor level and orientation	Field measurements Simulation	Adjust window sizes by floor level and orientation to optimise daylight and thermal comfort.
(Rukiah et al., 2022) Penang, Malaysia	-	To assess air and lighting quality in low-cost high-rise housing	Field observation Survey	Improve corridor ventilation and daylight access in dense residential buildings
(Dhayal et al., 2023) India	-	To review factors influencing indoor visual comfort and assessment techniques	Systematic Literature Review	Promote dynamic lighting design and conduct more studies in residential settings
(Dinapradipta et al., 2024)	Daylight Factor (DF)	To evaluate the performance of adjustable bent louvres for daylighting in tropical apartments	RADIANCE and ECOTECT simulation	Use adjustable two-bent slat louvres for optimal daylight distribution in tropical apartments.

For example, Dabe and Adane (2019) found that optimal CAWR values vary between lower and upper floors to balance UDI and thermal comfort, while Syed Fadzil et al. (2009) showed that excessive WFR can lead to glare. Similarly, glazing properties strongly affect daylight transmittance and visual quality (Kalaimathy et al., 2023; Syed Husin & Hanur Harith, 2018; Wang et al., 2023).

Daylighting performance further improved with daylighting technologies by integrating shading devices, especially in tropical countries. Studies show that horizontal louvres, bent slats, and light shelves can improve daylight distribution, reduce glare, and help deep floor plans daylight penetration (Al-Tamimi & Fadzil, 2011; Dinapradipta et al., 2024; Dutta et al., 2017; Iqbal et al., 2023). Advanced shading technologies, such as the dynamic shading system also proven to achieve fifteen per cent (15%) of energy saving and at the same time can improve the visual comfort (Dutta et al., 2017). These findings show that integrating daylight strategies can optimise the daylight usage as well as reduce the use of artificial lighting in residential buildings. The other benefit of daylighting is toward the occupant's well-being (Tanveer et al., 2023). Recent research shows that indoor visual comfort is influenced by environmental factors, design strategies, and user perceptions (Dhayal & Jha, 2023). In Malaysia, a field study was conducted in low-cost high-rise housing and shows that the residents were experiencing inadequate daylight, particularly at the lower floor level, forcing the residents to depend on artificial lighting, including during the daytime, contributing to dissatisfaction and poor living conditions of the residents. Thus, a well-planned architectural design that addresses the daylight issues is beneficial to the residents, thereby creating a more livable and comfortable residential environment (Rukiah et al., 2022).

Although technical practitioners were aware of the importance of daylight strategies in building design, it is noticeable that most of the common practices still rely on static metrics such as Daylight Factor and simulation-based evaluations, with limited field validation (Nazari & Matusiak, 2024). While dynamic metrics like UDI, sDA, and ASE offer greater reliability, they are rarely applied in low-cost high-rise housing studies (Kalaimathy et al., 2023; Nazari & Matusiak, 2024). Moreover, most fieldwork is confined to single floors, overlooking vertical variation in daylight access. This limits the transferability of findings to real-world contexts. The following subsection outlines the research gap identified from the review and highlights the novelty of the present study.

Research on daylighting in vertical residential buildings has expanded considerably over recent years. However, there are still notable gaps, especially when it comes to affordable housing in tropical climates. Many existing studies tend to depend heavily on computer simulations or theoretical frameworks, with limited validation through actual field measurements. These methods can affect the accuracy and reliability of the findings. Furthermore, in terms of building typology, not much research that focuses on high-rise residential buildings compared to low-rise residential buildings. Thus, the real challenge and the specific needs in high- rise residential buildings remain unexplored, especially in a tropical country like Malaysia, where extreme climatic factors really affect the daylight performance in buildings. Moreover, existing fieldwork studies for high-rise residential building focusing within single floors, without considering the high-rise setting of the buildings.

Simulation Programs, Integrated Environmental Solutions-Virtual Environment (IESVE)

Over the past fifty years, the development of building performance simulation tools has significantly advanced in the construction industry and has become an important tool in evaluating and improving energy efficiency as well as sustainability in buildings. These tools help technical experts to simulate and analyse many aspects of building services, such as indoor comfort, energy efficiency and building life cycle cost, such as evaluating the thermal conditions of emergency shelters, which was notably utilised by the U.S. government during disaster response efforts (Attia et al., 2009). As these technologies continue to evolve, experts have used these tools not only to analyse energy efficiency but also to predict environmentally friendly design to ensure a better life quality and sustainability for a healthier planet (Crawley et al., 2008).

ECOTECT, EnergyPlus, IES-VE, TRNSYS, and ANSYS are several simulation programs that have been used in the construction industry. For example, research by Ozorhon and Caglayan (2011) focused on assessing the effectiveness of EnergyPlus and IES-VE in designing energy-efficient buildings by comparing these tools to determine their suitability for Building Information Modelling (BIM)-based simulations. The simulations focused on window size and building orientation, and the results showed that IES-VE is more user-friendly, offering easier parameter management and reporting, and supports daylighting analysis.

Thus, this paper presents a combination of fieldwork measurement and simulation measurement that aimed to validate the performance of IES-VE in terms of daylight analysis for high-rise low-cost housing. The fieldwork measurements involved measuring indoor and outdoor illuminance within a depth of typical units located at different floor levels (upper floor level and lower floor level), and the same scenarios were modelled in IES-VE using its Radiance engine. The results were then compared by using static daylight metrics, Daylight Factor (DF) and the introduction of Daylight Ratio (DR), which is more relevant in tropical climates, which remain fundamental to both Malaysian standards and international codes. The study demonstrates that IES-VE predictions differ from field measurements by approximately 15–20%, within the acceptable range reported in prior daylight validation studies. These findings confirm IES-VE's suitability as a predictive tool for assessing daylight in tropical residential housing, while also addressing the challenges in the field of daylight distribution for high-rise building typology. By addressing these issues, this research can provide further recommendations for using dynamic daylight metrics for more comprehensive results. By doing so, this research will provide comprehensive results tailored to the local context that can help to standardise better building regulations and standards. Ultimately, this study aims to promote the use of dynamic daylight metrics by applying a reliable CBDM software, which can lead to better building design by reducing the use of artificial lighting while optimising the use of daylighting to shape a better and healthier environment for the residents.

METHODOLOGY

This study adopts a quantitative approach involving fieldwork measurements of daylight conditions in selected high-rise low-cost housing developments in Kuala Lumpur. To support model validation, the fieldwork concentrated on the measurement of fundamental luminous parameters, particularly indoor illuminance, which served as the empirical dataset for evaluating simulation accuracy. Mardaljevic et al. (2016) emphasised that confidence in daylight simulation predictions should first be established through comparisons with measured illuminance data from real occupied spaces before more advanced daylight assessments are undertaken. Therefore, the present study adopted illuminance-based static daylight metrics as the validation framework. Once validated, the IES-VE model can be reliably applied in subsequent research stages to assess annual daylight performance and visual comfort using climate-based daylight modelling approaches.

The exact building characteristics were modelled in SketchUp and subsequently exported to the Integrated Environmental Solutions – Virtual Environment (IES-VE) platform to perform daylight simulations using the IES-VE Radiance engine. The accuracy of the simulation model in predicting daylight performance under tropical conditions was assessed using standard static daylight metrics as benchmark indicators. This combined approach aims to provide a clearer understanding of daylight performance in high-rise low-cost housing and to support improved daylight-responsive design practices. By integrating empirical field measurements with simulation modelling, the study enables a direct comparison between measured daylight conditions and simulated outputs to evaluate the predictive reliability of the simulation model under tropical climatic conditions (Quek & Jakubiec, 2021).

Case Study Selection

An initial observation of ten (10) PPR developments in Kuala Lumpur was conducted to identify representative high-rise low-cost housing typologies. From this observation, two projects were selected representing Generation 1 and Generation 2 PPR design. These 2 projects with simple façades and minimal shading elements represent typical Malaysian low-cost housing design (Gonzalez-Longo, 2019). Case study one (1) PPR Intan Baiduri represents an older generation of housing (built before the year 2000) with a limited basic façade and small floor area; 19.62 m² as shown in Figure 2 and Figure 4, while case study two (2) PPR Seri Aman reflects a newer generation development (post-2019) that incorporates basic façade modifications such as horizontal fins and larger floor area; 20.89 m² as shown in Figure 3 and Figure 5. Case studies 1 and 2 were further categorised into sub-cases (1 and 1a; 2 and 2a) to represent the respective floor levels, as presented in Table 2. Both projects are located within a 1.09 km radius to ensure similar outdoor daylight conditions as shown in Figure 1.

The inclusion of two generations of housing allows for comparative analysis of how daylight conditions vary with design evolution while still being representative of the low-cost housing typology (Gonzalez-Longo, 2019). These developments share common features of Malaysian affordable housing: high-density, narrow floor plan, repetitive unit layouts, single-sided fenestration design, making them suitable testbeds for evaluating daylight distribution and validating simulation outputs. The selection of these case studies also allows comparison between buildings with different façade treatments and orientations, which may influence daylight penetration patterns.

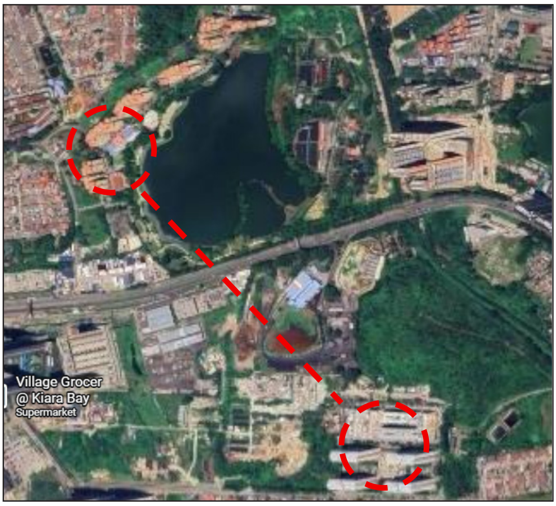


Figure 1. The distance between 2 PPR is 1.09 km

Figure 2. PPR Intan Baiduri

Figure 3. PPR Seri Aman

Table 2
Detailed overview of the on-site low-cost housing units

Case Study	Building Height (m)	Measured Point	Orientation	Floor Area (m²)	Window Area (m²)	WFR %	Shading Devices
1	Gen 1 45m	T01 T02 T03	East	19.62	1.94	9.89	No shading
1a	Gen 1 24m	T01 T02 T03	East	19.62	1.94	9.89	No shading
2	Gen 2 54m	T01 T02 T03	North	20.89	2.16	10.34	With shading
2a	Gen 2 30m	T01 T02 T03	North	20.89	2.16	10.34	With shading

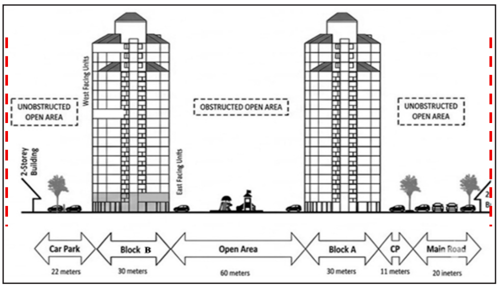


Figure 4. PPR Intan Baiduri Contextual Elevation

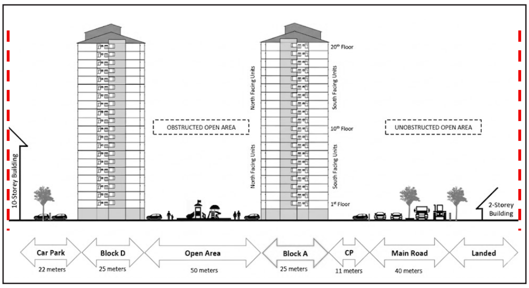


Figure 5. PPR Seri Aman Contextual Elevation

Fieldwork Measurement

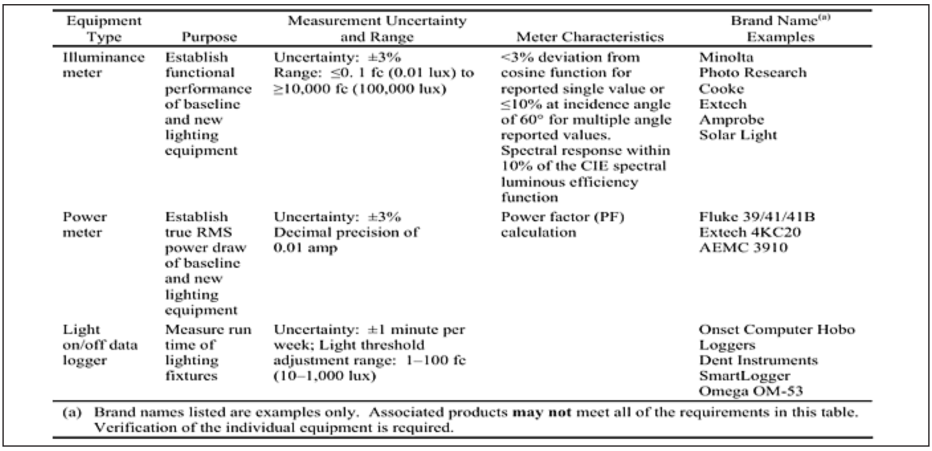
Instruments

Indoor illuminance levels were measured using a Lux meter as shown in Figure 8, Onset HOBO U12-012 Temperature/Humidity/Light and HOBO Temp/RH/Light/Ext-Analogue MX 1104 with data loggers that had been calibrated to ISO/CIE standards as well as recommended by IESNA 10th Edition as shown in Figure 7, which was checked against a reference source before each measurement session to ensure accuracy as shown in Table 3. Simultaneous outdoor illuminance was recorded using a lux meter (HOBO Temp/RH/Light/Ext-Analogue MX 1104 with data loggers) positioned in an unobstructed location to provide reference values for calculating Daylight Ratio (DR).

Before field deployment, all instruments were collocated under identical lighting conditions for five days to verify measurement consistency. The readings showed stable agreement within each instrument type, with minor deviations of approximately 0.9 and 0.54.

These differences were considered negligible relative to the daylight illuminance range recorded during the fieldwork, as shown in Figure 6.

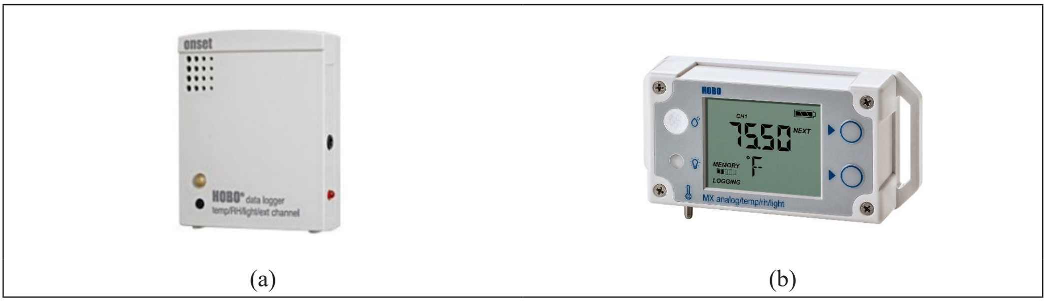
Figure 6. Verification of measurement consistency



Equipment Type	Purpose	Measurement Uncertainty and Range	Meter Characteristics	Brand Name[a] Examples
Illuminance meter	Establish functional performance of baseline and new lighting equipment	Uncertainty: ±3% Range: ≤0. 1 fc (0.01 lux) to ≥10,000 fc (100,000 lux)	<3% deviation from cosine function for reported single value or ≤10% at incidence angle of 60° for multiple angle reported values. Spectral response within 10% of the CIE spectral luminous efficiency function	Minolta Photo Research Cooke Extech Amprobe Solar Light
Power meter	Establish true RMS power draw of baseline and new lighting equipment	Uncertainty: ±3% Decimal precision of 0.01 amp	Power factor (PF) calculation	Fluke 39/41/41B Extech 4KC20 AEMC 3910
Light on/off data logger	Measure run time of lighting fixtures	Uncertainty: ±1 minute per week; Light threshold adjustment range: 1–100 fc (10–1,000 lux)		Onset Computer Hobo Loggers Dent Instruments SmartLogger Omega OM-53

(a) Brand names listed are examples only. Associated products **may not** meet all of the requirements in this table. Verification of the individual equipment is required.

Figure 7. Example Instrument and Specification (IESNA 10th Edition)



(a) (b)

Figure 8. a) Onset HOBO U12-012 Temperature/Humidity/Light Data Logger; b) HOBO Temp/RH/Light/Ext-Analogue MX 1104

Table 3
Instruments reference value of accuracy

Equipment	Parameter Measured	Measurement Range	Accuracy	Logging Interval
Onset HOBO U12-012 Temperature / Humidity / Light Data Logger	Illuminance (lux)	0 – 90,000 lux	±5% of reading	1-minute interval
	Air temperature	-20° to 70°C	± 0.35°C from 0° to 50°C	1-minute interval
	Relative humidity	5% to 95% RH	±2.5% RH	1-minute interval
HOBO Temp/RH/Light/ External-Analogue MX1104 Data Logger	Illuminance (lux)	0 to 167,731 lux (15,582 lum/ft2)	±10% typical for direct sunlight	1 second to 18 hours
	Air temperature	-20° to 70°C (-4° to 158°F)	±0.20°C from 0° to 50°C (±0.36°Ffrom 32° to 122°F)	1 second to 18 hours
	Relative humidity	0% to 100% at -20° to 70°C (-4° to158°F)	±2.5% from 10% to 90% (typical)	1 second to 18 hours

Measurement Points

For each project, measurements were conducted at two floor levels representing upper and lower zones, resulting in four case studies. A total of fourteen (14) measurement points (Figure 11) were used, consisting of twelve indoor points (three points per unit) and two outdoor reference points installed outside the highest unit to record external illuminance, as shown in Figure 9. Within each residential unit, measurement points were established across the living room and dining areas, as these spaces represent the primary occupied zones where most daytime activities take place and therefore require adequate daylight availability for visual tasks and general indoor comfort, as shown in Figure 9 and Figure 10. Illuminance measurements were recorded at 0.75 m above the floor level, representing the standard horizontal working plane height commonly adopted in daylight performance assessment. This measurement height was selected to ensure consistency with the recommended procedures outlined by the Illuminating Engineering Society (IES) guidelines (Kruisselbrink et al., 2018) (*Illuminating Engineering Society THE LIGHTING HANDBOOK 10th Edition | Reference and Application*, 2011). The use of this measurement height also follows the methodology adopted in previous daylight field measurement studies conducted in tropical environments (Elsiana et al.,2023; Lim & Heng, 2016), ensuring methodological consistency and comparability of daylight performance evaluation.

There are three (3) measurement points established within each unit, namely T01, T02, and T03, to represent the daylight distribution within the living and dining area based on the dimensions of the investigated residential units. The combined depth of the living and dining area was approximately 5.6 m in PPR Intan Baiduri and 5.9 m in PPR Seri Aman. Measurement points were positioned at regular 1.5 m intervals extending from the window opening towards the rear of the space to capture the daylight gradient across the occupied zone. This arrangement enabled the assessment of daylight penetration of the area from the façade. According to recommended daylight measurement practices, spaces should be divided into daylighted zones based on distance from the window and the activity within the space, where each zone is represented by a measurement point placed at a critical or representative location of typical illuminance levels. For continuous measurements, one measurement point is sufficient to represent the illuminance condition within each daylighted zone at the working plane level (Kruisselbrink et al., 2018). Therefore, three (3) measurement points were considered sufficient to represent the daylight distribution within the living and dining area, particularly within the active daylight zone extending from the window opening towards the rear of the space, considering the depth of each residential unit.

To capture vertical daylight variation, measurements were conducted at both lower floor levels (approximately 24 m and 30 m above ground level) and upper floor levels (approximately 45 m and 54 m above ground level) in each building. In addition, units with different orientations (south-oriented and east-oriented) were selected to account for variations in solar exposure. This measurement configuration enables the evaluation of daylight distribution within the daylight active zone, both horizontally across the room depth and vertically across different building heights. In total, fourteen (14) measurement points were monitored, consisting of twelve indoor points and two outdoor reference points. Illuminance data were recorded using data loggers at 5-minute intervals over a seven-day monitoring period, allowing continuous measurement of daylight conditions under the same sky conditions for all points.

Figure 9. Placement Point T1, T2 and T3 in PPR Intan Baiduri

Figure 10. Placement Point T1, T2 and T3 in PPR Seri Aman.

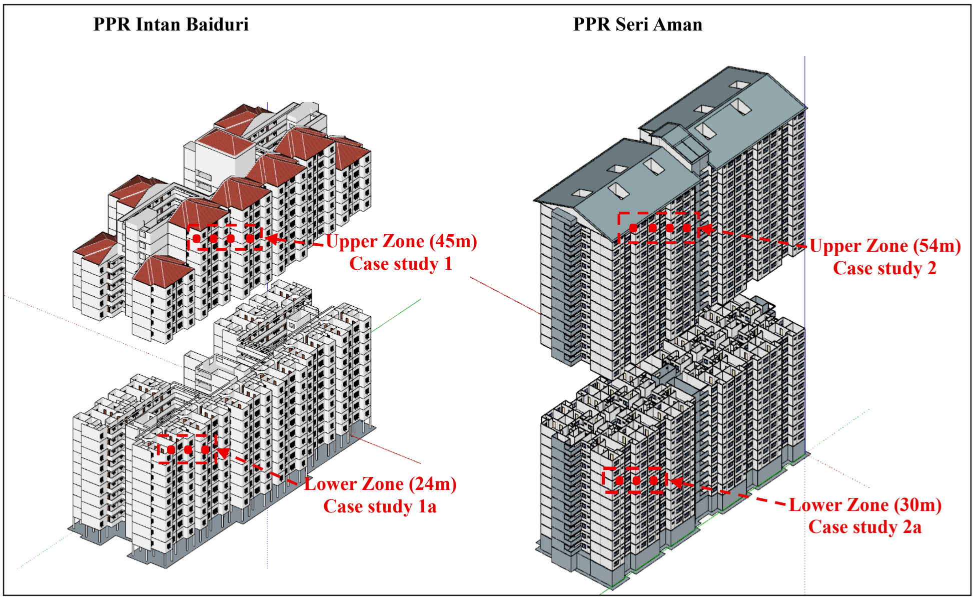


Figure 11. 14 points were set on the same day from 16/07/25 to 22/07/25

Fieldwork Procedure

To ensure accurate assessment of daylighting conditions, all artificial lighting in the selected units was switched off during data collection. Since the units were unoccupied, measurements could be conducted without any interference from internal light sources, allowing the study to focus solely on the impact of natural daylight within the living spaces. Data collection for each unit was conducted on days with stable sky conditions, on the 16th of July 2025 until the 22nd of July 2025 (7 days), simultaneously across different building heights in two low-cost housing schemes. The total number of points involved in the fieldwork is fourteen (14) points, with two (2) points to measure the outdoor illuminance, and the time used for daylight measurement is between 08:00 and 18:00. Simultaneity between indoor and outdoor measurements was ensured by configuring all data loggers using HOBO logging software before fieldwork. The instruments were synchronised and set to record illuminance at a 5-minute logging interval, allowing indoor and outdoor illuminance data to be captured simultaneously throughout the monitoring period, under intermediate sky conditions, as mentioned in Malaysian Standards. To further minimise the influence of short-term sky variability, the recorded field measurements were verified against corresponding weather station data for each monitoring day to confirm the prevailing sky conditions. This verification procedure was consistently applied throughout the fieldwork period to ensure the reliability of the measured daylight data. The selection of the lowest and highest daylight conditions was based on the average indoor illuminance values, which is a simplified and acceptable method recommended by IES guidelines for determining representative illuminance levels. After the seven-day monitoring period, the average lux values from the three indoor measurement points were compared. The results showed that 18/07/2025 recorded the lowest average illuminance, while 21/07/2025 recorded the highest. This approach allows daylight conditions to be evaluated based on daily illuminance variations rather than annual calculations, using multiple monitoring days, which improves reliability compared to a single-day measurement (Al-Ashwal et al., 2024). This research, therefore, applies appropriate static daylight metrics to evaluate fundamental daylight performance, which are further described in the Criteria of Analysis section.

The selection of the fieldwork period in July was also informed by the daylight availability characteristics described in MS 2680:2017. As illustrated in Figure 12 of the standard, the monthly average hourly illuminance in tropical regions shows that March generally represents the maximum daylight condition, December represents the minimum daylight condition, while June represents the average daylight condition throughout the year. Since July occurs within the mid-year period following June, the outdoor illuminance levels are typically closer to the annual average range rather than the extreme maximum or minimum conditions. Conducting field measurements during this period, therefore, provides relatively stable daylight conditions with moderate variation in outdoor illuminance. This stability is important for daylight validation studies because it reduces extreme fluctuations in sky brightness and allows a more reliable comparison between measured daylight ratios (DR) and simulated daylight factors (DF). Consequently, selecting July as the fieldwork period supports the generation of representative daylight data that can be used to produce more consistent and reliable validation results. Nevertheless, if field measurements were conducted during March or December, when absolute illuminance levels may differ due to variations in solar position and sky conditions, the overall daylight distribution patterns and the validation relationship between measured and simulated results are expected to remain generally consistent.

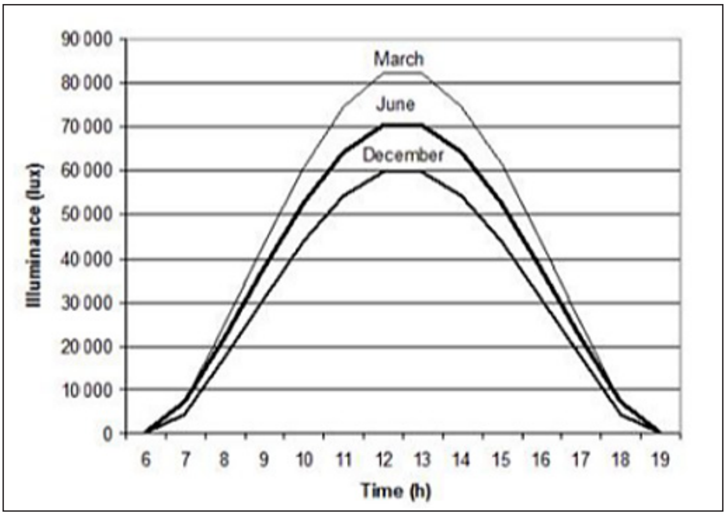
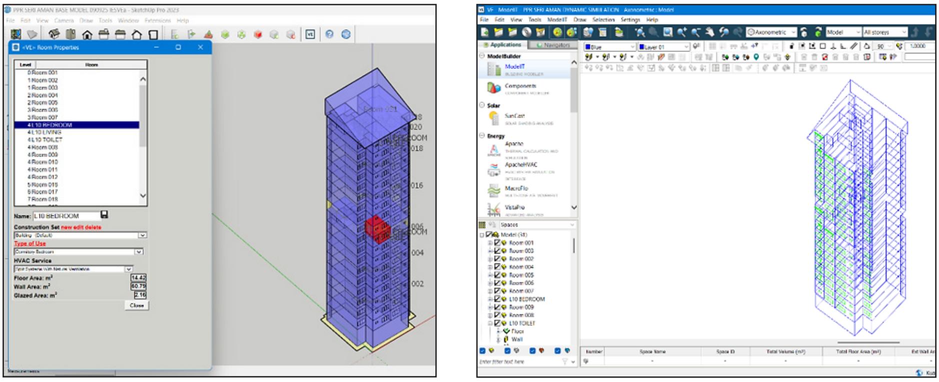


Figure 12. Monthly average hourly illuminance in March (maximum), June (average) and December (maximum)

Simulation Setup Integrated Environmental Solutions – Virtual Environment (IES-VE)

The case study buildings were generated using AutoCAD as shown in Figures 4 and 5, modelled in SketchUp, then exported to the IES-VE platform using the Radiance-IES module. Building geometry, unit layouts, wall finishes, and glazing specifications, as shown in Figure 13, were reconstructed based on architectural drawings and site plan layout. The building geometry was created in SketchUp and exported to IES-VE using the VE plug-in. During the export process, only fully enclosed spaces are recognised as "rooms" by IES-VE, which are automatically highlighted in blue within the SketchUp interface. Any incomplete geometry appears yellow and cannot be exported as a room, ensuring that only properly enclosed spaces are transferred to the simulation model. This process helps maintain geometric fidelity between SketchUp and IES-VE. After export, the room dimensions, wall thickness, and window openings were rechecked using IES-VE tools to confirm that the geometry matched the original SketchUp model before running the daylight simulation, as shown in Figure 13.

External obstructions were not explicitly incorporated into the digital model because the selected case study buildings have minimal surrounding obstruction conditions. The lower measurement level (approximately 24 m above ground, Level 8) is already above typical ground-level elements such as trees or small urban features. In addition, the selected PPR blocks are located with wide building setbacks and without adjacent high-rise buildings directly facing the measured façades, which minimises potential shading effects from surrounding structures. The façade design of the selected units also does not include balconies that could obstruct daylight penetration. Furthermore, the



Name: L10 BEDROOM

Construction Set: Building (Default)

Type of Use: Dormitory Bedroom

HVAC Service: Split Systems With Natural Ventilation

Floor Area: m² 14.42

Wall Area: m² 60.79

Glazed Area: m² 2.16

(a) (b)

Figure 13. a) Building modelling and b) export building to IES-VE

Table 4

Construction material of 3D model in IES-VE

Case Study	Orientation	Floor Area (m²)	Wall / Floor Finish	Wall/Floor Reflectance	Window Area (m²)	Glazing Visible Light Transmittance
1	East-West	19.62	Paint/cement Render	0.7/0.4	1.94	0.7
1a	East-West	19.62	Paint/cement Render	0.7/0.4	1.94	0.7
2	North-South	20.89	Paint/tiles	0.7/0.6	2.16	0.7
2a	North-South	20.89	Paint/tiles	0.7/0.6	2.16	0.7

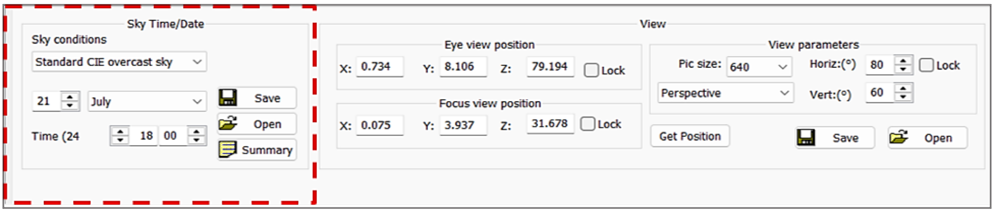
absence of significant external obstructions was verified through contextual elevation drawings generated using AutoCAD software based on actual site dimensions and building geometry. These technical drawings provided a reliable and accurate representation of the surrounding built environment and confirmed that no substantial neighbouring structures interfered with the daylight access to the selected units. Therefore, external obstruction was considered negligible for the purposes of both the field interpretation and the simulation model. However, the building orientation, window-to-wall ratio (WWR), glazing visible light transmittance (VLT), and external shading devices such as horizontal fins were carefully modelled to replicate the actual conditions of the case study buildings as shown in Table 4. The reflectance values as well as the glazing visible light transmittance used in the model were obtained from product catalogue references and Jabatan Kerja Raya (JKR) specifications and supplemented with default material properties from the IES-VE material library.

Kuala Lumpur, with a latitude of 3.13° and a longitude of 101.55°, is set to represent the tropical climate. The Kuala Lumpur (Subang) IWEC weather file in APlocate IES-VE was used, providing monthly climate data including sun path, direct solar flux, and sky illuminance distribution Figure 6. In Radiance-IES engine settings, WP Zone Data (Dynamic) is used with 0.75m WP Height and 0.25m WP grid as well as applying the rtrace_dc method, a high-resolution sky model (2305 sky patches), and 20% ground reflectance, while other parameters followed the standard Radiance-IES default configuration. The sky models were refined according to the recommendations of (Elsiana et al., 2023; Lim et al., 2017; Tsang et al., 2022; Wei et al., 2023), which are overcast and intermediate sky to ensure reliable daylight propagation and accurate light distribution within the interior spaces, as shown in Figure 14. They work uses for North-South is overcast sky, while for East-West is intermediate sky condition. The simulation settings, including date and time, were aligned with the corresponding fieldwork measurement periods to replicate the actual conditions and ensure accurate validation of the simulation model, as shown in Table 5.

The simulation generated outputs for illuminance levels (Lux) and Daylight Factor (DF), which were extracted at the same measurement points used during field surveys to enable direct comparison. This point-to-point comparison enables validation of the simulation results against the measured daylight conditions. The simulation framework in this research was designed to allow future extension with dynamic daylight metrics such as Useful Daylight Illuminance (UDI), Spatial Daylight Autonomy (sDA), and Annual Sunlight Exposure (ASE), which could provide a more comprehensive evaluation of daylight performance.

Table 5.
Summary of case study orientation, dates, time intervals, and applied sky conditions

Case Study	Orientation	Date	Time	Sky Condition
1	East-West	18/07/2025 and 21/07/2025	8.00 until 16.00 (1 hour interval)	Intermediate
1a	East-West	18/07/2025 and 21/07/2025	8.00 until 16.00 (1 hour interval)	Intermediate
2	North-South	18/07/2025 and 21/07/2025	8.00 until 16.00 (1 hour interval)	Overcast
2a	North-South	18/07/2025 and 21/07/2025	8.00 until 16.00 (1 hour interval)	Overcast



Sky Time/Date
Sky conditions: Standard CIE overcast sky
21 July
Time (24 18 00

View
Eye view position
X: 0.734 Y: 8.106 Z: 79.194 ☐ Lock
Focus view position
X: 0.075 Y: 3.937 Z: 31.678 ☐ Lock
View parameters
Pic size: 640
Perspective
Horiz:(°) 80 ☐ Lock
Vert:(°) 60

Figure 14. Simulation of dates, time intervals and applied sky conditions in IES-VE

CRITERIA OF ANALYSIS

A traditional static metric known as Daylight Factor (DF), a static daylight metric is used widely to calculate daylight performance in buildings. The calculation of DF uses the ratio of indoor illuminance over the outdoor illuminance under an overcast sky. However, in tropical regions like Malaysia, the use of DF to measure the daylight performance becomes a big constraint as the Malaysian sky conditions are very unpredictable. As noted by Lim et al. (2010) and further emphasised by Al-Ashwal et al. (2024) DF does not really capture the actual time-varying environmental influences, building orientation, or solar path variations. Thus, this study applied the use of Daylight Ratio (DR), which uses the ratio of actual indoor illuminance compared to actual outdoor illuminance values under actual sky conditions. This method, supported by the work (Al-Ashwal et al., 2024; Kalaimathy et al., 2023; Lim & Heng, 2016), gives a more accurate on-site measurement of daylight availability, which is relevant in tropical environments where the sky condition is variable. Equation 1 for DR is as follows:

$$DR = \frac{Indoor\ Illuminance\ (WPI)}{Outdoor\ Illuminance} \times 100 \qquad [1]$$

As for the IES-VE validation process, data gathered from fieldwork measurements were compared with IES-VE simulated data measurements. Both illuminance values and static daylight metrics are considered, with the Daylight Factor (DF) derived from IES-VE simulations and the Daylight Ratio (DR) obtained from fieldwork measurement was used as a basis for comparison. The comparison was undertaken because both DR and DF are dimensionless ratios that normalise indoor illuminance against outdoor illuminance, thereby reducing the influence of fluctuating absolute illuminance levels. Although DF is traditionally associated with the CIE overcast sky assumption, previous studies have demonstrated that DR can serve as a practical field-based equivalent for validating daylight simulation models under real conditions. In the present study, the IES-VE simulation was configured using an intermediate sky condition to replicate the prevailing sky conditions observed during the field measurement period. However, despite the flexibility of the sky model settings, the software continues to report the simulation output using the Daylight Factor (DF) terminology. Therefore, the purpose of the comparison was not to establish absolute equivalence between DR and DF, but rather to evaluate the consistency of daylight distribution patterns and relative daylight performance between measured and simulated conditions across the selected measurement points. Furthermore, (Elsiana et al., 2023b) demonstrated that the correlation between simulation and field measurement results based on DR and DF was strong, significant, and positive, supporting the use of these metrics for evaluating the consistency between measured and simulated daylight performance.

To ensure accuracy, the simulated measurement points are aligned with point of lux meter during fieldwork measurement, with reference height of 0.75 m above the floor level and corresponding room positions.

RESULTS AND DISCUSSION

Within the unit, the results show a reduction from the window point (T01) to the back of the dining room point (T03). The east- facing unit, which is Case Study 1, had reductions of daylight penetration from point T01 to T03 were 63.3% at the upper level and 52.2% for Case Study 1a, while for Case Study 2, which is a north-facing building, the reductions were 52.6% and 54.5% for Case Study 2a. As for the comparison between floor levels, the fieldwork result for Case Study 1 indicates that daylight at the window zone (T01) was 23.3% lower at the lower level, whereas in Case Study 2, the lower level recorded 13.6% lower values than the upper floor. These findings highlight both within-unit daylight loss with depth and indicate within-floor daylight inequity, varying by orientation, façade design, and window-to-wall ratio (WWR).

Next, the field measurement data and the IES-VE simulation outputs are analysed and compared to determine the percentage differences in accuracy and precision. The calculation of these differences follows Equation 2, as recommended by (Ab.Razak, 2023; Lim et al., 2010; Maamari et al., 2006).

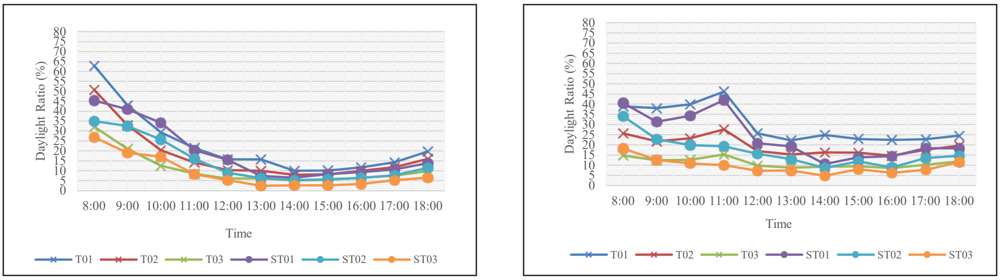
$$PD = \frac{(SM - FM)}{FM} \times 100 \qquad [2]$$

Where,
PD. Percentage Difference
SM. Simulation Measurement
FM. Fieldwork Measurement

Maamari et al. (2006) recommended that the acceptable percentage difference between field measurements and simulation results should range between 10% and 20%. This guideline is further supported by the validation of IES-VE studies conducted by Elsiana et al. (2023) who reported differences of 7% and 12% differential of DR in an office building. Heng et al. (2016) Also mention the DR is from 11% - 15% for light pipe performance in an office building. In this study, following the benchmark provided by these scholars, 20% maximum differences were allowed between fieldwork measurements and IES-VE simulations to confirm the reliability and suitability of the software for current and future applications.

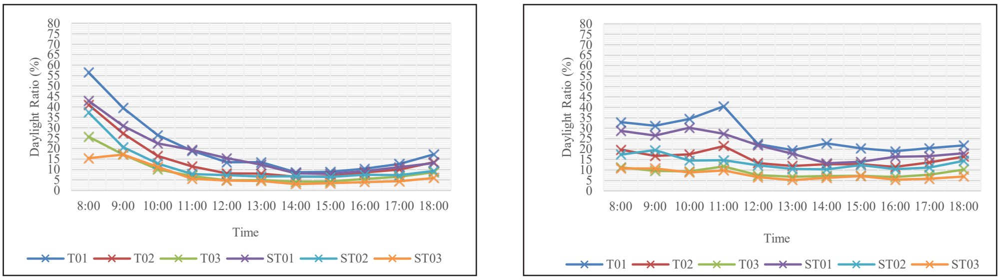
Within a two (2) day duration, from 8:00 a.m to 6:00 p.m, the average DR differences between field measurements and IES-VE simulations were compared. In Case Study 1, 18/07/2025 was selected as it showed the lowest lux condition compared to the other days. At points T01-T03 from fieldwork measurement, the average DR values ranged between 11-23%, while the corresponding IES-VE simulation results ranged between 9-19%.

The percentage differences (PD) recorded between fieldwork and simulation values for these points were 16% (T01), 18% (T02), and 20% (T03). Then, on 21/07/2025, where the highest lux condition was recorded, average DR values from field measurements ranged from 11-30%, compared to 10-24% from IES-VE simulations. The percentage differences (PD) were 20% (PD01), 15% (PD02), and 15% (PD03) as shown in Figure 15 and Table 6.



(a) Case study 1: 18/07/2025

(b) Case study 1: 21/07/2025



(c) Case study 1a: 18/07/2025

(d) Case study 1a: 21/07/2025

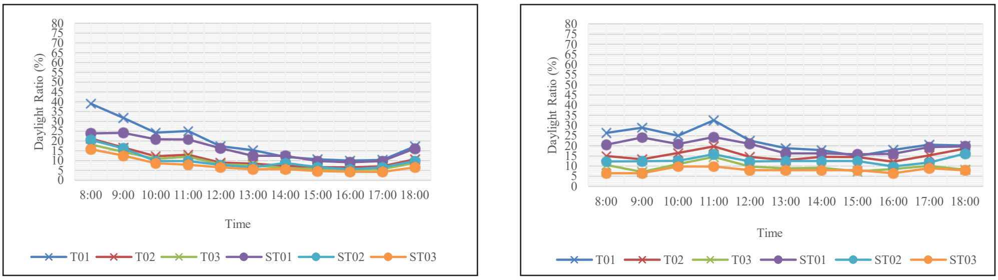
Figure 15. Daylight Ratio (DR) profiles for case study 1 and 1a, showing field measurements (T01-T03) and IES-VE simulations (ST01-ST03) at hourly intervals from 08:00 a.m. to 6:00 p.m.
Note. Data were collected at one-hour intervals to calculate the average daylight ratio (DR), which was then used for comparison between fieldwork measurements and IES-VE simulations

Table 6
Case study 1 and 1a: Average DR of fieldwork measurement and average DF of simulation in IES-VE, as well as the percentage differences

Date	Time	Fieldwork Measurement (FM) %			Simulated Measurement (SM) %			Percentage Different (PD) %		
Case Study 1		**T01**	**T02**	**T03**	**ST01**	**ST02**	**ST03**	**PD01**	**PD02**	**PD03**
18/07/25	08:00 a.m-06: 00 p.m.	30	20	11	24	17	10	20	15	15
21/07/25	08:00 a.m-06: 00 p.m.	23	17	11	19	15	9	16	18	20
Case Study 1a		**T01**	**T02**	**T03**	**ST01**	**ST02**	**ST03**	**PD01**	**PD02**	**PD03**
18/07/25	08:00 a.m-06: 00 p.m.	21	14	9	18	12	7	15	18	20
21/07/25	08:00 a.m-06: 00 p.m.	26	15	9	21	13	8	19	12	13

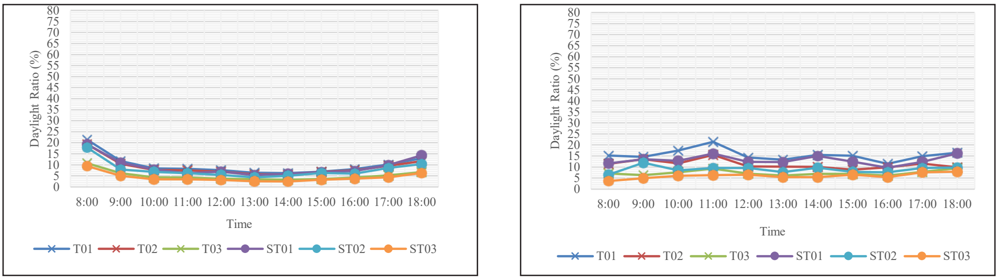
For Case Study 1a, on 18/07/2025, the average DR values obtained from field measurements at points T01-T03 ranged between 9-21%, while the corresponding IES-VE simulation results labelled as (ST01-ST03) ranged between 7-18%. The percentage differences recorded between field and simulation values for these points were 15% (T01), 18% (T02), and 20% (T03). On 21/07/2025, the average DR values from field measurements ranged from 9-26%, compared to 8-21% from IES-VE simulations. The corresponding percentage differences were 19% (PD01), 12% (PD02), and 13%(PD03) as shown in Figure 15 and Table 6.

For Case Study 2 and 2a, on 18/07/2025, the average DR values obtained from field measurements at points T01-T03 ranged between 9-19% for case study 2, while the average DR values obtained from field measurements at points T01-T03 ranged between 5-10% for case study 2a. The corresponding IES-VE simulation results ranged between 8-16% for case study 2, while for 2a, the range is between 4-9%. The percentage differences recorded between field and simulation values for these points were 17% (PD01), 9% (PD02), and 20% (PD03) for case study 2, while for case study 2a, the percentage differences were 7% (PD01), 14% (PD02), and 15% (PD03) as shown in Figure 16 and Table 7.



(a) Case study 2: 18/07/2025

(b) Case study 2: 21/07/2025



(c) Case study 2a :18/07/2025

(d) Case study 2a :21/07/2025

Figure 16. Daylight Ratio (DR) profiles for case study 1 and 1a, showing field measurements (T01-T03) and IES-VE simulations (ST01-ST03) at hourly intervals from 08:00 a.m. to 18:00 p.m.
Note. Data were collected at one-hour intervals to calculate the average daylight ratio (DR), which was then used for comparison between fieldwork measurements and IES-VE

Table 7

Case study 2 and 2a: Average DR of fieldwork measurement and average DF of simulation in IES-VE, as well as the percentage differences

Date	Time	Fieldwork Measurement (FM) %			Simulated Measurement (SM) %			Percentage Different (PD) %		
Case Study 2		**T01**	**T02**	**T03**	**ST01**	**ST02**	**ST03**	**PD01**	**PD02**	**PD03**
18/07/25	08:00 a.m-06: 00p.m.	19	11	9	16	10	8	17	9	20
21/07/25	08:00 a.m-06: 00p.m.	22	15	10	19	13	8	13	16	17
Case Study 2a		**T01**	**T02**	**T03**	**ST01**	**ST02**	**ST03**	**PD01**	**PD02**	**PD03**
18/07/25	08:00 a.m-06: 00p.m.	10	9	5	9	8	4	7	14	15
21/07/25	08:00 a.m-06: 00p.m.	15	11	7	13	9	6	15	20	19

On 21/07/2025, the average DR values obtained from field measurements at points T01-T03 ranged between 10-22% for case study 2, while average DR values obtained from field measurements at points T01-T03 ranged between 7-15% for case study 2a. The corresponding IES-VE simulation results ranged between 8-19% for case study 2, while for 2a, the range is between 6-13%. The percentage differences recorded between field and simulation values for these points were 13% (PD01), 16% (PD02), and 17% (PD03) for case study 2, while for case study 2a, the percentage differences were 15% (PD01), 20% (PD02), and 19% (PD03).

The results indicate that the IES-VE simulations were lower than the fieldwork measurement data, with average differences ranging from 15% to 20% across both test days. These differences show the range of ≤20% as recommended by (Elsiana et al., 2023; Heng et al., 2016; Maamari et al., 2006), therefore confirming the reliability of IES-VE accuracy in imitating daylight performance under tropical high-rise residential conditions. As for the sky condition to be applied in IES-VE simulation, the percentage difference (PD) provides a useful indicator for choosing the right sky condition, weather it is an intermediate or overcast sky. In this context, maintaining PD values below 20% ensures that the selected sky condition reflects actual tropical daylight patterns with acceptable accuracy.

Following the comparison between field measurements and IES-VE simulation results presented in the case study analysis, additional statistical indicators were calculated to further evaluate the agreement between measured and simulated daylight values. In addition to the percentage difference (PD) analysis, Mean Bias Error (MBE) and Root Mean Square Error (RMSE) were applied as statistical validation indicators to quantify the deviation between field measurements and simulation outputs. These indicators are widely used in building performance simulation validation studies to evaluate systematic error and the overall dispersion between measured and simulated datasets (Elsiana et al., 2023). The Mean Bias Error (MBE) represents the average tendency of the simulation model to either overestimate or underestimate the measured values, while the Root Mean Square Error (RMSE) represents the overall magnitude of deviation between simulated and measured values. Lower values of RMSE and MBE indicate stronger agreement between simulation predictions and field measurement results.

The equations used to calculate the statistical indicators are presented in Equations 3 and 4.

$$\mathrm{MBE} = \frac{1}{\mathrm{n}}\sum(\mathrm{SM} - \mathrm{FM}) \qquad [3]$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{\mathrm{n}}\sum(\mathrm{SM} - \mathrm{FM})^2} \qquad [4]$$

Where
SM = Simulation Measurement
FM = Fieldwork Measurement
n = number of observations

The calculated validation indicators for all investigated case studies are presented in Table 7.

The RMSE values range between 1.01% and 3.71%, while the MBE values range between –0.93% and –3.53%. These relatively small deviations indicate a strong agreement between the measured daylight ratio values obtained from field measurements and the daylight factor values generated from the IES-VE simulation. The negative MBE values indicate that the simulation model slightly underestimates the measured daylight ratios, although the magnitude of this deviation remains small. These findings demonstrate that the simulation model can reproduce the daylight distribution observed during field measurements with a high level of accuracy, as shown in Table 8.

Table 8
Statistical validation between field measurement and IES-VE simulation

Case Study	Level	Daylight Condition	MBE (%)	RMSE (%)
PPR IB (1)	L15	Lowest Lux (18/07/25)	-2.83	3.03
PPR IB (1)	L15	Highest Lux (21/07/25)	-3.53	3.71
PPR IB (1a)	L8	Lowest Lux (18/07/25)	-2.43	2.59
PPR IB (1a)	L8	Highest Lux (21/07/25)	-2.67	2.86
PPR SA (2)	L15	Lowest Lux (18/07/25)	-2.07	2.20
PPR SA (2)	L15	Highest Lux (21/07/25)	-2.27	2.41
PPR SA (2a)	L10	Lowest Lux (18/07/25)	-0.93	1.01
PPR SA (2a)	L10	Highest Lux (21/07/25)	-1.97	2.07

Furthermore, the correlation between the measured daylight ratio (DR) and the simulated daylight factor (DF) is illustrated in Figure 17. The scatter plot shows a strong positive linear relationship between simulation and measurement results with a coefficient of determination of $R^2 = 0.9917$, indicating excellent agreement between field measurements and simulation outputs.

CONCLUSION

The results from the fieldwork measurements indicate that daylight distribution within the investigated residential units is uneven across the two housing developments, namely PPR Intan Baiduri (represented by Case Study 1 and Case Study 1a) and PPR Seri Aman (represented by Case Study 2 and Case Study 2a). The findings demonstrate that daylight penetration in high-rise low-cost housing units is significantly influenced by building height, layout depth, and façade configuration. In all investigated units, the window zone (T01) received more than half of the available daylight compared to the rear zone (T03) located deeper within the living space. This pattern confirms that daylight intensity decreases progressively with distance from the façade opening.

When comparing the two residential developments, Case Study 1 and Case Study 1a (PPR Intan Baiduri) recorded higher daylight availability compared with Case Study 2 and Case Study 2a (PPR Seri Aman). This difference indicates that façade design and building orientation play an important role in determining the amount of daylight entering interior spaces in high-rise low-cost housing. In addition, comparisons between floor levels show that upper floors generally receive higher daylight levels than lower floors due to increased sky visibility and reduced external obstruction. Despite these variations, the overall pattern of daylight reduction from the window point (T01) toward the rear of the living room (T03) remains consistent across all case studies.

These findings highlight the significant influence of building height, layout depth, and façade design on daylight penetration and distribution in high-rise residential environments. By analysing these factors, this study provides empirical evidence of the actual daylight performance conditions in high-rise low-cost housing in Kuala Lumpur.

To simulate daylight performance, the Integrated Environmental Solutions – Virtual Environment (IES-VE) software was employed. Therefore, validating the accuracy of the simulation model is essential to ensure its reliability for future applications. In this study, the Daylight Ratio (DR) was adopted as the primary indicator to represent the relationship between indoor and outdoor illuminance under actual sky conditions. The comparison between field measurements and IES-VE simulations revealed relatively small deviations, with percentage differences ranging between 15% and 20%, which remain within the widely accepted validation threshold of $\leq$20% reported in previous daylight simulation studies.

Further statistical validation using Mean Bias Error (MBE) and Root Mean Square Error (RMSE) demonstrated small deviations between the measured and simulated datasets, with RMSE values ranging between 1.01% and 3.71% and MBE values between –0.93% and –3.53%. In addition, correlation analysis between the measured daylight ratio (DR) and the simulated daylight factor (DF) showed a very strong positive relationship with a coefficient of determination of $R^2 = 0.9917$. These results confirm that the IES-VE simulation model provides reliable predictions of daylight performance within the investigated residential units and is suitable for daylighting analysis in tropical high-rise residential buildings.

International guidelines such as the Illuminating Engineering Society of North America (IESNA) and the Malaysian Standard MS 2680:2017 recommend the use of advanced daylight performance metrics, including Useful Daylight Illuminance (UDI), Spatial Daylight Autonomy (sDA), and Annual Sunlight Exposure (ASE). These dynamic metrics are typically evaluated using Climate-Based Daylight Modelling (CBDM) approaches, which analyse daylight availability and glare potential over an entire year using real climate data. However, reliable application of these dynamic metrics requires prior validation of the simulation environment to ensure that model predictions accurately reflect real daylight behaviour.

Once the reliability of the IES-VE simulation model has been established and appropriate sky conditions for tropical contexts have been identified, the software can be applied to evaluate these advanced CBDM-based daylight metrics in future research. The integration of dynamic daylight analysis will allow a more comprehensive assessment of visual comfort, glare potential, and daylight performance in high-rise residential buildings.

Overall, this study contributes to the understanding of daylight performance in tropical high-rise low-cost housing by combining empirical field measurements with validated simulation modelling. The findings provide a reliable methodological framework for evaluating daylight performance in dense urban residential environments and offer useful insights for improving façade design strategies and visual comfort conditions in future high-rise housing developments in Kuala Lumpur.

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