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Architectural Computer Simulation Methodology: Process and Procedure of Thermal Assessment using IES<VE>

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Abstract: ***Computer Simulation is the most advanced method for investigating whole building energy performance within a short period. It is used to simulate building models to investigate its performance with regards to thermal, daylighting, heating, ventilating and air-conditioning (HVAC), energy efficiency, life cycle assessment, egress, among others. However, this paper aims at revealing the processes and procedures of using computer simulation in architectural research to enhance proficiency in handling simulation methodology through the first-hand information. Therefore, the paper represented the processes and procedures involves in the simulation methodology with a flow chart comprises of: selection of the appropriate simulation software, modelling of the building design and configuration in ModelIT module after proper location of the region/country/city from the Aplocate section of the program. Furthermore, the right creation of construction and thermal template, assigning construction and thermal templates to the model(s), proper orientation of the models, Suncast exercises for solar shading calculations, then thermal simulation via ApacheSim. Finally, extracting results from IES-VE using 'VistaPro' section of the program. The paper in addition indicated aspect of architecture where this methodology is usually applicable. Lastly, the importance and limitations of this methodology were stressed in this paper. The paper recommends further study on the processes and procedures of daylighting and other modules of IESVE that have not been discuss here.***

Keywords: computer simulation, research methodologies, architecture integrated environmental solution<virtual environment> (IES<VE>)

1. Introduction

The portrayal of the evolution of a real-world system or process over time is called computer simulation. It is the most cutting-edge technique for quickly examining the energy performance of a whole building. It is used to simulate a building model to investigate its performance. Basher (2018), Chan (2010) and Al-Tamimi and Fadzil, (2011) among others used this technique to provide numerical findings and obtain the necessary output numbers on building's energy performance.

It is accurate and gives chance for studying several parameters at the same time.

In order to simulate building energy performance, one of the first steps is to create a model that embodies the essential traits, actions, and purposes of the chosen physical structure. (Kavgic et al., 2010). Owing to the intricate procedure of other forms of methodologies with their restrictions and constraints, the possible ideal option left to explore is the use of computer simulation. Several simulation tools have been produced in the market in order to simulate various indoor environmental quality (IEQ) conditions for various designs of building and industries. For example, thermal condition (heat loss, heat gain, solar shading, etc.), air conditioning load calculation, daylighting, insulation thickness, life cycle assessment, among others (Ossen, 2005).

The inclusion of thermal and radiative processes between the building, shading devices, and external environment in the computations is one advantage of using computer simulation in building energy modelling. As a result, any early design issues may be examined before the design is finished. The ability of comprehensive energy simulation systems to provide hourly broad output data is another benefit of computer simulation. However, it takes some time to learn how to utilize them for input preparation, execution, and result interpretation according to study requirements (Ossen, 2005). The accuracy of the building components model, as previously stated, and the program input assumptions determine how precise the programs are. These are few functions and benefits of computer simulation among numerous others.

A recent comprehensive systematic literature review (SLR) conducted by (Alejandro Prieto, et al., 2017) made it clear that the leading method in use for building performance research purposes is computer simulation. The study stressed the reason behind this was due to the continuous improvement both the accuracy of results and the time saving for the calculation processes of energy simulation software throughout the past two decades. The study assertion for giving simulation method number one methodology among others was discovered when 407 out of 861 articles on office building cooling strategies reviewed used simulation method, while others for the various methodologies as illustrated in figure 1.0. Similarly, the effectiveness of computer simulation was also uncovered in table 1.0 among other methods.

To avoid erroneous results in the use of computer simulations, there is a need to be well familiar with the software programme. Therefore, the proficiency in using this type of methodology can be enhanced through attending training organised by the software experts and regular readings of tutorial modules provided by the software. Similarly, in the software website, there are several tutorial videos that helped improved the author's skills in this software. The proficiency in using this software also arise from the contributions of the supervisors; if is an expert or have knowledge about the software. In testing one's proficiency in the use of the computer simulation software, there is a need in performing several pilot simulation exercises to achieve the closeness of results with physical measurement before detail building performance simulations.

However, this paper aims at revealing the processes and procedures of using computer simulation in architectural research to enhance proficiency in handling simulation methodology through the first-hand information.

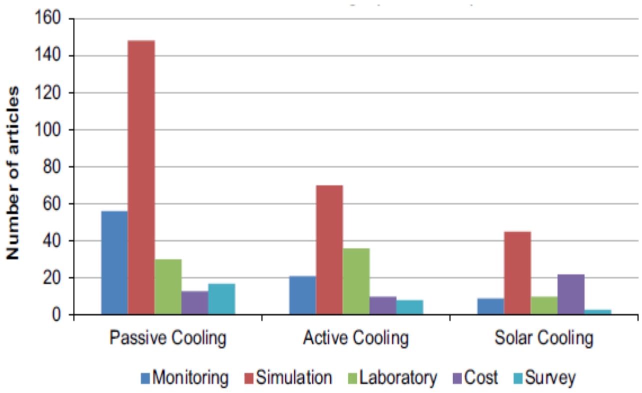

Figure 1: Various research methods on cooling strategies in buildings from 1990-2014
Source: Alejandro Prieto, *et al.* (2017)

Table 1: Efficiency of common research methods

Effectiveness of The Methods / Common Research Methods	Model & tools very costly	Expensive tools	Highly affordable	High time wasting	time wasting	Less time wasting	Very good result accuracy	Good result accuracy	Fair result accuracy	High experience with tools	Good experience with tools	Good software experience	Highly flexible	Flexible & difficult	Not flexible	High Suitability to the study	Fairly Suitable to the study	Not Suitability to the study
Real-scale model (Case study)		■			■			■			■				■	■		
Numerical and experimental		■		■			■			■				■			■	
Reduced scaled model		■			■				■	■				■			■	
Mathematical calculation			■	■			■			■				■				■
Real simulation	■			■				■		■				■				■
Computer simulation			■			■			■			■	■			■		

■ relationship □ No Relationship

2. Justification for the Selection of a Computer Simulation Program

While building performance technologies were formerly solely available to HVAC engineers, researchers, building scientists, and specialists, architects have been increasingly interested with them over the past 20 years. Several building simulation programs available on the market today have prompted studies into architecture. Rapid advancement has been going on with this program to improve more precise, versatile, and technological alternatives. Ten building performance simulation tools were compared from the Attia (2009) research, and a survey was also conducted for various stakeholders involved in the building design. Nonetheless, the majority of architects stated that the user-friendliness of the program and its ability to integrate additional inputs from relevant databases play a significant role in their selection of the most suited software. IES-VE, ECOTECT, Energy Plus, DOE-2, Green Building Studio, eQUEST, Energy Plus-SketchUp Plugin, and HEED were the 10 simulation tools. The capacity of these tools to link programs like AutoCAD and BIM tools, as well as to incorporate data from worldwide standards like LEED and ASHRAE standards, has recently led to a significant increase in the familiarity with their use.

The survey's findings indicated that, in decreasing order, IES-VE, eQUEST, and HEED are the most "Architect Friendly" programs. (Weytjens, et, al. 2011; Weytjens, et, al. 2010; Issa, 2018). Considering IES-VE is based on thermal templates, which provide simple parameter input and adjustment, it was highly recommended due to its usefulness in all design stages, from idea to detailed design. When analyzing many designs at once and offering standards for varying climates, HEED proves to be a powerful tool. Regarding eQUEST, it is similar to IES-VE in that it can simulate many kinds of systems; nevertheless, it is a little rigid when it comes to creative and intelligent construction systems. The next category of simulation tools consists of ECOTECT, DB, GBS, and E10, which are well-known for being straightforward simulation tools. Using these tools has the drawback that they are unable to integrate the architectural features of other programs, making them incompatible with the full process of architectural design stages. The last group consists of DOE-2, EPSU, and EP, which are limited to working with extremely basic building models.

Thus, the choice of simulation software has been made based on a number of factors, such as the program's market popularity, accuracy and dependability, flexibility in performing various types of simulations, ability to integrate valid weather data, user-friendliness of the interface, and ability to import materials and thermal data. Integrated Environmental Solutions-Virtual Environment (IES-VE) is also chosen for simulation analysis in this study, because of its versatility, dependability, and accuracy, it has emerged as the top building performance simulation program that architects suggest using for environmental assessments.

3. Simulation procedures

The IES<VE> simulation software has efficacy and general acceptability in building performance investigations (Kirimtat et al., 2016). It provides results in tables and graphs, which helped to simplify subsequent data analysis. The simulation methodology as adapted from Almhafdy et. al. (2013) is illustrated in Figure 2 with field measurement to validate the software before final building performance simulation.

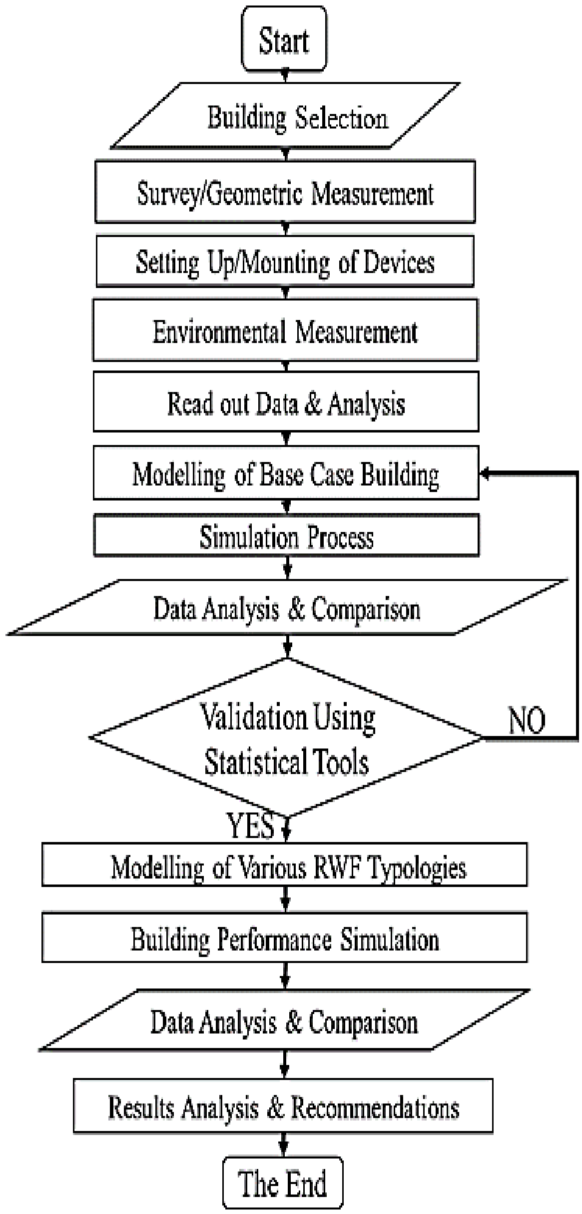

Figure 2: The simulation processes' flow.
Source: Almhafdy and Associates (2013)

A single integrated data model and a common user interface connect the many control modules that make up IES-VE. Each control module is in charge of certain tasks and related parameters. These modules comprise:

[1]ModelIT—geometry creation and editing

[2]ApacheCalc—loads analysis

[3]ApacheSim—thermal analysis module

[4]MacroFlo—natural ventilation analyzer

[5]Apache HVAC—component-based HVAC

[6] SunCast—shading visualisation and analysis

[7] MicroFlo—3D computational fluid dynamics

[8]FlucsPro/Radiance—lighting design

[9]DEFT—model optimisation

[10] LifeCycle—life-cycle energy and cost analysis

[11] Egress: Lisi—building evacuation and safety

The "ModelIT" module is in charge of producing the building's geometry, details and surrounding architectural elements, such as shading devices. In contrast, the "Solar" module offers a visual representation of solar radiation performance so that its effects on the interior and exterior building envelopes—which in turn affect heat gains and energy performance—can be evaluated. The "ApacheSim" module is in charge of carrying out the thermal simulation of the building, incorporating the meteorological data, the internal and external heat gains, and the model building materials and their characteristics. In addition, it offers ventilation, solar gain, and the building's cooling and heating system performance profiles. On the other hand, mechanical engineers utilize the "ApacheHVAC" technical module to design heating and cooling systems. While "FlucsPro" is used to measure both natural and artificial light intensities inside the space, "FlucsDL" is used to measure daylight quantity in terms of daylighting illuminance and daylight factors at the required spaces of the model; additionally, it could provide results based on the LEED specifications. The "Radiance" module is a visualization tool that uses ray tracing techniques to produce lifelike pictures. It can also analyze glare and offer information on how much light each occupant receives. Regarding "MacroFlo," it is the module that can simulate natural ventilation by identifying the direction and velocity of the airflow. A more sophisticated module that works with the computational fluid dynamics model (CFD) is called "MicroFlo." LifeCycle is for performing life cycle analyses for buildings. This type of analysis is becoming more and more essential to building owners and designers as they try to trade-off the impact of building resources and cost of building operations. Through complete life cycle analyses, a building possessor can save significant costs over the building lifespan. Egress: Lisi is another IESVE module that help to determine the safety nature of design of high rise building with regards the lift design and position. This module aid in determining the best design for easy way of evacuating building occupants in case of emergency. In order to take into account their settings and to gain from the other simulation results, the majority of these module outcomes might be connected together. The software's official website, www.iesve.com, has further information.

3.1 Loading of Weather Data

The first step to take in simulation procedure is to set the location of the study area in the software as numerous locations or regions on earth have appropriate weather files in IESVE. Therefore, Johor weather file was selected and station of Singapore International Weather for Energy Calculations (IWEC) was chosen as nearest to the site. The manner of loading the weather data is demonstrated in Figure 3. Figure 4 a shows the Aplocate interface leading to the wizard button while figure 4 b illustrates site locations including "region", "country" and "city" where the research is being conducted.

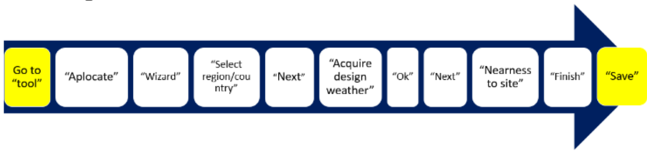

Figure 3: Site weather data location processes in IESVE

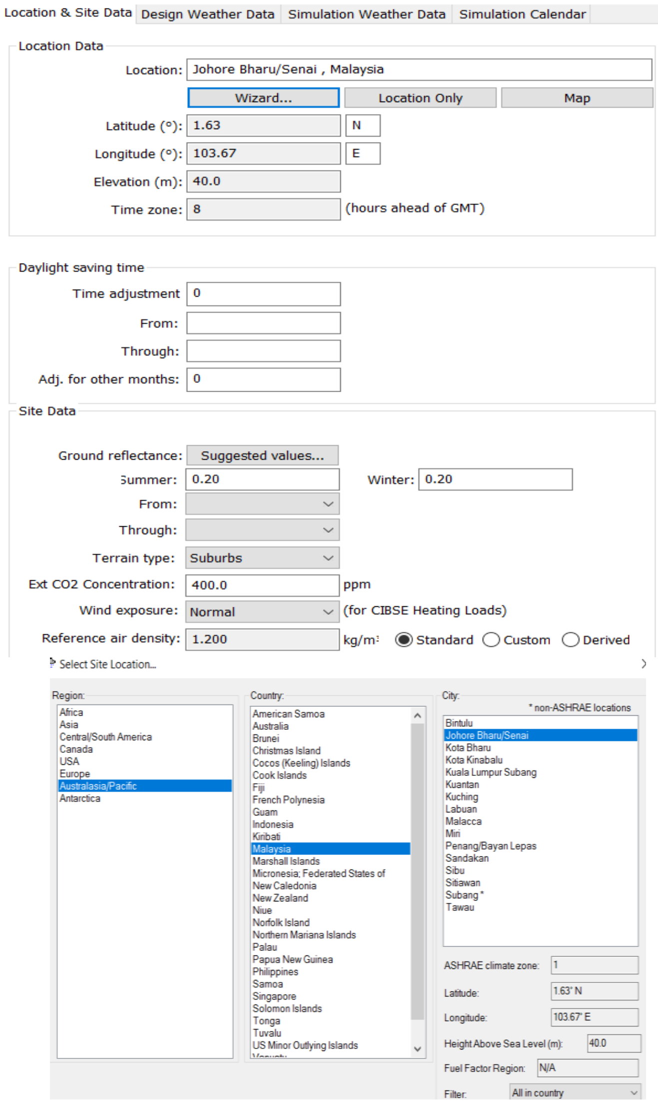

Figure 4 a & b: Site selection in IESVE for Johor Bahru meteorological data

3.2 Building the Model

The "ModelIT" module, which is the model builder in the IESVE, is in charge of producing building geometry in addition to the surrounding architectural elements. Before the modelling, the complete measurements and construction details of the test room had to be taken and recorded for use in the "ModelIT" module. The model is placed on the ground level by inputting zero (0.0) or 3.0m for second (2nd) level or first floor, if height above the ground is 3.0m. The other building components such as windows and doors among others, can be added to the model depending on the intended interior and exterior design. The model can be viewed in 2-D and 3-D (Figure 5). The model-viewer tab is use to view the model to ascertain its conformity with the model requirements for further process. Figure 4 illustrate IESVE interface when the ModelIT module was accessed.

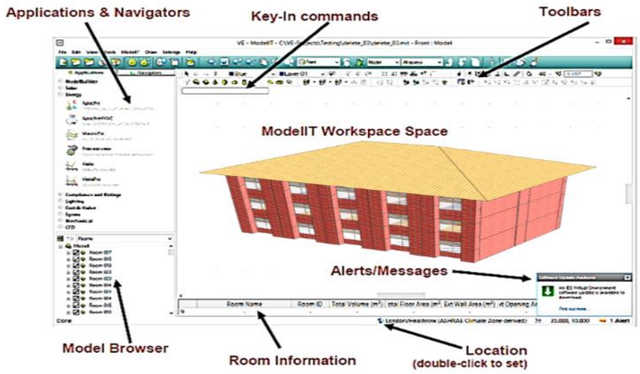

Figure 5: The ModelIT workspace

3.3 Building Input Parameters

For accuracy of the simulations, building input parameters such as construction and thermal template creation were required. Patterns pertaining to opaque buildings, such exterior walls, interior partitions, exposed floors, ceilings, and doors, are known as construction templates. This is in addition to transparent structures like windows on the inside and outside. (Table 2). The materials and configuration used applied to base case model and all simulated models.

Table 2: Construction Template Creation

Building component	Materials	Description	U-value (W/m^2K)
Ground Floor	100mm cast concrete with 20mm concrete finishes	2013 Exposed Floor	0.2235
External Wall	125mm brick with 12.5mm thick cement plaster on the both sides bonded with solar Absorptance of 0.700	IES External Wall	0.2587
External Window Glazing	6mm thick Glass Window with Window to Wall Ratio, 18%	IES External Window	1.5653
Door	38mm thick Solid Timber Flush door	New Door	1.1997
Ceiling	4.5mm cement board on noggins	IES 2013 ceiling	1.0866
Roof	10mm Clay roof tiles with solar Absorptance of 0.700	IES 2013 Roof	0.1800

Furthermore, insulating material was configured and tested to see it effect as compared with the wall without insulation to ascertain it contributive thermal performance to the particular build design and or configuration, as shown in the Table 3. The study of Abdulhalim (2013) specified 75mm insulated thickness with R-value of 2.142m2 K/W as shown in the table 3.0. Furthermore, gypsum board is one of the most important insulation materials for wall and ceiling in Malaysia as opined by Aathaworld (www.aathaworld.com 2019) so adapted in this study.

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Table 3: Construction template of wall with insulation

Building component	Materials	Description	U-value (W/m²K)
RWF External Wall	125mm brick with 12.5mm thick cement plaster on the both sides bonded with solar Absorptance of 0.700	IES External Insulated Wall	0.2587
	75mm insulation with R-value 2.14m²K/W (Abdulhalim, 2013)		0.4672

Thermal templates, on the other hand, are schematic representations of the building's internal heat gains. For instance, the room's equipment, occupants, and lighting. There is also, exterior heat gains from outdoor of the building, including; infiltration rate and ventilation. Moreover, there is the technical input relating to the cooling and heating systems. For normal building condition, all specifications were made to conform to the original base case building. That would ensure successful execution of the program.

The interior heat gains selected for lighting was fluorescent, as that was the type found in the test room, and was most commonly used in office lighting due to its energy efficiency (Table 4). Consequently, it had a radiant percentage of 0.45 and a maximum power usage of 10 W/m2. As the office occupancy time, the variation profile was intended to run continuously from 8 a.m. to 6 p.m. 10sqm was the area ratio per person that was anticipated and taken into consideration (Shahidan, 2011). The sensible maximum gain was 90 W/m2 while the latent heat gain for the office occupiers was 60 W/ m2, going along with the variation profile. Regarding computers provision in the office room, their maximum sensible gain and power consumption were 10 W/ m2 each as recommended by MS: 1525 (2014). Operating continuously from 8 am to 6 pm, the radiant fraction was 0.22. With a maximum flow of 0.25 ACH and a constant variation profile, the external source of heat was shown to be the only infiltration for the external heat gains (Table 4).

Table 4: Thermal template internal heat gains

Input	Description	Max. Sensible Gain/other details
Internal gain	Fluorescent Lighting	10w/m²
	People	90w/m²
Air exchange	Infiltration Natural ventilation	0.25 ach on continuously 1.00 ach on continuously
Working hours profile	All days	On continuously

3.4 The Model's Assignment of Construction and Thermal Templates

After the creation of construction and thermal template, it is then followed by the assigning of the templates to the office model to depict the exact features of the real model of the building in the simulation model before simulation process. Alternatively, one can also create the template first before the modelling so that the model bears the features of the created template. The assigned construction interface is categorised into three. Construction category containing the building components to be selected, assigned construction type as the required template, and possible replacement construction types with a different template of the components (Figure 6). Select the required template in the possible replacement construction types and select the one in the assigned construction type and replace. The red colour-highlighted component in the model (Figure 6) indicates the component already assigned "New Exposed Floor".

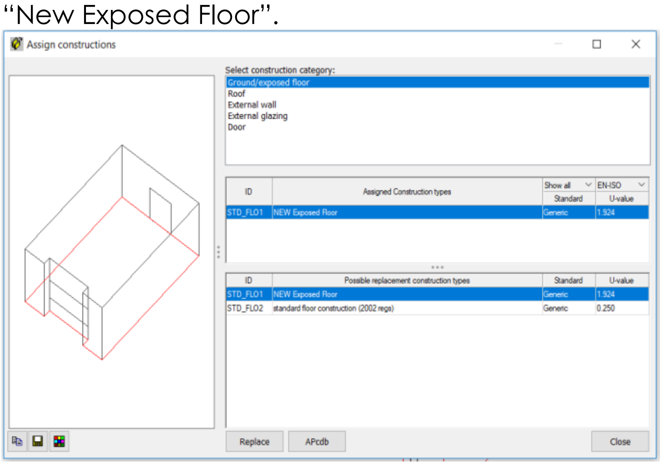

Figure 6: Assign construction template

3.5 Orientation Navigation in IES-VE

Orientation plays a vital role in building energy efficiency as different orientations have varied solar radiation incidence on the building. Therefore, in investigating the effect of orientations on building using the software, it is essential to know how to navigate to a particular type of direction with regards to north, east, south and west orientation.
In the ModelIT module of the IES-VE, the site rotation icon is clicked to reveal the site rotation box with the angle of the north in degrees. The zero degrees (0°) default value indicates the north orientation, and signifies direction of the arrowhead representing the north direction. However, with the reference façade and the north arrowhead direction, various orientations are achieved with different degree values input (Figure 7).

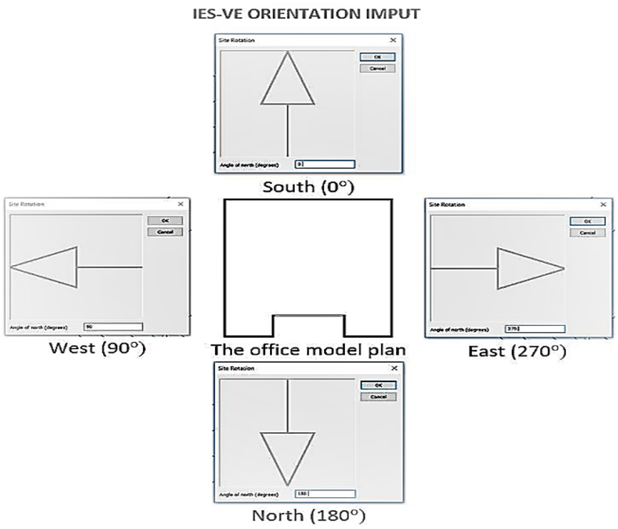

Figure 7: IES-VE orientation navigation with respect to the reference façade

3.6 Suncast

The performance of thermal simulation process begins with "Suncast" module for solar shading calculations which will later be linked to "ApacheSim". The "Suncast" module is used to analyze solar radiation and calculate the amount and severity of shade on the façade (Figure 8.0). The building thermal analysis is carried out using the "ApacheSim" module, which takes into consideration all thermal and construction templates.

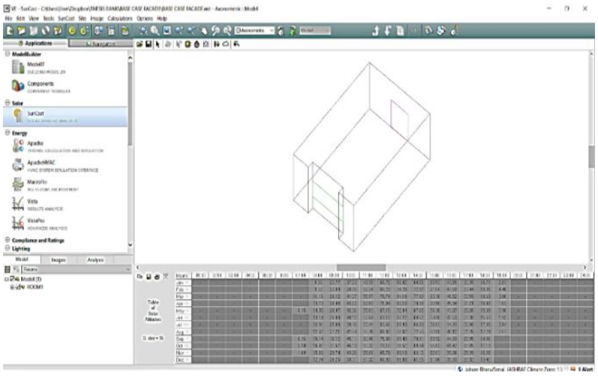

Figure 8: 'Suncast' solar shading analysis

3.7 ApacheSim

Following solar computation using the IES "SunCast" module, ApacheSim operates utilizing the principles of heat transfer, which are connected to the thermal performance of the structures (Integrated Environmental Solution Limited, 2011). The Characteristics of ApacheSim is shown in Figure 3. It involves some parameters which should be set before running the simulation.

First is to tick the 'enable SunCast link' in the Apache Simulation and making sure that in the 'Output Options', all the boxes are ticked, and the model room is selected. The resulting file is named, and the weather file is cross-checked to be the right one. Then, the simulation period is specified from 1st January to 31st December for the whole year or otherwise. The first and last days of the simulation should be specified in the simulation for this study; all models were simulated in four Malaysian design days separately. Therefore the first and last days for simulation are considered the same as (21st March, 22nd Jun, 24th Sep and 21st Dec) (Ossen,2005). In the simulation, the time step, reporting interval, and preconditioning period must all be stated. For construction simulations, a time step, reporting interval, and preconditioning duration of ten minutes, sixty minutes, and ten days, respectively, are adequate. (figure 9.0). Smaller time steps may be necessary to achieve more detail (Integrated Environmental Solution Limited, 2011).

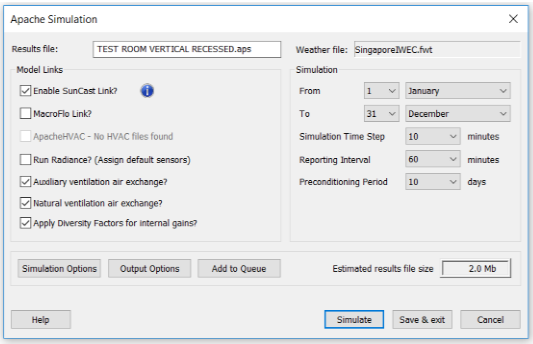

Figure 9: Apache dynamic simulation features IES (VE)

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3.8 Extracting Results from IES-VE Using 'VistaPro'

After completion of Apache Simulation analysis, the 'VistaPro' module serves as the data collection tool. The 'VistaPro' module function as a toolbar that provides the means of assessing various forms of results including tables, graphs, synopsis, total, range test, among others. Before extracting the result, the required component or space of the model must be highlighted (Figure 10). This module provides the user with an opportunity to plot several types of files to be evaluated. For instance, the total results of indoor and outdoor thermal performance parameters can be produced in graphs and tables as demanded. Moreover, the module allows the extraction of daily, weekly, monthly and even annual results depends on the period of the resulting requirement. Results of various building components and space can also be extracted, sometimes using the level of decomposition if surface results are required. The results can be copied and send to Microsoft Excel for further evaluation and analysis.

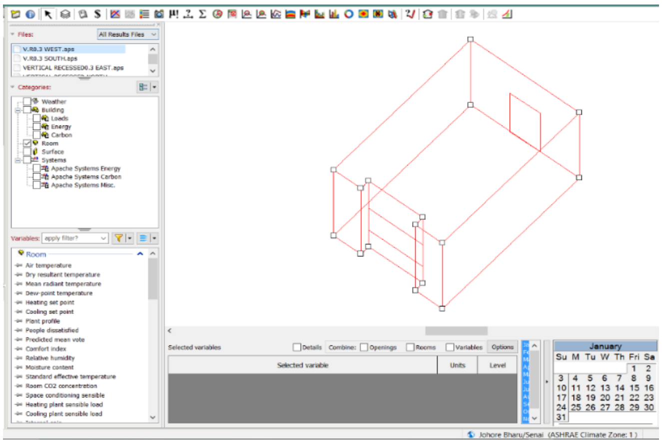

Figure 10: Extraction using 'VistaPro'

3.9 Models for Simulation and Investigations

This study looked at modeling three different types of exterior shading devices (ESD): horizontal overhang, egg-crate (figure 11.0), and vertical fins. The models were used in simulations to determine the ESDs' energy efficiency, thermal performance, and visual appeal in addition to other building investigations found in the IES<VE>. Computer simulation methodology gives architectural research the opportunity to investigate the effect of design configuration of buildings, effect of colours either on walls and or roof, thickness of the wall, different materials used in the building, ceiling design and types, window configuration and types, and to an extension the indoor environmental quality (IEQ) of a building among others.

Two other models (unshaded and the case study building). Every model was evaluated in all directions (North, South, East, and West) and on Malaysian climatic design days, which were, as previously noted, March 21, June 22, September 24, and December 21 (Ossen, 2005).

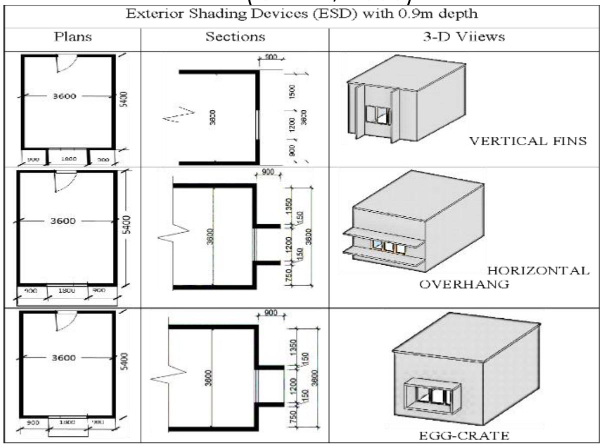

Figure 11: Three different models with same construction and thermal template simulated for their shading ability

Figure 10 shows the proposed models that were used for the last stage of building performance simulation investigations. The width or depth of the various investigated shading devices varied at 300mm, 600mm and 900mm. The effect of shading on indoor air temperature, relative humidity, solar gain and surface temperature were investigated annually and during Malaysian design days (21st March, 21st June, 22nd September and 21st December) in terms of the following:

a. The surface temperature, solar gain, relative humidity, and the lowest, maximum, and mean annual air temperatures.
b. The impact of varying depth.
c. Performance analysis among the various shading strategies.
d. Effect of orientation on the various variables.
e. Effect of insulation material on the shading devices' thermal performance.

3.10 Data Analysis Method

Comparison analysis is available and may be carried out with IES software, which provides the lowest, maximum, and average values of various parameters in various scenarios. The application includes Excel files that may be used for additional graph analysis to produce harmonious relationships. Comparing the outcomes of different variables and their interactions with one another can serve as the basis for the analytic approach. They can also be compared in each of the cases among the Malaysia or any country's various design days' results. The effects of different building orientations on the outputs can also be compared in each of the investigation. Effect of insulation material(s) can be applied in the building configuration and can be tested to see the level of further thermal performance. Design recommendations can be finally made to serve as guide for future design. The modelling of environmental factors, including air temperature, relative humidity, solar gain, and surface temperature, among others, revealed thermal performance results. These processes and procedures is represented by a flowchart (figure 12) for easy comprehension. The final results analysed can now be discussed, findings indicated and final conclusion drawn.

4. Simulation Limitation

As reported by Frenz, (2007), performance of the simulation program had few limitations as follows:

a.a. Accurate findings from thermal simulations required the inclusion of weather files with observed sun radiation data. Accurate thermal findings could not have been obtained by using non-solar weather information.

b.In computer simulation, re-creation of real-life situations is not always certain.

c.Some simulation software are costly and requires the need of frequent maintenance and updates.

d.Not all programs are present in many simulation software.

e.The accurate results depends on the proficiency of using the simulation software.

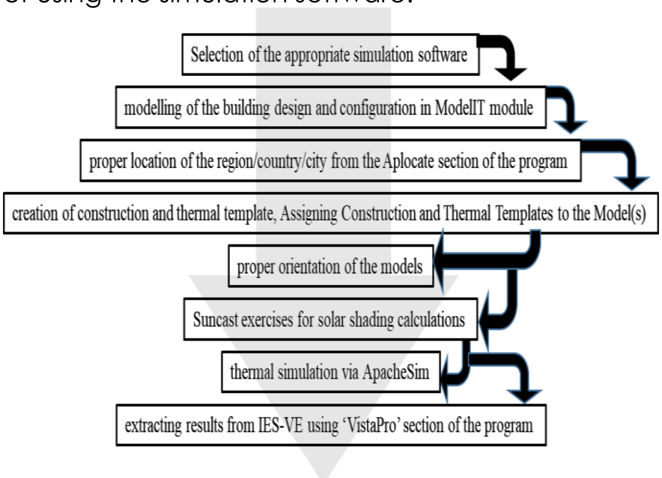

Figure 12: The flow of thermal simulation processes. Source: Author.

4. Conclusion

This study presented several steps of computer simulation methodology for architectural studies selected in the mix of other methods to study Indoor Environmental Quality of building space. The method in this paper is used to determine the thermal aspect of building design concerning their IEQ level. Out of many simulation software available, IES<VE> was chosen for its versatility. The process of handling this software will represent the other simulation software. The thermal aspect of this simulation program dealt with in this study was able to use three modules out of eleven modules of the IESVE. The other modules not really used here are for daylighting, ventilation, energy cooling and heating, model optimisation, life cycle energy and cost analysis and building egress and evacuation for safety. The research method steps for carrying-out this study was represented and presented in a flow chart (framework). These steps include the selection of the appropriate simulation software, modelling of the building design and configuration in ModelIT module after proper location of the region/country/city from the Aplocate section of the program. Additionally, correctly creating the construction and thermal templates, assigning the templates to the model or models, aligning the models correctly, using Suncast exercises to calculate solar shading, and using ApacheSim for thermal simulation. Finally, extracting results from IES-VE using 'VistaPro' section of the program. The paper in addition indicated aspect of architecture where this methodology is usually applicable. The importance and limitations of this methodology were stressed in this paper. Lastly, it is recommended for future study to explore the processes and procedures of other modules in IESVE software such as daylighting and other modules of IES<VE> that have not been discussed.

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