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# Capability of Computer Simulation Software for Predicting Average Daylight Factors in a Vertical Top-Light Atrium

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## ABSTRACT

Computer modelling have increased in daylight performance research over the past 20 years. A major disadvantage of the scale modelling technique is that it cannot predict the average performance of daylighting over an entire year. In this respect the lighting computer model simulations at the early design stages are very useful. The aim of this study was to validate the Radiance in IES <VE> (integrated Environmental Solution <Virtual Environment>) software to estimate the average daylight factor (ADF) in the adjacent spaces of a vertical top-lit atrium in tropical regions. To this end, a comparative analysis between average daylight factor (ADF) values obtained from Radiance simulation and physical scale model was carried out for different height of clerestory of four sided vertical top-lit atrium under overcast sky condition. Daylighting model was built using a physical scale model to be experiment under real sky conditions in Malaysia. The results of this research have indicated that the similarity between computer simulation result and scale model measurement is around 80% , it can be proved Radiance in IES < VE > has adequate validity to estimate the average daylight factor value in the atrium research. Thus, IES can be applied as an environmental design tool, to develop daylight research on atrium buildings in tropical regions.
**KEY WORDS**: Daylight, Computer simulation, Scale model , Vertical Top-lit Atrium, IES<VE> software

## 1. INTRODUCTION

Saving of energy is the most important factor in the large commercial building design, such as hotels, shopping malls and office headquarters. With reducing the resources of fossil fuel the price of energy has been increased day by day [1]. Therefore, Using daylight as part of an integrated and controlled lighting strategy is a key component of a sustainable, environmental approach to architectural design [2]. Daylight not only reducing energy consumption in the buildings, but also provides a healthy and enhancing visual performance for the users[3]. In the daylighting research, the most commonly used illuminance measurement is the Daylight Factor (DF). This method requires the use of the overcast sky model [4].

The use of daylight by an atrium is one of the best ways to enhance the energy efficiency and improve the indoor environment against external harsh conditions [5]. This form not only was energy efficient, but also was successful in organizing the adjoining spaces. Moreover, the atrium is a place for social activities with aesthetic and iconic features. But, The most important benefit of an atrium is in allowing natural daylight to penetrate into the core of a building [6-2]. Thus, the need for artificial lighting in the light box of atrium and its adjoining spaces is reduced and therefore energy is saved [7]. The importance of daylight in an atrium's environmental performance, has led to several investigations concerning atrium daylighting in the space of atrium and its adjoining spaces, since the 1980s [8-9].

Most of the previous studies on daylighting from atriums have been done in temperate climates. The atrium poses a challenge to architects designing for the hot and humid regions. In general, the major problem of the atrium in tropical regions is the conflict between the daylight and cooling loads. This problem causes by the large areas of glazing cover and large volume of the space [10]. In these regions, solar radiation penetrating through the large glazed envelope can severely worsen indoor thermal environment of a building during the occupied hours [11].

In tropical areas, it suggested by several researchers that the use of sidelight glazing (vertical or clerestory fenestration) is a good strategy to solve this problem. It avoids direct sunlight, minimize cooling load and daylight levels within the atrium floor space (Light Box) are generally sufficiently high [12-13], (Figure1). Physical characteristics of the investigated atrium in this research, which established upon previous literatures of Malaysian atrium office buildings, are based on local and vernacular architecture properties in tropical regions (Figure 2).

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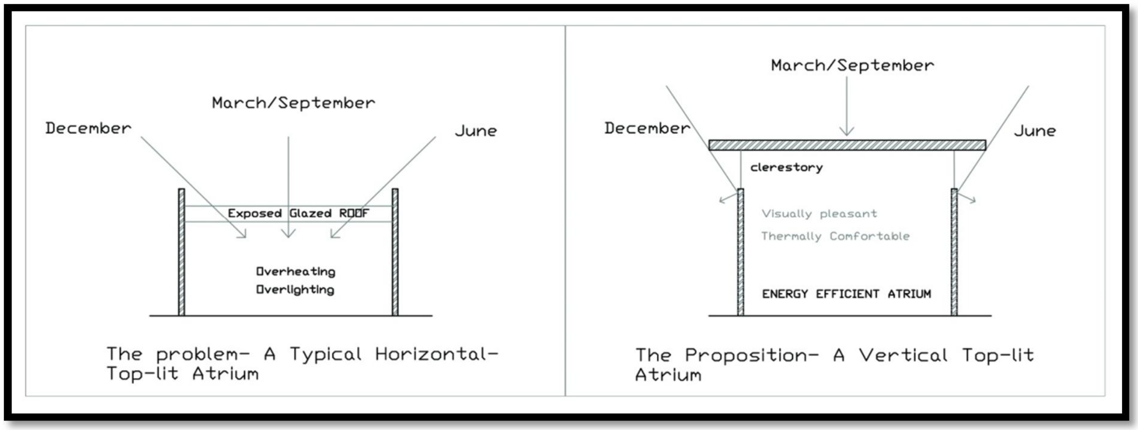



Figure 1: overheating and over lighting in tropical atrium

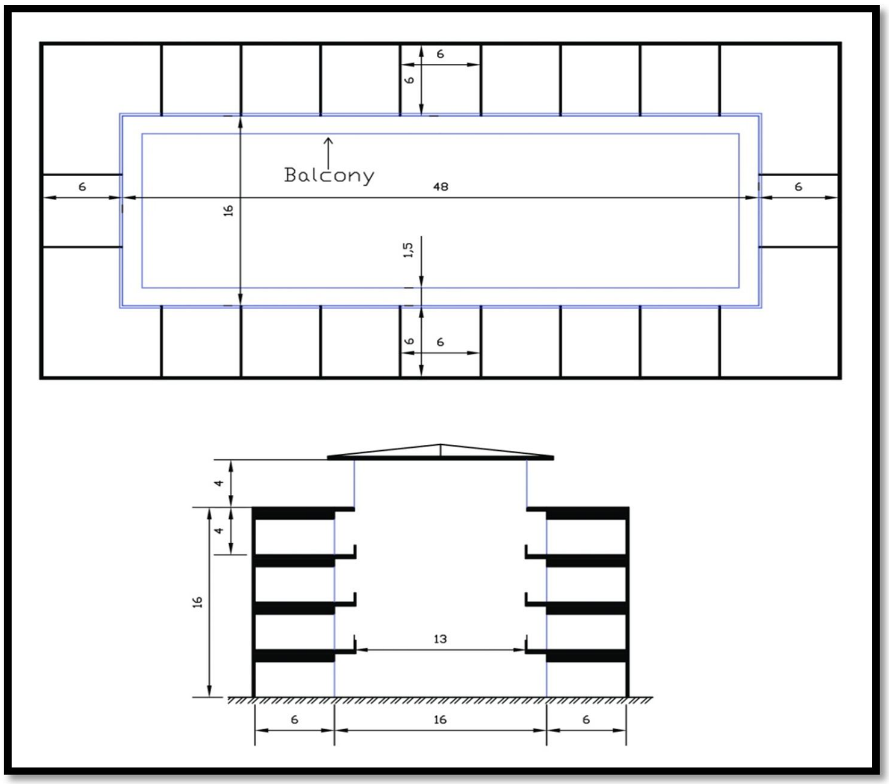



Fig 2:A central vertical top lighted atrium based on vernacular architecture in tropical regions

In general, the survey of previous studies, indicates that there are four methods, which are often applied in energy-related atrium research. They can take the form of actual building measurement, physical scale modelling measurement, simulation via computer modelling, simplified design and calculation tools, and a combination of any or all of these (table1). Each has its own advantages and limitations.

As it can be seen in the table (1), most of the researcher in the previous studies used of scale model method and computer modelling simulation to predict the daylight performance in the atrium buildings. The use of real atrium buildings as a research resource is much more limited, mainly for the some reason such as: access, high working environment and security [2]. Moreover, measurements are made of the real building which has already been built, the problem is that any improvements and corrections might involve alterations to the existing atriums which may not be feasible in construction or economic terms [14].

The use of computer in design and research is growing and becoming more popular as it is now designed to be more user friendly, cheaper and most importantly reliable . A major disadvantage of the scale modelling technique is that it cannot predict the average performance of daylighting over an entire year. In this respect the lighting computer model simulations at the early design stages are very useful [15].

Table 1- Research method in Previous Studies of Daylight Performance in the Atrium Buildings

| | **Author** | M. Szerman | MoradAtiff | Song Kyoo Dong | Hamdan Ahmad | Ibrahim Al-Turki | B.Calcagni | TalalAbdulrhman | SwinalSamant | Soon | AbdHalid Abdullah | Benson Lau | Ran Yi | Jiangtao | Gon Kim | Jiangtao | Jiangtao | JulittaYunus | Jiangtao | Jiangtao | SwinalSamant | SwinalSamant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Year** | 1992 | 1992 | 1993 | 1996 | 1997 | 2004 | 2004 | 2006 | 2006 | 2007 | 2008 | 2009 | 2009 | 2010 | 2010 | 2010 | 2011 | 2011 | 2011 | 2011 | 2011 |
| **Research Method** | **Real Building** | | | | * | | | | | | * | | * | | | | | | | | | |
| | **Scale Model** | * | * | * | | * | * | * | * | | | * | * | * | * | * | * | * | * | * | | * |
| | **Theoretical** | | * | * | | | | | * | | | | | * | | * | | | | * | | |
| | **Simulation** | | | | * | * | * | | * | * | * | | * | * | | * | * | * | * | * | * | * |

For applying a computer simulation tool, validation of simulation software should be evaluated. The performance of a simulation program tool can be considered by different methods of validations. Some researcher validated a computer simulation by method of comparative analysis between scale model measurements and computer simulation results.

IES<VE> (Integrated Environmental Solutions <Virtual Environment>) is a computer simulation tool which has ability to indicate the level of energy consumption in terms of daylight performance, heating and cooling loads. It can design a 3-D shape of a building with characteristics of its materials and elements [16].

Most of the previous study by IES <VE> validated this computer software in terms of energy performance in the buildings. Beevor (2010) by a comparative analysis between experimental measurements and IES predictions, found out the accuracy of IES results in terms of solar heat gain, cooling load and air temperature [17]. IES <VE>has been tested and validated by CIBSE and ASHRAE, it is prevalent and perfect with integration of analysis. A good level of confidence in the IES<VE> model results has been obtained through the comparison of model prediction against actual building measurements [18]. Leng, p. et al. (2012) investigated IES <VE> accuracy in terms of air temperature and humidity. Findings of this research have shown that IES has enough validity for calculating thermal and humidity analysis in a room [19].

IES have been using Radiance over a wide range of research projects for daylighting research. It is evident that computer lighting simulation software will progressively come to predominant in atrium buildings research over the next 20 years. Finding of research by Reinhart & Fitz (2006) on the use of daylight analysis in building design showed an increasing confidence in the accuracy of computer modelling and a developed use of such software, particularly Radiance [2]. Currently, with the development of computer technology, Radiance has become the most powerful package for simulating complex scenes and supplying realistic results [20].RADIANCE can be used in terms of predicting light levels, and also provide realistic pictures of the modelled building which can be useful for the evaluation of visual comfort [1].

Validation of Radiance for analyzing daylight in atria has been verified by several researchers. Aizlewood and et al. (1997) investigated a very important validation analysis for Radiance in an atrium light box with various geometric and surface reflectance. Finding of this research showed that, in a square atrium without roof glazing, Radiance simulations agreed well with experimental measurements[21] .Galasiu and Atif (2002), in a comparative analysis between measured data of a real atrium building and Radiance simulated have been found that, there is a more accurate correlation between Radiance and experiment results under various sky conditions [22].

When using Radiance as a computer simulation program, the ambient parameters settings are quite crucial for the accuracy of the ultimate simulated data. It has been recommended improper ambient parameters could create big errors and convergence testing is necessary for each different model [8].

However validity of Radiance simulation tools was verified by several researcher through different methods. But, validation of Radiance in IES<VE> in terms of daylight performance in atrium buildings has not been investigated until now. Therefore, present study aims to investigate the accuracy of Radiance in IES <VE> simulation program in terms of Average Daylight Factor (ADF) in a vernacular form of atrium (Vertical Top-lit Atrium) for Malaysia as a tropical region.

## 2. MATERIALS AND METHOD

### 2.1- Physical Scale Model Study:

For the scale model study, a model was made to the scale of 1:25 with the following characteristics(Figure 3):

The structure of the model was in polystyrene and was fixed stiff board. All internal surfaces of model were covered using white color cards with a reflectance value of about 85% .Whilst all external surfaces of the atrium model were covered with black sheets to avoid any light leak. Four sided rectangular atrium form with Plan Aspect Ratio (PAR) 1:3, and elongated along East-West axis. The average of Plan Aspect Ratio of the surveyed atriums in Malaysia was found to be 1:3 by Ahmad Ridzvan and et al.[23]. Therefore an atrium of 16 (m) width, 48 (m) length and 16 (m) height was constructed ( four-story). Adjacent spaces were also modelled of 6 (m) office depth, 6 (m) office width and 3 (m) height. Moreover there was a one meter zone for false ceiling and ceiling thickness. The width of balconies outside the office rooms was 1.5 (m). Window to Wall Ratio (WWR) for all adjacent spaces around atrium was considered 100%. The height of clerestory in this study was variable. Therefore 4 different heights were considered (2 m, 4 m, 6 m and 8 m height). Since this model was an energy efficient model for Malaysia, the use of shading device (overhang) above clerestory windows, as to be sufficient enough to block direct was necessary. Therefore in this model with different height of clerestory was used of overhang with different depth ; for clerestory of 2 m, 4 m, 6 m and 8 m height, the depth of the overhang was 1 m, 2 m, 3 m and 4 m, respectively). All experiments were conducted under real sky conditions in Malaysia. Equipment used in the experiments were 2 Photometers HD 2012.2 (range 0-200000 Lux) for measuring external and internal illuminance (Figure 3). The test site was located on the roof of the new faculty of Built Environment, university technology Malaysia.

Figure 3:Model for field measurement (left) - Photometers HD 2012.2 for measuring external and internal illuminance (right)

### 2.2- Computer Simulation Study:

The scale modelling methods have used by researchers to estimate daylight available in the atrium buildings. However, computer simulation techniques suggests more advantages with respect to complexity of the experiments compare to physical scale model. In this study, the computer simulation strategy focused on daylight simulation in the adjoining spaces of the vertical top-lit atrium in Malaysian office buildings. a comparative analysis between simulation results and scale model results indicated the level of validity of Radiance in IES <VE> program.

IES<VE> software is a system of integrated building analysis simulation tools, which can simulate large number of result include lighting, thermal, energy costs and heating-cooling load calculations within a building. Based on Doyle (2008) IES <VE> has a sufficient capability simulate daylight performance in the building [24]. IES have been using Radiance over a wide range of research projects for many years and to facilitate this work IES have integrated Radiance into the <Virtual Environment>. Radiance is a computer software package developed by the Lighting Systems Research Group at Lawrence Berkley Laboratory in California, USA. It was developed as a research tool to accurately calculate and predict the visible radiation within a space.

Validity of Radiance simulation tools were conducted in many previous studies. These investigations indicated that Radiance could achieve a good level of agreement when simulating typical daylight spaces and comparing with conventional techniques such as physical scale model and theoretical calculation. But, a few research have been done based on Radiance in IES <VE> (Integrated Environmental Solutions<Virtual Environment>). Therefore validation of Radiance in IES <VE> should be investigated in terms of daylight performance for using in atrium buildings. This research aimed to study the level of accuracy of IES<VE> software in terms of average day light factor and illuminance over the work plane in office spaces of a vertical top-lit atrium in the city of Johor Bahru in Malaysia, which is situated at 1.48° North and 103.73° East longitude. The sky condition was assumed to be overcast sky condition (10K CIE Overcast Sky)This type of sky was chosen as it represents a 'Worse Case' scenario for daylightig research. Intensity of daylight changes from 1000 to 30,000 lux, depending on the measure of overcast and solar altitude[25].

## 3. FINDING AND DISCUSSION

This paper is including two main stages: at first, it presented the results obtained from a physical scale model which has investigated the daylight factor (DF) value in the office rooms around the light box of atrium building with different height of the clerestory. Then, a validation analysis of Radiance simulation in IES <VE>was carried out by way of comparison between results from simulation and scale model measurements.

In respect to atrium model, the offices which located at the central of South and North side were considered in terms of daylight illuminance. The level of daylight factor (DF) on the work plan (0.85 cm) was investigated in the 9 points of each room at the each level (Figure4 ).Measurements were taken on February and March 2013 at the working hours 9:00until 11:00 Am on the roof of $B_{12}$ Built Environment faculty of University Technology Malaysia (UTM). Experiments were performed under real sky conditions, when the sky was overcast and the External Illuminances were the range between 15000 and 20000 Lux. Each set of reading was repeated four times and the average of the readings taken [27].

Three positions in the offices at each storey can be expressed by the lines A (75% of office depth to atrium light box), B (50% of office depth to atrium light box) and C (25% of office depth to atrium light box). All tested were shown in table(2). By summering these values and dividing by 3 it was possible to evaluate the average daylight factor (ADF) across the each office rooms of the atrium [27].

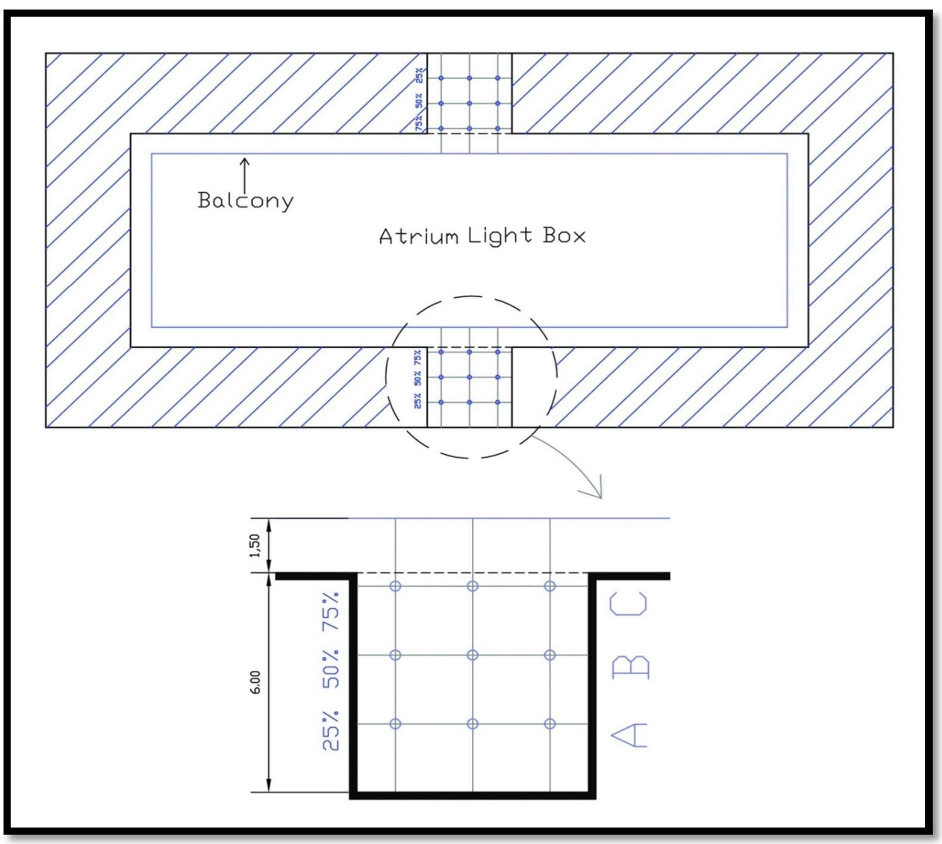



Figure 4:Measurement points in the South and North office rooms in the four-storey atrium model

Table 2: Average daylight factors in North and South rooms of atria with various height of clerestory (h) in the different positions.

| **h=2 M** | **North Facing Rooms** | | | **h=2 M** | **South Facing Rooms** | | |
|---|---|---|---|---|---|---|---|
| Position | A (25%) | B(50%) | C(75%) | **Position** | A (25%) | B(50%) | C(75%) |
| **3rd floor** | 0.74 | 0.90 | 1.07 | 3rd floor | 0.78 | 0.94 | 1.11 |
| **2nd floor** | 0.66 | 0.87 | 1.14 | 2nd floor | 0.7 | 0.94 | 1.36 |
| **1st floor** | 0.51 | 0.64 | 0.83 | 1st floor | 0.55 | 0.68 | 0.87 |
| **Ground floor** | 0.40 | 0.50 | 0.63 | Ground floor | 0.44 | 0.54 | 0.67 |
| **h=4 M** | **North Facing Rooms** | | | h=4 M | South Facing Rooms | | |
| Position | A (25%) | B(50%) | C(75%) | **Position** | A (25%) | B(50%) | C(75%) |
| **3rd floor** | 1.58 | 1.95 | 2.32 | 3rd floor | 1.57 | 1.95 | 2.24 |
| **2nd floor** | 1.21 | 1.54 | 1.88 | 2nd floor | 1.25 | 1.65 | 1.99 |
| **1st floor** | 0.98 | 1.15 | 1.32 | 1st floor | 1.05 | 1.24 | 1.52 |
| **Ground floor** | 0.55 | 0.77 | 1.27 | Ground floor | 0.55 | 0.75 | 1.37 |
| **h=6 M** | **North Facing Rooms** | | | h=6 M | South Facing Rooms | | |
| Position | A (25%) | B(50%) | C(75%) | **Position** | A (25%) | B(50%) | C(75%) |
| **3rd floor** | 2.21 | 2.74 | 3 | 3rd floor | 2.41 | 2.85 | 3.26 |
| **2nd floor** | 1.57 | 1.94 | 2.9 | 2nd floor | 1.64 | 1.99 | 3.04 |
| **1st floor** | 1.25 | 1.53 | 1.82 | 1st floor | 1.28 | 1.60 | 2.00 |
| **Ground floor** | 0.98 | 1.24 | 1.73 | Ground floor | 0.98 | 1.25 | 1.77 |
| **h=8 M** | **North Facing Rooms** | | | h=8 M | South Facing Rooms | | |
| Position | A (25%) | B(50%) | C(75%) | **Position** | A (25%) | B(50%) | C(75%) |
| **3rd floor** | 1.99 | 2.70 | 3.2 | 3rd floor | 2.1 | 2.80 | 3.48 |
| **2nd floor** | 1.96 | 2.46 | 3.15 | 2nd floor | 1.98 | 2.48 | 3.26 |
| **1st floor** | 1.52 | 1.91 | 2.42 | 1st floor | 1.59 | 2.02 | 2.51 |
| **Ground floor** | 1.10 | 1.40 | 1.82 | Ground floor | 1.15 | 1.48 | 1.90 |

The same physical model configurations were modelled in IES <VE> (Figure 5). The 3D geometric model was created within the <VE> using Model IT, then this model was transferred into Radiance IES. All physical model properties were simulated for the 3D model, such as location and site data, sky conditions, surface reflectance and etc. The level of quality for simulating was set on "High" degree. The average daylight factor (ADF) on the work plane in the office rooms at the each level was simulated by Radiance. Table (3) shows all results from Radiance in IES <VE>for models with different height of clerestory. For the four types of model the absolute relative divergences between simulation and measurement were:

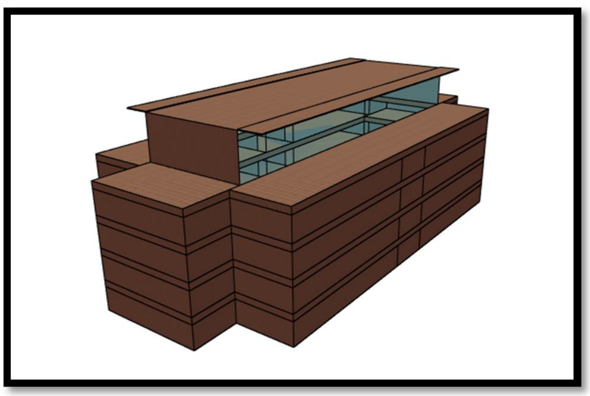


Figure 5: Simulated model using Model IT in IES <VE>

Table 3: Measured and simulated Average Daylight Factors (ADF) in the different level of North and South facing rooms

| **ADF** | **h=2** | | | | **h=4** | | | | **h=6** | | | | **h=8** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Simulation** | | **Measurement** | | **Simulation** | | **Measurement** | | **Simulation** | | **Measurement** | | **Simulation** | | **Measurement** | |
| | North | South | North | South | North | South | North | South | North | South | North | South | North | South | North | South |
| **3RD** | 0.62 | 0.6 | 0.90 | 0.94 | 1.52 | 1.52 | 1.95 | 1.92 | 2.32 | 2.33 | 2.65 | 2.84 | 2.99 | 3 | 2.63 | 2.79 |
| **2ND** | 0.73 | 0.71 | 0.89 | 1.00 | 1.48 | 1.5 | 1.54 | 1.63 | 2.08 | 2.09 | 2.14 | 2.22 | 2.55 | 2.57 | 2.52 | 2.57 |
| **1ST** | 0.48 | 0.48 | 0.66 | 0.70 | 0.99 | 0.99 | 1.15 | 1.27 | 1.39 | 1.37 | 1.53 | 1.63 | 1.72 | 1.72 | 1.95 | 2.04 |
| **G** | 0.31 | 0.31 | 0.51 | 0.55 | 0.56 | 0.57 | 0.86 | 0.89 | 0.82 | 0.81 | 1.32 | 1.33 | 1.04 | 1.03 | 1.44 | 1.51 |

**1- Office rooms, which located in side of North facing (Figure 6):**

**-** For model with 2 m height of clerestory, the level of divergence in the ground floor was 39%, first floor 27%, second floor 18% and third floor 31%. Total divergence between simulation and experiment for (h=2) was 28.75%.

- For model with 4 m height of clerestory, the level of divergence in the ground floor was 35%, first floor 14%, second floor 4% and third floor 22%. Total divergence between simulation and experiment for (h=4) was 18.75%

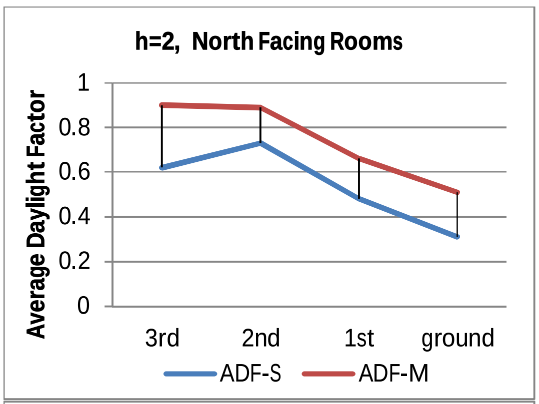
- For model with 6 m height of clerestory, the level of divergence in the ground floor was 38%, first floor 9%, second floor 3% and third floor 12%. Total divergence between simulation and experiment for (h=6) was 15.5%.

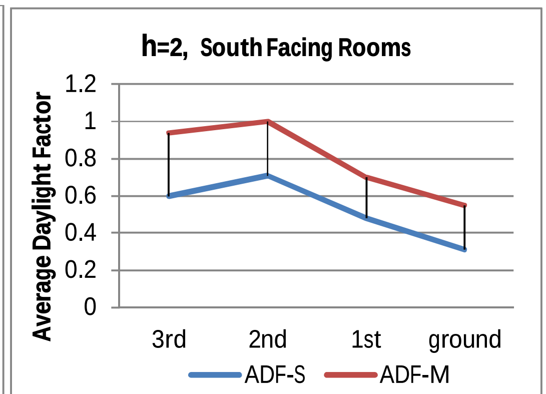
- For model with 8 m height of clerestory, the level of divergence in the ground floor was 28%, first floor 12%, second floor 1% and third floor 12%. Total divergence between simulation and experiment for (h=8) was 13.25%.

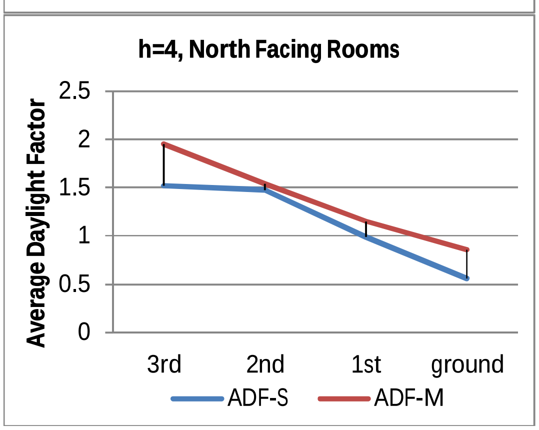
Table (4) shows that the least similarity between measurement and simulation results in north facing offices was on the ground floor (65%), whilst, the most similarity was on second floor (93.5%). Totally the average of similarity between simulation and scale model in the north facing offices for all models was 81%.

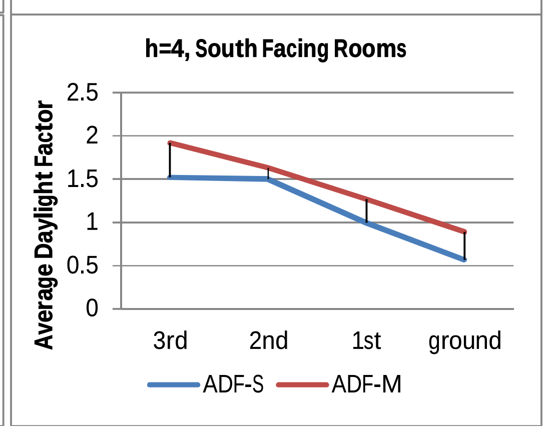
Table 4: Level of similarity between simulation and measurement results in north facing office rooms

| North Facing | h=2 | h=4 | h=6 | h=8 | Total (in terms of positions) |
|---|---|---|---|---|---|
| **3RD** | 69% | 78% | 88% | 88% | 80.75% |
| **2ND** | 82% | 96% | 97% | 99% | 93.5% |
| **1ST** | 73% | 86% | 91% | 88% | 84.5% |
| **Ground** | 61% | 65% | 62% | 72% | 65% |
| **Total (in terms of h value)** | 71.25% | 81.25% | 84.5% | 86.75% | |
| **TOTAL** | | | **81%** | | |



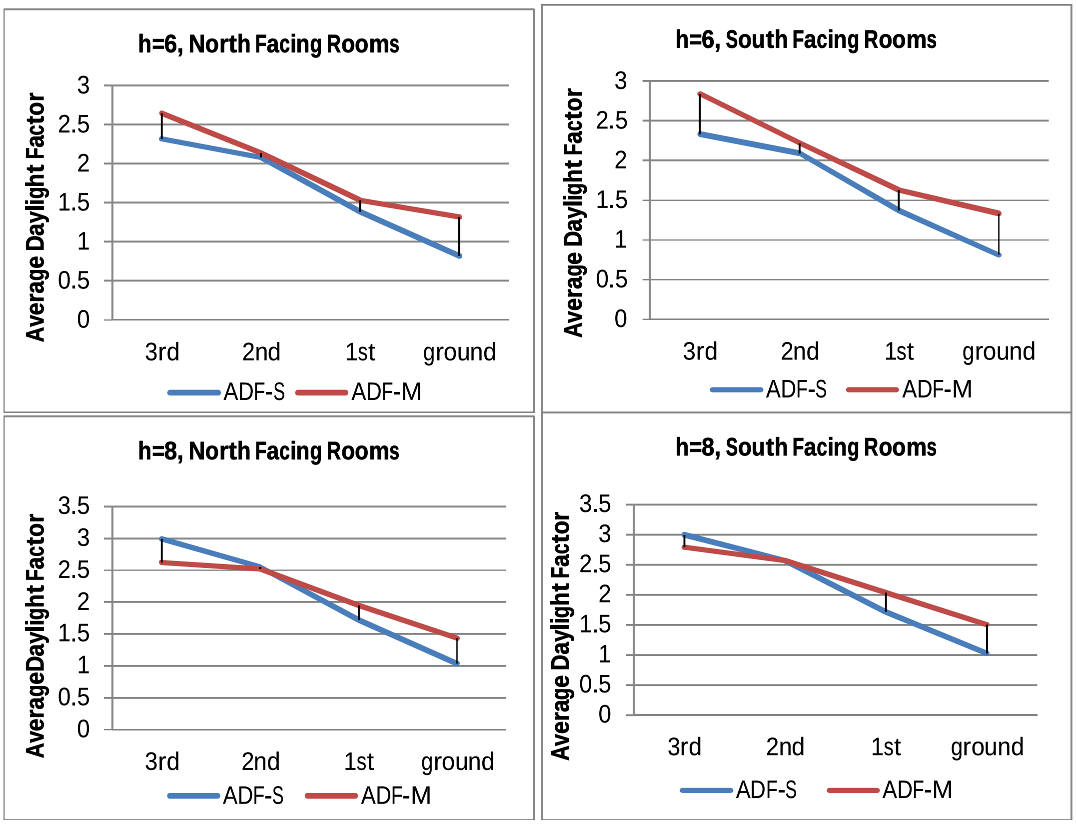



Figure 6: the level of divergence between average daylight factor simulations (ADF-S) and measurements (ADF-M) in the North and South facing rooms of various height of clerestories (h) in different levels.

**2- Office rooms, which located in side of south facing (Figure6):**

**-** For model with 2 m height of clerestory, the level of divergence in the ground floor was 44%, first floor 31%, second floor 29% and third floor 36%. Total divergence between simulation and experiment for (h=2) was 35%.

**-** For model with 4 m height of clerestory, the level of divergence in the ground floor was 36%, first floor 22%, second floor 8% and third floor 21%. Total divergence between simulation and experiment for (h=4) was 21.75%

**-** For model with 6 m height of clerestory, the level of divergence in the ground floor was 39%, first floor 16%, second floor 6% and third floor 18%. Total divergence between simulation and experiment for (h=6) was 19.75%.

**-** For model with 8 m height of clerestory, the level of divergence in the ground floor was 32%, first floor 16%, second floor 0% and third floor 7%. Total divergence between simulation and experiment for (h=8) was 13.75%.

Table (5) shows that the least similarity between measurement and simulation results in south facing offices was on the ground floor (62.25%), whilst, the most similarity was on the second floor (89.25%).Totally the average of similarity between simulation and scale model in the south facing offices for all models was 78%.

Table 5: Level of similarity between simulation and measurement results in south facing office rooms

| South Facing | h=2 | h=4 | h=6 | h=8 | Total (in terms of positions) |
|---|---|---|---|---|---|
| 3RD | 64% | 79% | 82% | 93% | 79.5% |
| 2ND | 71% | 92% | 94% | 100% | 89.25% |
| 1ST | 69% | 78% | 84% | 84% | 78.75% |
| Ground | 56% | 64% | 61% | 68% | 62.25% |
| Total (in terms of h value) | 65% | 78.25% | 80.25% | 86.25% | |
| TOTAL | | | 78% | | |

Figure 6 shows that, when the height of clerestory (h) is increasing, the level of divergence between scale model measurements (M) and simulation results (S) in both of the South and North facing rooms will decrease.

In addition, it shows the level of convergence between experimental and simulation results in the second floor is the most for all office rooms in this research, while the level of divergence occurred in office rooms which located on the ground floors,

According to comparisons at the working plan of adjoining spaces around the atrium light box, the simulation displayed a good similar variation of an average daylight factor (ADF) to the measurement in the physical model of the atrium. Radiance in IES <VE> can perform on precise result in the process of simulating average daylight factor on the adjoining spaces of vertical top-lit atrium in tropical regions.

The divergence between simulation and scale model measurements in the study are due to two main reasons:

1- Experimental errors: some errors may happen in the experiment process, such as reading errors and speed changing brightness in the real sky. Even the reflectance value of the surrounding environment may affect the daylight performance [3].

2- Photometric errors: a number of materials with various photometric characteristics were applied in the physical scale model, which produce much more complex light attenuation. Also it is very difficult to reproduce exactly the same reflectance and other material characteristics in IES <VE> as in physical model. In addition previous studies indicated that simulation of atrium buildings with a higher reflectance underestimates the measuring data [27]. In this study the reflectance of the surfaces in the physical model were very high (white color, 85%).

## 4. CONCLUSION

Present study carried out a comparative analysis for validation of a daylight simulation tool (Radiance in IES<VE>) for prediction of average daylight factors in a vertical Top lighted atrium under overcast sky condition of Malaysia.

The level of similarity between experimental measurements and computer simulation results was 80%.It can be concluded that Radiance in IES has a good validity for predicting the level of illuminance in terms of Average Daylight Factor (ADF) in adjacent spaces of vertical top-lit atrium. Some experimental and photometric errors affect on the accuracy of the performance in this research include reflectance value of the surrounding environment, speed changing of the sky illuminance and various reflectance of materials which applied in the physical scale model.

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