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Research Article

Validating integrated environmental solutions software for air temperature of a typical Malaysian recessed wall façade office building

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Abstract

Technological advances have assisted in the development of modern software tools which can be used to assess and improve the energy efficiency of a building at the early stage of conceptual design. However, this study aims at validating the accuracy of one of the paramount building simulation software Integrated Environmental Solutions - Virtual Environment (IES-VE), widely used today. The methodology of this study involves physical measurements and simulation exercises. A longitudinal physical measurement was carried out using HOBO ware U-12 in 5 different points of the room space from 18th October to 4th December 2016. But, for validation, a critical atmospheric day (21st November 2016) was selected for the comparison. The room air temperature was first measured before comparing it to the simulated air temperature obtained from IES<VE>. After several analyses, the comparison of the measured room air temperature and simulation results showed similarity, discrepancy, closeness, significance, and accuracy. The investigation findings revealed a percentage discrepancy of 11.03%, which is less than the threshold of 20% between the measured and simulated air temperature of the case study model. Other findings show that: R2 = 0.98, MBE = 0.8, °C and RMSE = 1.70°C are all within the acceptable values of significance between the two data. These results signify that IES-VE is valid, accurate, and applicable for this study's further Building Performance Simulation (BPS).

Introduction

Software for energy simulations is progressively used to analyze the energy performance of buildings and the thermal comfort of the dwellers. Currently, building performance simulation programs with various user interfaces and diverse simulation engines have the capability of these analyses. Given the important variety of such simulation tools, it is crucial to understand the limitations of the software tools and the complexity of such simulations [1]. The reliability of data exchange and straightforward, user-friendly interfaces are major aspects of the practical usage of these tools [2]. Due to the high amount of data to be inputted and rich Three-Dimensional (3D) geometry, making engines, efficient data exchange with software interfaces is vital to enable the quick and reliable performance of the simulation tools [1].

In the last twenty years, architects have become more

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involved in building performance tools after it was only limited to HVAC engineers, researchers, building scientists, and experts. There is multiple building simulation software in the market, which has been developing rapidly to enhance more technical, flexible, and accurate options. Referring to a study done by [3,4], ten building performance simulation tools were compared, in addition to a survey for different parties working closely in the building design was performed.

However, most architects declared that their choice of the appropriate software is made significantly according to the integration of other inputs from related databases and how user-friendly interface the software is. The ten simulation tools were IES-VE, ECOTECT, Energy Plus, DOE-2, Green Building Studio, eQUEST, Energy Plus-SketchUp Plugin, and HEED. Recently, the familiarity of using these tools has been growing rapidly after their ability to integrate programs to them. These include AutoCAD, BIM tools (such as Revit architecture), and integrating data from global standards, such as; LEED and ASHRAE standards, which helped implement integrated design processes by involving architects, engineers, and other disciplines involved in the construction process.

The survey results showed that the most "Architect Friendly" software are IES-VE, eQUEST and HEED in descending order, respectively (Attia, 2013). IES-VE was strongly recommended for its effectiveness in all design stages, starting from the concept to the detailed design. It is also based on thermal templates, which allow easy input and modification of parameters. HEED is very useful in comparing several designs together, plus providing guidelines for diverse climates. As for eQUEST, it has a lot in common with IES-VE regarding the ability to simulate different types of systems. However, it is a bit inflexible when dealing with innovative and intelligent building systems. The next category of simulation tools includes ECOTECT, DB, GBS, and E10, which are familiar for being simple simulation tools. However, the disadvantage of using those tools is that they can't integrate other programs' architectural features, which is incompatible with a complete architectural design stages process. The last category includes EPSU, EP, and DOE-2, which are restricted to dealing with very simple building models.

Therefore, the selection of the simulation software has been decided according to some values. For instance, the ability to integrate valid weather data, have a friendly user interface, the flexibility to perform different types of simulations, import materials and thermal data, its popularity in the market, and provide accurate and reliable results [5-9].

The purpose of this research is to evaluate the capabilities of the IES<VE> in furtherance to building performance simulation of a typically recessed wall façade of room space. The conduct of the evaluation will be from the comparison between the result of field measurement and the result of the simulation model of the same building.

The choice for selecting IES-VE simulation software

Fifty 50 years ago, a wide multiplicity of building energy simulation software was developed, improved, and used throughout the building energy simulation community. These building energy simulation software have different features and capabilities such as general geometry modeling, internal zone loads, building envelope properties, daylighting and solar, infiltration [1]. Similarly, ventilation and multi-zone airflow; renewable energy systems; electrical systems and equipment; HVAC systems; HVAC equipment; environmental emissions; economic evaluation; climate data availability, results reporting, and validation [1], among others. Nearly all energy analysis tools targeted mechanical engineers and code, compliance specialists. Architects need tools that provide a qualitative response in an extremely graphical form to illustrate to the clients.

Software tools that incorporate graphical output with context-sensitive guidance are probable to have the best appeal for building designers. On the other hand, architects require software tools that can be used in the conceptual design phase, when little is known about the building, in addition to the final design stages, when most project details have been finalized [1]. Software, like IES<VE> that has a simplified model builder with various application modules such as:

a) Model IT which is for the creation and editing of building geometries

b) ApacheCalc for analysis of loads

c) ApacheSim, which is for analysis of thermal quality

d) MacroFlo module, which is for airflow and natural ventilation application

e) Apache HVAC component for HVAC analysis

f) SunCast for shading analysis and visualization

g) MicroFlo for computational fluid dynamics(CFD) 3D

h) FlucsPro/Radiance for lighting design and investigations

i) DEFT for model optimization

j) LifeCycle module for cost analysis and life-cycle energy and finally,

k) Simulex module for emergency and building evacuation, mostly for a fire outbreak.

[10] studied thirteen (13) simulation software and rated IES-VE third among them, as shown in Figure 1. Therefore, IES-VE has detailed simulation tools with one of the most prospective to meet these several necessities at various design development phases.

Some programs are conceptualized for specific building components like the wall, roof, building shape, form, and openings. Similarly, software tools are precisely used for one or more parameters like lighting, heat transfer, wind, and shade. When a building is modeled for the same climate in different simulation programs, the performance of the building presented as the result of the simulation run is predictable to be the same. However, in reality, they show a difference in

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output. Hence, there is a need to compare output and analyze the discrepancy by percent.

The case study building and the room geometry

The case study building is the international students' center (ISC) office building in Universiti Teknologi Malaysia Skudai Johor-Bahru, the capital of Johor Darul Takzim (JDT) in Malaysia located at Latitude 1.56°N and Longitude 103.64°E (Figure 2) with the total covered area of 583.20m2. The experimental office room is a small office room with an operable single-sided window located at the third level of the ISC building with a floor area of 17.80m2. The test room facade is oriented towards S360W measured using a portable handheld compass. The building is a typical vertical recessed wall façade with a recessed depth of 0.60m with an equal total area of the bared wall and a recessed wall of 6.40m2 each. The calculated window recessed-wall ratio (WRWR) is 31.20%, as the wall height is 3.60m.

The ISC building is located at the South East of Universiti Teknologi Malaysia Johor Bahru Campus, surrounded by the fine green of low grasses with dotted trees far around it and facing the 24-number capacity chipping-fill car parking square. The 3 level ISC building is a typical post and beam concrete structure building painted with off-white and milk color. The roofing material is corrugated clay tiles. The building comprises offices meant for international students' affairs. It also houses an open hall where visa applications are processed for students, a general store, and an office for each country's international students' Society (ISS).

Each room has a ceiling covered with a 2ft x 4ft mineral fiber ceiling board. The case study room window encompasses a primary wooden frame and a secondary glass iron frame side hung in Figure 3. The window has an overhead louver window of 0.5m×1.8m, possibly for ventilation and daylight, with a side-by-side fixed glass window for natural lighting in Figure

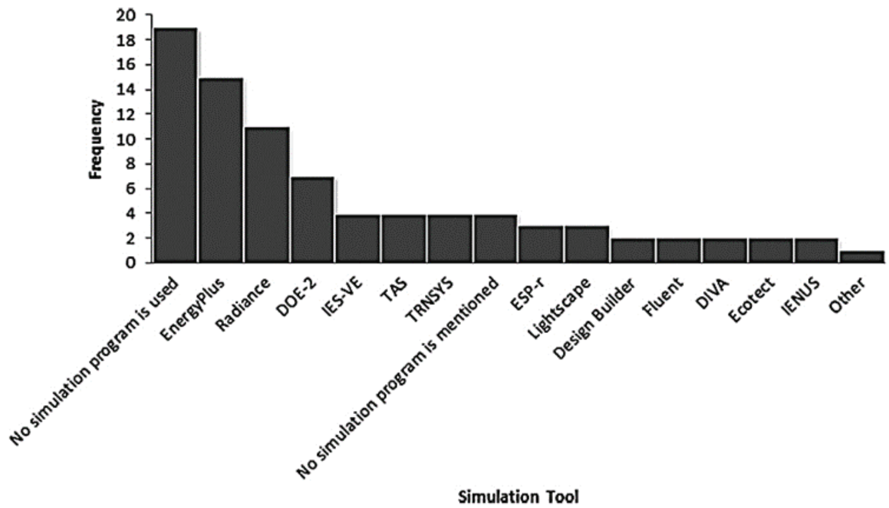

Figure 1: Various simulation tools used in previous studies [10].

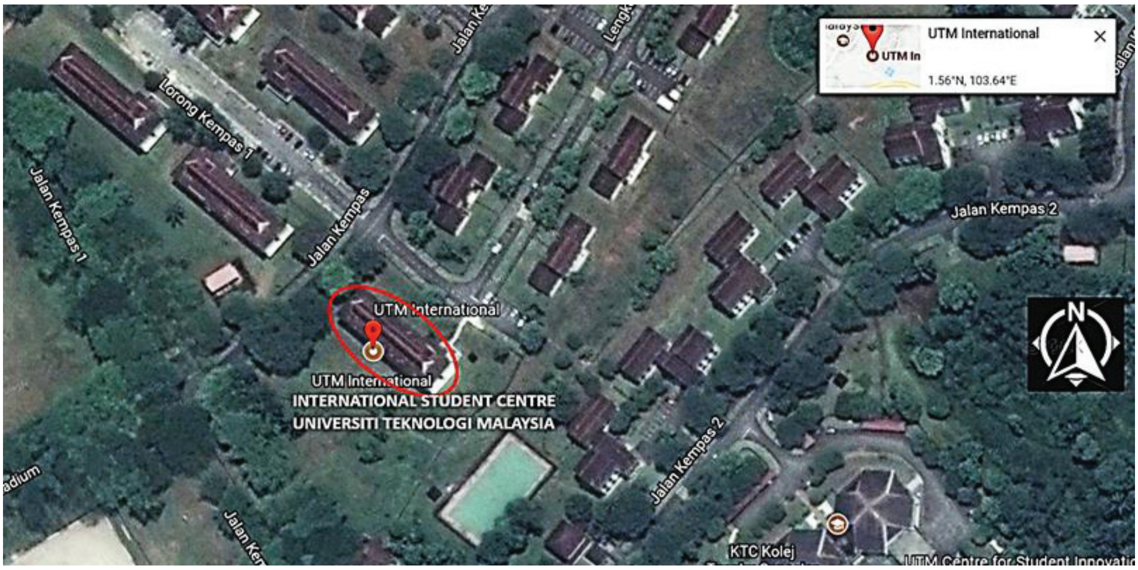

Figure 2: Google earth location of ISC building in Universiti Teknologi Malaysia.

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3. The hardwood timber flush door also contains an overhead louver window of 0.5m×0.9m, probably for ventilation Figure 3. The ceiling to floor height is 3.6m, with a total room volume of 57.02m3. The case study office room is typical for the international students' Society (ISS). The room has installed a unit of ceiling fan only and may need the practice of window opening due to the poor thermal performance of the single-sided ventilated room.

All these descriptions and measurements of the case study room are essential during simulation modeling for the accuracy of simulation software validation Table 1.

The research was conducted in two phases: field measurement in realistic conditions and computer simulation. The field measurement aims to validate the IES-VE simulation software for further building performance simulation. The recessed wall façade building is a third-floor office building located at UTM Johor-Bahru, Malaysia. However, the experiment was an elongated one, nonstop data recording for the whole period of seven (7) weeks (from October to December 2016). But, the period considered was from 7.00am to 5.00pm, being the office occupancy period. These months were selected because they are the weather months that exit from the driest months to the wettest months in Johor, Malaysia Figure 4.

The measurements were conducted outdoors and indoors of the recessed wall façade room at a height of 0.90m above ground level. This height is the possible measure for a reasonable sitting position when carrying out an office task. Three indoor points were identified for investigation at the office room, one point in the corridor and one point at the outdoor about 1.5m from the façade wall and horizontal to the indoor points for a better and more accurate corresponding result as earlier shown in Figure 3. The measurable parameter is the air temperature (°C) which can determine the thermal environment condition inside the office room of the recessed wall facade. These measurable parameters were recorded at 10minutes intervals but were computed hourly, indoor and outdoor during the whole period of the experiment (diurnal and nocturnal recording). But, only office occupant hours from 7am to 5pm for two weeks nonstop at all points were considered for precise

Figure 3: Building test room geometry and exterior view of the building.

Table 1: Some details of devices and materials used in the study.

S/No	Instruments	Qty	Function	Task	Remarks
1	Measuring tape	1	Dimensioning	Measuring geometry of the room	Length, width & height
2	Four chambers Hobo data loggers with wire-probe sensors	1	Four surface temperature Data recording	Linked to all probe sensors	Record radiant temperature
3	HOBO U-series data logger	5	Temperature/humidity data reader	Measuring temperature /humidity data	Measure temp. And humidity
4	dual laser infrared (IR) thermometer	1	Radiant temperature reader	Measuring long time and instantaneous radiant temperature	Measure all surface temperature
5	Portable compass	1	building Orientation determinant	Measure direction where the façade faces	Measures north, south, east and west orientations

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handling of the data. The night measurements from 6 pm to 6 am were excluded in this study since the occupancy period of office buildings is confined to 7.00 am to 5.00 pm in Malaysia. The measuring device used for the air temperature is HOBO U12-011 series data loggers because the device's specification suits the requirement of this study, as shown in Table 2. Also, four chambers Hobo data loggers with wire-probe sensors and dual laser infrared (IR) thermometer were used to measure the surface temperature of the façade walls. Portable compass and measuring tape were used to determine the orientation of the building and measure distances of the room geometries, respectively Figures 5,6.

Setup and mounting of devices for recording

Before mounting the devices, the launching and setting have been configured. The start recording time was set to delay for 15 hours for the whole devices from 4.00pm on 17th October 2016; therefore, the recordings of all the devices will start simultaneously at 7.00am on 18th October 2016. This time interval will give room for the setting and mounting of all the devices to start recording at their various points at the same time as earlier mentioned. The devices were left continuously for seven (7) weeks from 18th October to 4th December 2016 for comprehensive recording before reading out.

During the measurement, the only door and window were closed while the other fenestrations, such as overhead louvers, were kept silently opened. However, the experiment was conducted under natural ventilation without any occupants for the whole period of measuring exercise. The experimental measurement was performed using a calibrated data logger system to monitor the 24-hourly variation of outdoor and indoor weather conditions, test room thermal performance, and use the data to validate the IES<VE>. Simulation software model for further building energy modeling.

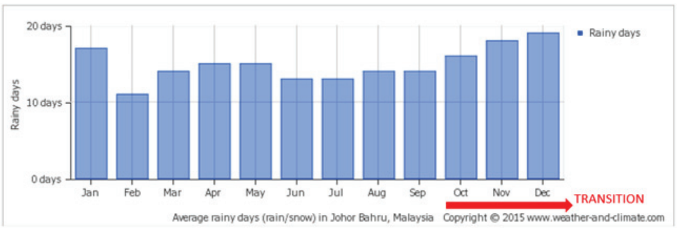

Figure 4: Average monthly rainy days over the year.

Table 2: Assigned construction material for case study room in IES-VE.

No	Component category	Code	Construction Type
A	External wall	STD_WALL1	Brickwork single leaf construction dense plaster
B	Internal partition	STD_PART	115mm single-leaf brick (plastered both side)
C	Ceiling	CCR101	Reinforced concrete ceiling
D	Door	DOOR	Wooden door
E	External Glazing	STD_EXTW	Single-glazed windows- domestic
F	Exposed Floor	STD_FLO1	150mm Reinforced concrete Floor

Simulation procedure

After completing the physical measurement, the next is to model the exact test room taking into consideration the dimension of the geometry and construction materials and techniques used. In the Model IT application of the IES-VE software.

Johor Bahru's location was set through the [APlocate], where Singapore was the nearness to Johor Bahru/Senai airport since the Johor Bahru weather station is not provided in the weather wizard. According to the Malaysia Standard (MS1525:2007), the location was set via the Design Weather Data tab. The dry bulb temperature and wet bulb temperature setpoints for outdoor design conditions in Malaysia are 33.3°C and 27.2°C [12]. Therefore, these temperature set points were inputted accordingly in the IES-VE [APlocate]. ASHRAE standard profile was used for hourly temperature variation input. The materials, construction, and texture of each building component (opaque and transparent) were properly assigned in Figures 2, 7 and 8. As the setting of the opening types is essential, the window was kept close to record the worse scenario of the test room. Hence, the modulating profile was set as "off continuously" since the experiment does not allow natural ventilation mechanisms.

Evaluation of the model validation

For any model to be used confidently, satisfactory validation or verification of the degree of the errors that may result from their usage should be executed [15,16]. Model validation can simply be defined as the form of comparison between simulated and measured values of air temperatures. The air temperature was selected for this study due to its significant climatic factor used to validate the performance of several models in various published research works. Beyond comparisons, there are several statistical measures available to evaluate the quantitative association between predicted and observed values; among them are the correlation coefficient (r) and its coefficient of determination (r^2). Willmott [16] has pointed out that the main problem with this analysis is that the magnitudes of r and r^2 are not consistently related to the accuracy of prediction, where accuracy is defined as the degree to which model simulation approaches the magnitudes of their measured counterparts. However, previous studies have agreed that for a better model comparison between measured (X) and the simulated (Y) values, the coefficient of determination value (r^2) should range between 0.5–1.0 [14]. Although, several measures provide exhaustive and valuable information concerning the general model performance [14-16]. Because the result of r^2 alone cannot verify the precision and accuracy of a model, several other statistical parameters were equally used with a series of trial input data to achieve a precision and accurate range between the measured (X) and simulated (Y) air temperatures. These parameters include: root mean square error (RMSE), Mean Bias Error (MBE), unsystematic root mean square error (RMSEU), systematic Root Mean Square Error (RMSES) [17], the mean relative error index of agreement (d) and the residual percentage difference (PD). Numerous research has emphasized the effectiveness of RMSE, with its systematic and unsystematic types, and the index of agreement (d) for evaluating model performance [14,18].

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Figure 5: Setting-up and mounting of devices for recording.

Figure 6: Measuring devices and materials used in the study.

However, for an accurate model, the index of agreement (d) should either be equal to one (1) or approach one (1) [14]. Therefore, the value of d=0.93 in this measure signifies a good accuracy and precision of the model since mathematically, the value is almost 1.0. This index of the agreement provides the amount to which the simulated is free from error [14,19,20]. On the other hand, since there is no definite range of RMSE, it varies with the type and nature of the dependent variable (DV) [21]. Nevertheless, established previous literature evaluation has indicated that the measured (X) and the simulated (Y) air temperature in Figure 9 shows an (RMSE) of 1.70 Figure 9, which is a statistically negligible error. RMSE is influenced more strongly by big errors than by minor errors. Its range is from 0 to infinity, with 0 being a perfect score [22-26].

Similarly, the experimental result and simulation result produced by IES<VE> were compared and evaluated. Comparing the percentage differences between the results will ascertain the software's accuracy through the investigation. According to Vangimalla, et al. [27], the comparison of the result of the field measurement (X) and the simulation measurement (Y) for

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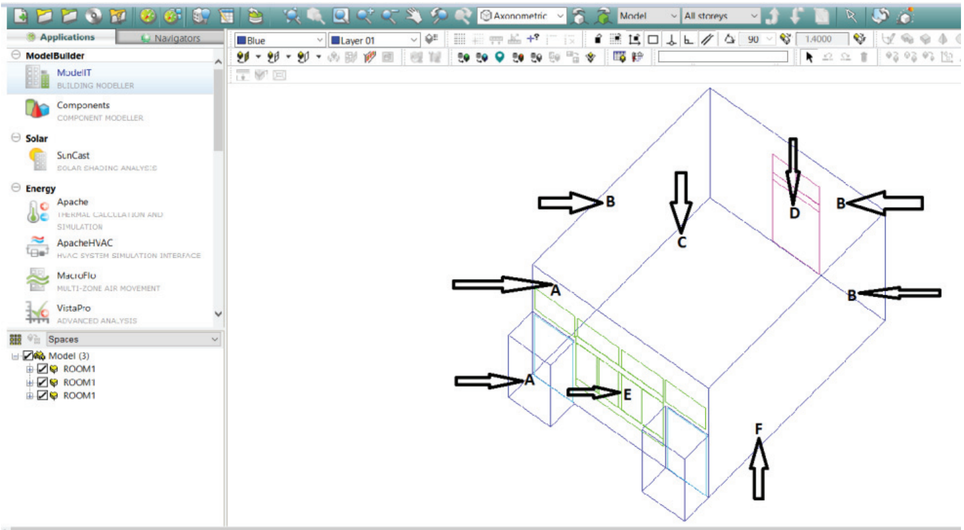

Figure 7: Components (parameters) of the Case Study Room Layout in IES-VE that can affect the result, explain in detail in Table 2.

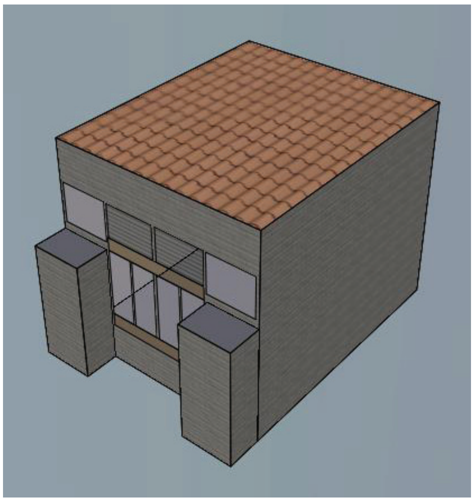

Figure 8: Case study model room with assigned material texture in IES-VE.

the thermal loads and luminance levels could be simplified by using the equation (1).

$$PD=\frac{(Y-X)}{X}\frac{(Y-X)}{X}\times 100 \quad (1)$$

Where: PD is the percentage difference (%), X is the measured value, and Y is the simulated value.

Vangimalla, et al. [27] compared the luminance level and the thermal loads of Rinker Hall by 2009 in other to validate the precision and the accuracy of the Ecotect simulation software model. The simulation software model applied in the case study of their study does not express the correlated result, and the level of accuracy of the software is very weak. Nevertheless, equation (1) proposed by [27] to compare the simulation result and the measured result would be similarly adopted in this study.

Moreover [28,29] stated that the difference of the result produced by the predicted (wind-tunnel) and measured (full-scale) flows could be 20% or less for the model to be accurate. This assertion means that the accuracy of the percentage difference of the compared simulated, and measured value should be within the range (0% ≤ PD ≤ 20%). Their paper further explained that the percentage is suitable in environmental design; on the other hand, it may be too high for the discrepancy between the field measurement and numerical values [29]. Accepted the work of [28] and suggested that the percentage difference of the software simulation output result and the field measurement result should be within 10% - 20%. The highest percentage difference between the two models is essential to set the range for the software validation analysis. The software validation is considered accurate and viable if the percentage differences between the predicted and observed do not exceed 20%. Hence, the range set by [29] was adopted in this study; this implies that if the percentage difference between measured data and simulation data was less or equal to 20% signify the simulation software and the model considered accurate, viable, and applicable [30], also used the above formula and the assertion by validating the IES-VE software model of air temperature and relative humidity with the field measurement. The study confirmed the software model is accurate and viable when the percentage difference between the measured and simulated is calculated to be between the ranges from 0.02% to 13.62% for air temperature and 0.01% to 14.90% for relative humidity. The study outcome indicated that IES-VE could perform accurately in almost all the calculated hours since the percentage difference is within the range of 10% to 20%. Therefore, it was finally concluded that IES-VE could be used for further building performance simulation of air temperature and relative humidity in the building design project.

Data analysis and discussion of air temperature comparison

The test room measurement data collected through the measuring devices were compared with the IES-VE simulation model result. The physical room measurements

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of the air temperature indicate the maximum air temperature recorded was between 10pm and 11pm, which measured up to 32.89ºC, while the simulation model results illustrate the maximum temperature at the same time with 36.11ºC value. The measurements resulted in an absolute difference of 3.22°C, which represents the highest percentage difference of 11.30% Figure 9. Moreover, minimum measured air temperature and simulated results also occurred at the same time by 2.00pm with values 25.04ºC and 24.40ºC, respectively. Similarly, the value of the average measured and simulated air temperature of 28.49ºC and 29.33ºC, respectively was also observed at the same time (5.00 pm) with 2.94% PD. The PD values have shown significant closeness as no value exceeds 20%. Similarly, the line graph (Figure 9) has also shown clearly that out of the 24 points of both measured and simulated results compared, only 5 points did not touch the straight line. However, out of the 5 points that did not touch the line, two are almost touching the line while the other 3 are not too far from the straight-line graph. This proximity of the points signifies the fitness of the IES-VE software.

This pattern of dual results recording coincidence of maximum, minimum, and average results simultaneously implies that the recording follows the same trend and pattern as illustrated in Figure 9. This behavior indicates the correlation between real life and virtual (simulation) situations. No time difference at recording maximum, minimum and average air temperature of both measured and simulated values; this signifies the applicability of the simulation software model. The rising of the air temperature of the both measured and simulated from 3.00pm and reached the peak values at 10pm and 11pm and later continuing decreasing until 3 am was perhaps due to the fact that the thermal mass behaviors of the building since the measurement was conducted under unventilated condition. Therefore, there was the absorption of heat in the daytime and the low release of it towards and during the night period [31].

It is good to note that the peak air temperature maintained by the simulation over the field measurement corresponds with most previous studies [14,30,32,33-38]. The percentage discrepancy of the maximum temperature logged by measured and simulated proved that the model is good enough for further building energy models because the discrepancy is within the range of 0% ≤ PD ≤ 20% as earlier discussed. Figure 10 represents the flow pattern of air temperature between experimental measurement and simulation value from 21st November 2016.

The profile patterns of the two results in Figure 10 that follow the rise and fall profile between the measured and simulated results, is also an indication that the simulated result matched with the behavior of the measured result. This shows that what was measured can also be simulated with a closed or similar value.

Conclusion

Evaluating the reliability of the software simulation tool (IES-VE) for the air temperature is vital because of the applicability of the software for further building performance investigation utilization. The results for the validation accuracy cannot be perfect due to some factors militating against the process. Some of the limitations include the influence of the airflow motion and direction, lack of its own specific International Weather for Energy Calculations (IWEC) as it has to use the nearness location of Singapore. The nature of the dynamism of weather for the real-life situation as compared with simulation data configuration, the possible

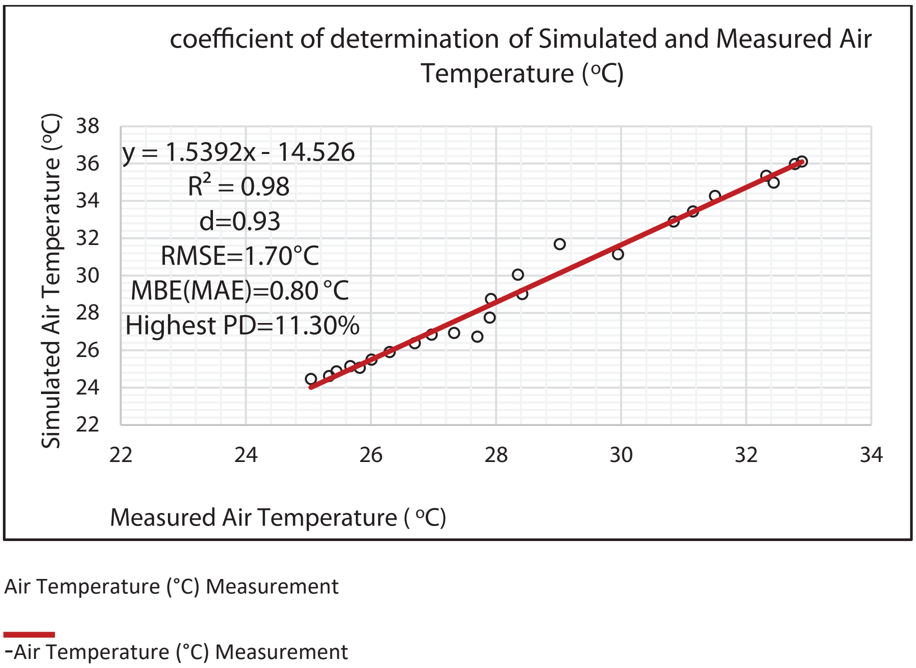

Figure 9: Case study model room with assigned material texture in IES-VE.

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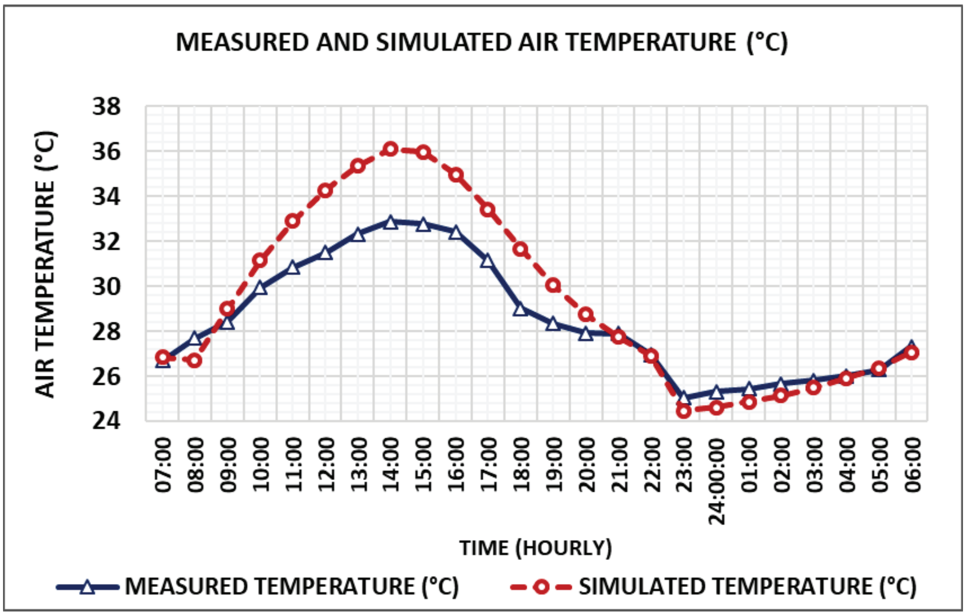

Figure 10: Measured and simulated air temperature of 21st November 2016.

interference of heat energy from the nearby space, which was overlooked in the process, can affect the results during the validation evaluation. However, with the limitations, the results achieved were significant and showed the viability and accuracy of IES-VE simulation software. Hence, the coefficient of determination (r2) is 0.98, mean absolute error/mean bias error (MAE/MBE) with root mean square error (RMSE) are 0.8°C and 1.70°C, respectively. While the index of agreement (d) is 0.93, the percentage difference (PD) range is (2.94%-11.30%), which is within the 0% ≤ PD ≤ 20% as specified in the literature. Therefore, with the good results obtained from the five statistical parameters used, it can be deduced that IES-VE can be used to simulate air temperature to investigate the thermal condition of a building and proffer better design options to achieve sustainable development architecture.

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