Empirical Validation of Daylight Simulation Tool for a Test Office with Anidolic Daylighting System

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ABSTRACT

The use of simulation tools to evaluate the daylighting performances of building design attracts enormous interest for architects, engineers and researchers. Integrated Environmental Solution <Virtual Environment> (IES<VE>) is a software tool to daylighting design and analysis. It intends to simulate daylight in buildings and to predict illuminance. The aim of this research is to validate the IES software simulated results and results measured of scale physical model with installed Anidolic Daylighting System (ADS) in a building under real condition in a tropical area. Scaled model was constructed to be tested under real sky measurement. In additional, the same model was designed in the IES<VE> for measuring illuminance. Using this software to study in the ADS, it can be found that absolute work plane illuminance in the intermediate and overcast sky recorded mean difference from the measured results, with 4.6% and 3.8% respectively also DF results illustrated promising results with 4.5% in the overcast sky. However in sunny sky is illustrated high mean difference with relative error 57%, while the trend of these results is approximately similar but the luminance ratio results shown acceptable mean measurement in sunny sky with 2.8%. The simulation results prove that inside illuminance can be modeled with comparable accuracy for ADS under real sky conditions in the intermediate and overcast sky. For future study, validation of other parameters can be carried out such as the size of the ADS, window sizes, environment setting.

KEYWORDS: Emprical Validation. Daylight Simulation. Office building. Anidolic Daylighting System IES<VE> Software

1. INTRODUCTION

Reducing the energy especially artificial lighting load is a critical step towards sustainable and energy-efficient buildings. In office buildings are consuming more than 40% of the over electricity with artificial lighting and reduction of that is particularly notable in these places [1;2;3]. Preparing available daylight in building not only desirable for energy efficiency reasons, but also improves a healthy and comfortable environment for the occupants [4]. Windows on vertical façades provide the aperture for daylight, but that can only penetrate a limited distance from the windows. For designing higher and longer aperture to provide more daylight at the back of the room lead to an unavailable area in near of the window and increase of cooling load and solar glare.

Methods are detected to solve above problems include to employing some form of daylight systems to transfer daylight to deep areas of the building. The ADS has proven to perform well in a tropical area [5;6]. This system forms three principal parts that include the collector on the external side of the façade, the rectangular mirror, and distributor at the end of the duct [7].

Recently, the use and interest in daylight simulation tools are increased [8;9]. Simulation tools are the best opportunities for improving a building's energy performance before design, and these are feasible for predicting and improve the building daylight design [10].

IES (VE) is a software tool dedicated to analysis and daylighting design. It is proposed to simulate daylight transport in building and contribute professionals to predicting and providing daylight levels and also visualization of a space prior to understanding of the building design [11]. The critical question is whether IES (VE) software produces trustable simulations that users can be confident. To answer this question, the software capability of simulating the light transport, should be assessed in a real model way [12].

The IES (VE) energy analysis software tool tends high accuracy and interoperability with Building Information Modeling (BIM) tools. It is a software for integrated building performance analysis, providing tools for Thermal analysis, Lighting, Cost planning, Lifecycle, Airflow, in one integrated system. IES (VE) contains thermal, solar, lighting, energy costs, and heating/cooling load calculations [13].

A research comparing 20 different building simulation programs concluded that IES (VE) is one of the most complete simulation packages, with its wide range of interlinked modules, and its unrivaled ability to analyze the heating, lighting and ventilation in buildings. The study also reports that IES (VE) has been tested and verified by

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both CIBSE and ASHRAE [14]. It has been shown that the IES (VE) model is able to estimates and predictions to a reasonable level of accuracy in order to examining design changes. It is difficult to expect any model to provide perfect predictions, but through the comparison of model predictions and real measurements, a reliable level of the IES (VE) model estimates has been obtained [14].

The IES (VE) uses international commission on illumination (CIE) sky model for simulation in overcast skies and also intermediate sky and sunny sky. Sky model influences the distribution and amount of entrance illuminance. Thus, the accuracy of using CIE sky to simulate buildings in a tropical area is considerable [15;16].

In this paper, the accuracy of IES is validated. The test methodology is based on the comparison of simulation results to analytical reference model under real tropical area. Moreover, the daylight performance of the simulation tool carries out for various variables.

2. METHODOLOGY

The scale physical model was structured to be tested under real sky condition. The same model was designed in the IES software to performing daylighting simulation experiments. All items were measured under intermediate and overcast tropical sky conditions in Malaysia While orientation of them were in south orientation [17].

### 2.1 Experiment condition and procedure constructed

A room with a window was according to the geometry and characteristic of Malaysia office [18]. The physical model of an office building was built by using plywood with 1:10 scales (figure 1). As shown in figure 2, the geometric configurations include: aperture without glazing was built on the south external. The window-to-wall ratio (WWR) of the windows was 25% [15]. The test site was located on the floor of building in University Technologi Malaysia, Skudai, Johor, Malaysia. The same model configuration was designed in IES for simulation study (figure 3). The location used for the simulation was Johor Bahru in latitude 1 28'0" N and longitude 103 45'0" E [10].

Figure 1. Construction and Installation of scale physical model on selected site
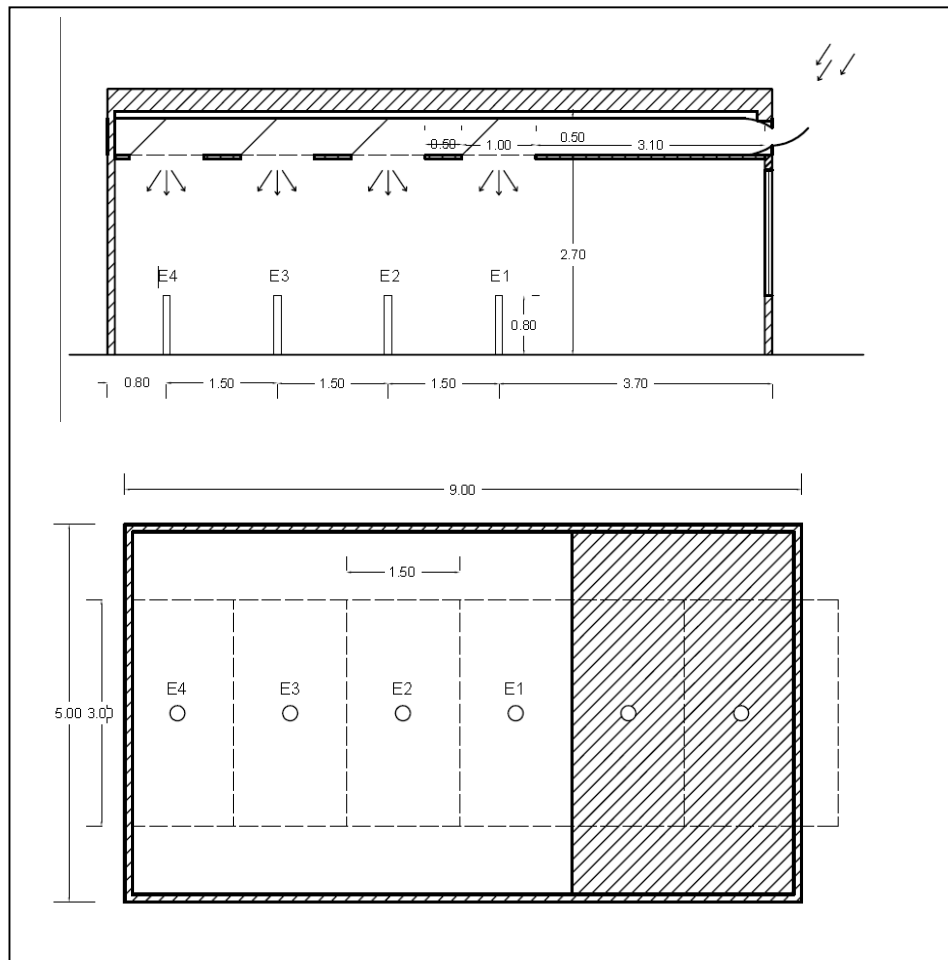
Figure 2. Geometrical configuration of model and the ADS device
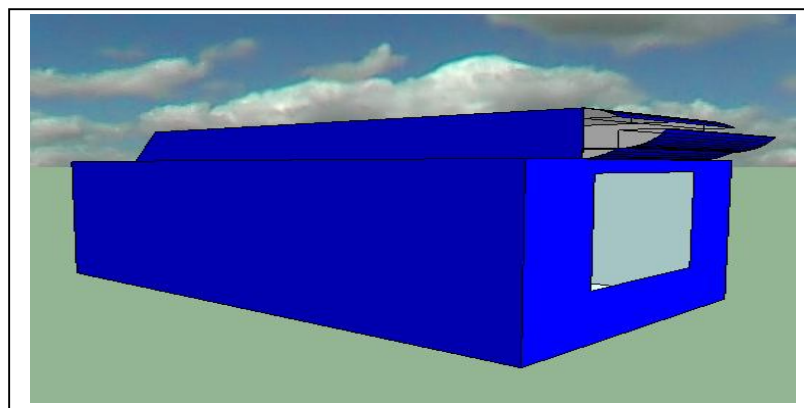
Figure 3. Model for computer simulation of IES software

2.2 Criteria of analysis

To validate the performance of the IES software were employed differences experimental:

a- External illuminance (Ee): it was measured and simulated for comparison in order to a clear view of the tropical sky and CIE sky characteristics.

b- Absolute Work Plan Illuminance (WIP): they were recorded and simulated at E1, E2, E3 and E4 for comparison as shown in figure 2. According to MS 1525:2007 [19] the recommended minimum absolute WPI for general office is 300 Lux.

c- DF: It is the ratio of interior illuminance on a horizontal surface (Ei) to the exterior illuminance on a horizontal surface (Ee). DF is employed only under an overcast sky.   DF=(Ei/Ee)*100

DF performance was accessed for quantitative analysis. Moreover, WPI uniformity and luminance ratio performances were evaluated for qualitative analysis. By using the external illuminance maximum 20000 Lux in tropical overcast, the optimum DF rang for tropical sky used in this model was from 1.5 to 2.5%. This benchmark is employed the MS 1525:2007 and GBI recommendation [19;20].

d- Test case: All tests summarized were shown in table 1. All tests were performed only on south orientation and were recorded every hour to compare the measured and simulation results.

Table 1 : Summary of test cases for field measurement and IES software

| Test case	Date	Time	Sky condition	Orientation
Absolute WPI (Sunny sky)	4 Mar 2013	10:00 - 10:10	Sunny	South
Absolute WPI (Intermediate sky)	4 Mar 2013	15:00 – 15:10	Intermediate	South
Absolute WPI (overcast)	4 Mar 2013	16:00- 16:10	Overcast	South
DF	4 Mar 2013	16:00- 16:10	Overcast	South
Luminance ratio	4 Mar 2013	10:00 - 10:10	Sunny	South
Luminance ratio	4 Mar 2013	15:00 – 15:10	Intermediate	South

2.3 The measurement

The measurements were performed on March 4 under Johor sky conditions for the period of the usual working hours from 09:00 until 17:00 with a time step of two minutes. The illuminance on the horizontal plane of the ambient space is recorded and also indoor illuminance of the model and in particular across the center of the model test on an axis perpendicular to the wall of in a plane representing the working surface with a height of 0.80m [21]. Four sensors were installed in the test case model at point E1, E2, E3 and E4, under the distributors of the light duct were located in 3.70m, 5.20m, 6.70m and 8.20m respectively. Illuminations were recorded in the interior of the test case model at points E1, E2, E3 and E4.Window produces optimum daylight in the building until 3.5 m from window wall [22].

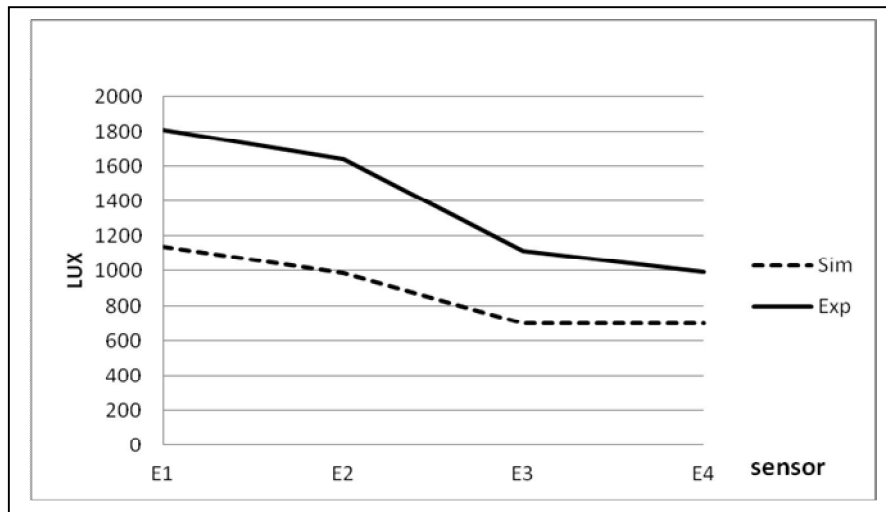## 3.   RESULT

3.1 Illuminance experiment

The illuminances were achieved both in the indoor of the scale models and the ambient environment. The variation of ambient illuminance during a typical day is shown figure 4. Data in different times were obtained an average of south orientation. It ranges from approximately 10Klux to 105Klux and obtains its maximum values during 11:00 until 14:00.
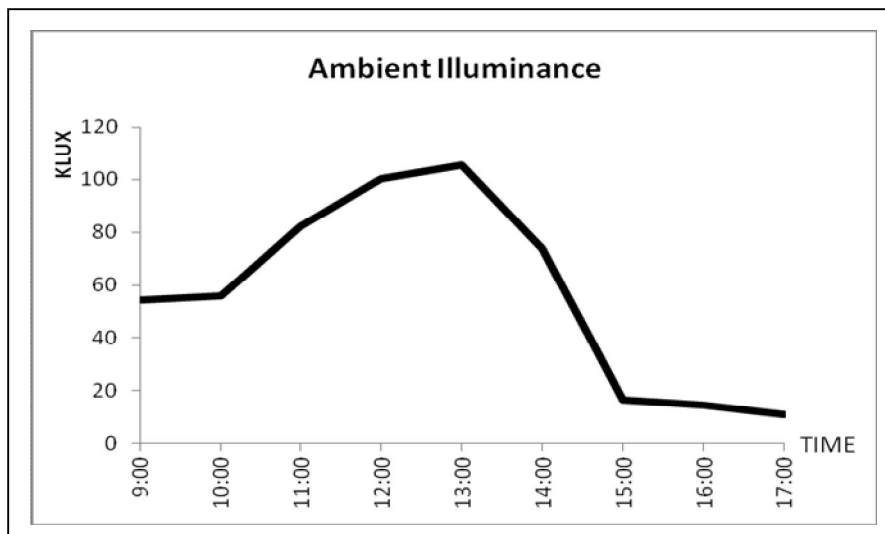

Figure 4. The average of illuminance variation a horizontal plane on the ambient environment during a typical day of the measurement period

3.2 WPI

The absolute WPI is influenced by external illuminance. As shown in figure 5, 6, 7, 8, 9 the measure results had performed in four points E1, E2, E3 and E4 with tree condition skies in the experimental process. Furthermore, the simulated results had fulfilled at equal date and external sky condition. These were performed with a sunny sky, an intermediate sky with the sun and standard CIE overcast sky in IES software. Tree condition was recommended that include in first the sunny sky at 10:00 AM in March while external illuminance was 55 Klux. In this condition simulated and experimental results are not same though the trend is similar between them and mean experimental result was 57% more than a mean simulated result that with changing external illuminance it was changed (figure 5). The Second was in the intermediate condition at 15:00 PM in March whereas illumination in outside was 16 Klux. The mean absolute WPI between experimental and simulation were 4.6% while outside illuminance influenced to this range (figure 6). The third was an overcast sky that it was measured at 16:00 PM in March with external illuminance 14 Klux. The mean absolute WPI of experimental and simulation results were 3.8% (figure 7).

Figure 5. Measured and simulated absolute WPI in the sunny sky
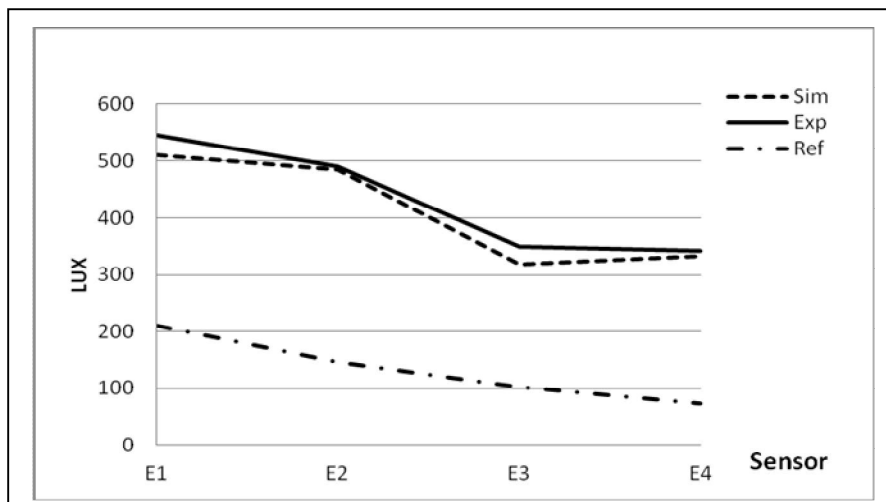

Figure 6. Measured and simulated absolute WPI in the intermediate sky
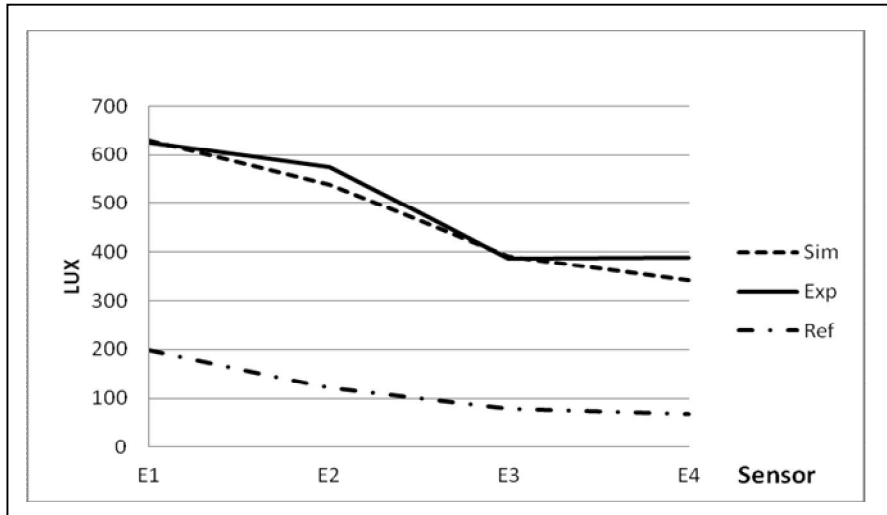
Figure 7. Measured and simulated absolute WPI in the overcast sky

3.3 DF

The simulated DF result and measured result are close together (figure 8). The lowest difference between simulations and experimental result was 0.4% while the highest difference was 13.7% higher, and the mean difference was 4.5%.
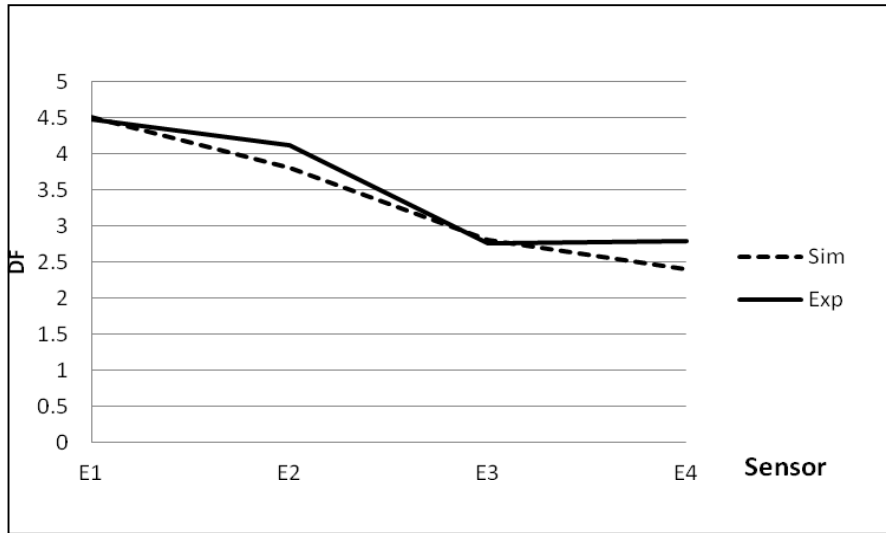
Figure 8. Measured and simulated DF in the overcast sky

3.4 Luminance Ratio

The difference between the simulated luminance ratio and experimented measured is shown. In according to the results, the mean differences were 2.8% while measurement external illuminance was 55 Klux in the sunny sky (figure 9) also, the mean differences were 1.5% while measurement external illuminance was 16 Klux in the intermediate sky (figure 10).
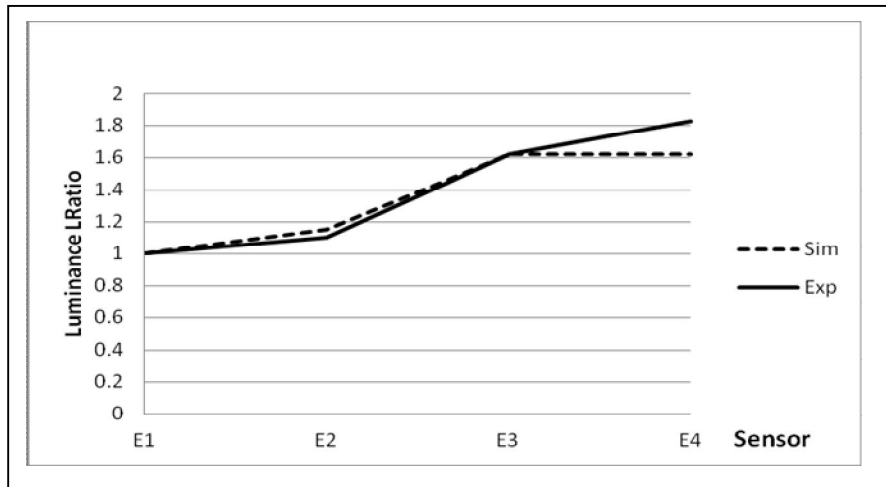
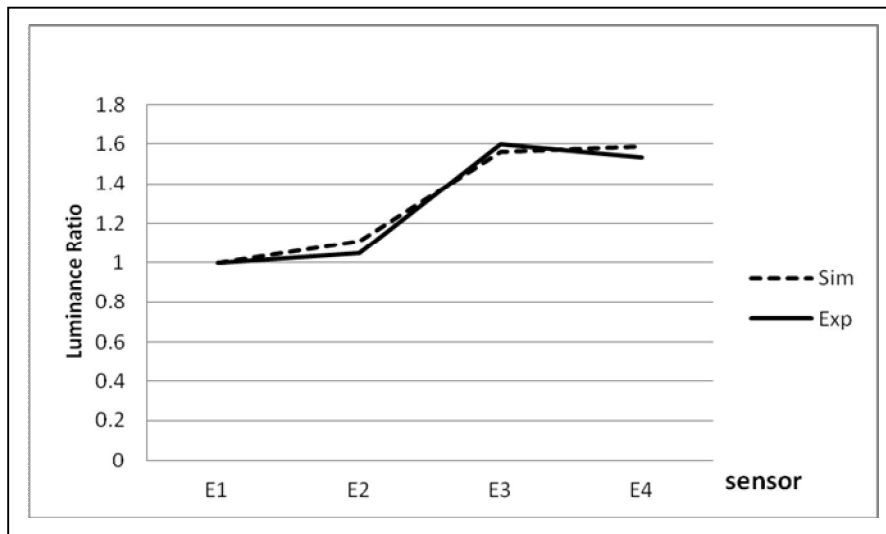**Figure 9.** Measured and simulated Luminance Ratio in the sunny sky

Figure 10. Measured and simulated Luminance Ratio in the intermediate sky

3.5 DISCUSSION

The differences of simulated results and measured results for various variables were summarized (table 2). The high mean differences between simulated and measured results are in absolute WPI in sunny condition with 57%. However absolute WPI in intermediate sky was 4.6%, but external illuminance influenced in this range although external illuminance in this experiment was 16klux. Results showed that the IES was unsuitable to use this simulation tool to predict internal illuminance in sunny and intermediate sky, while luminance ratio results showed more reliable and acceptable results in these sky conditions. Moreover the lowest differences were in absolute WPI and DF for overcast sky with 3.8 and 4.5% respectively.

Table 2 : Summary of the differences of simulated results from measured results

Criteria	Min (%)	Max (%)	Mean (%)	External illuminance (Klux)
Absolute WPI (Sunny sky)	41	59	57	55
Absolute WPI (Intermediate sky)	1.2	8.5	4.6	16
Absolute WPI (overcast sky)	0.6	12	3.8	14
DF (Overcast sky)	0.4	13.7	4.5	14
Luminance ratio (Sunny sky)	0	11.4	2.8	55
Luminance ratio (Intermediate sky)	0	5.7	1.5	16

According to previous research the hourly indices indicate that 85.6% of the time the sky is predominantly intermediate (2.3% intermediate overcast, 66.0% intermediate mean and 16.3% intermediate blue) and 14.0% overcast in Malaysia [15]. Since, clear sky is not applicable for tropical sky, it was not considered in this study as. The overcast sky was the worst condition for daylight availability hence it was base to measure and validate with DF and absolute WPI variables. Intermediate sky was chosen for work plane illuminance (WPI) and luminance ratio.

4.   CONCLUSION

In according to the results, the IES software in sunny condition was unable to predict internal illuminance. However, trends were similar and with increasing external illuminance, distance of simulation and experimental results raised. In additional, this software was promising to predict in the intermediate sky when external illuinance was approximately 14 Klux, whereas the average mean difference between the measured and simulated result was 4.6%. Therefore, by increasing external luminance in this sky condition the difference between them raised. Nevertheless, trend of both results was similar. Moreover, results in the overcast sky shown that the IES software was able to predict internal illuinance in building installed with the ADS due to the average mean difference between both results were 4.5. In additional, DF results illustrate better results via absolute WPI that it was 4.5; therefore, DF is a better choice to compare the performance daylight in the internal space. However absolute WPI is promising measure in tropical area under overcast conditions.

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