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VALIDATION OF DESIGNBUILDER SIMULATION ACCURACY USING FIELD MEASURED DATA OF INDOOR AIR TEMPERATURE IN A CLASSROOM BUILDING

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Abstract:

Studies have shown that a very wide range of parameters affect thermal comfort of building occupants. Heat transfer through the roofs has been identified as one of the causes of overheating in building interiors. Building Performance Simulation tools can be used to determine appropriate roof design parameters with optimum thermal performance in tropical climates like Nigeria. However, ensuring the reliability of the simulation results is essential for both occupants and designers. Therefore, this study seeks to verify and validate the accuracy of simulation results of DesignBuilder as a simulation tool for the present research works on roof thermal performance. The study primarily focuses on the impact of roof design on the air temperature in the indoor learning environment. Validation is examined by comparing the measured daily indoor air temperature of Kofar Wambai Secondary School Classroom, Bauchi city data and the simulation results. Comparative analysis indicate that the % deviation of field measured and simulated results for the tested days (18th and 21st September, 2018) were 2.39% and 1.25% respectively. The R^2 results indicated 99% and 75% correlation between the simulated and measured indoor temperature on the tested days.These results agreed with the recommendations of a study by (Andelkovic et al, 2016) which reported that the marginal value of R^2 for measurements and simulations validation is $R^2 \geq 75\%$. Therefore, DesignBuilder can be employed to evaluate roof thermal performance as well as predict indoor air temperature of classroom buildings.

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Validation, Classroom Environment, Simulation Accuracy, Air Temperature, Roof Thermal Performance

Introduction

Comfort in buildings refers to the provision of comfortable environment for the occupants. Previous studies on occupants' satisfaction with the indoor environment in buildings have identified four major factors that affect human comfort in buildings. These are; thermal, visual, acoustics, and indoor air quality (Saraiva et al; 2017; Nicol and Roaf, 2017; Olgyay et al; 2015 and Fanger, 1970). Climate change and global warming phenomena resulting from an increase of 1.1^{0}C in global mean temperatures is affecting the building occupants' thermal comfort. Sustainability seeks to provide holistic approach towards addressing the impacts of climate change and global warming in our environment. To achieve sustainability in buildings, the Architects and other professionals in the building industry have the responsibility to design buildings that are thermally comfortable, energy efficient, cost effective and healthy (Yang et al, 2014; Appah-Dankyi and Koranteng, 2012) Previous studies on thermal comfort in schools have shown that conducive learning environments pave ways for enhanced students' performance (Wargocki et al, 2019).However, due to the hot climatic conditions in the tropical regions, the classroom indoor environments become overheated causing discomfort to the students during lesson periods (Abba et al, 2020). Heat transfer through the roofs has been identified as one of the major causes of overheating in building interiors (Chang et al, 2019; Al-Obaidi e al, 2014).

The purpose of this study is to validate the accuracy of simulation results of DesignBuilder software. According to (Schwer, 2009) validation is the method of determining the level to which a model is a correct representation of the physical world from the perception of the proposed uses of the model.

Literature Review

Computer simulation is considered as one of the leading methods for holistically, investigating the entire performance of buildings (Prieto et al, 2017; Gunay *et al.*, 2016). As a result, the method can be employed to simulate model of a building and the climatic conditions, along with other required alterations if necessary. In addition, these methods have been employed by various researchers to acquire the required output or statistical data for measuring the performance of buildings (Mateus *et al.*, 2014). Previous studies have shown that, several tools have been developed to simulate various energy-saving applications (Dahanayake and Chow, 2017). Some have been designed for investigating the energy and thermal conditions of buildings or industrial structures (Kirimtat *et al.*, 2016). Furthermore, Nguyen *et al.* (2014), presented a broad study on simulation-based optimization methods for investigating building performance. Additionally, (Kirimtat *et al.* 2016) conducted a review of advances in the simulation and modelling of shading devices in buildings DesignBuilder software, which is the software tool for this study has been validated by many researchers. A study by (Mustafaraj et al, 2014) validated the DesignBuilder simulated results of a model university building by comparing it with field measured results. Similarly, (Sun, 2014) conducted a validation by comparing simulated and measured results of six university buildings in the US. Another study

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by (Baharvand et al, 2013) compared the results of CFD simulations using DesignBuilder software with a known simulated result. The study concluded that DesignBuilder can be used to forecast indoor temperature and air velocity accurately. The procedure followed for the validation of the DesignBuilder software simulation results is described below:

Methodology

Validation of Building performance simulation tools can be conducted using three methods. These are; a) empirical method which is based on comparing the field measured data with simulated results b) analytical method which involves comparison of simulation results with other known analytical or numerical results and c) comparative method which involves comparing simulation results of different programmes against each other (Judkoff, 1988). In this study the empirical method has been adopted to compare the field measured data obtained from Kofar Wambai Day Secondary School Classroom in Bauchi city with the simulated data of the virtual classroom model.

Experiment Setup and data

For the validation exercise, the experimental data gathered during the hot season in 2018 from the Kofar Wambai secondary school classroom is compared to the full-scale simulation model of the classroom in Bauchi city, Nigeria. The school classroom under consideration is a single space measuring 9.0m length x 6.0m width x 3.2m floor to ceiling height with a verandah measuring 1.4m width. The windows are made of steel frames and a combination of metal and glass shutters. The dimensions of the windows are 1200mm x1200mm in size and the window sill height is 0.9m above the floor level. The doors are made of steel frames and a combination of metal and glass shutters measuring 2100mm height and 1200m width. The external walls were constructed with 450mm x 225mm x 225mm hollow sandcrete blocks having a U-value of 0.48W/m/K. Ceramic tiles were used as floor finishes while the internal walls were painted with emulsion paint. The room's orientation is in the North-west to South-east which exposes the longer sides of the room to sunshine during the academic activities. Figure 1(a-c) shows the floor plan, exterior and interior views of the experimental classroom building. The HOBO data logger was set-up in the centre of the classroom as shown.

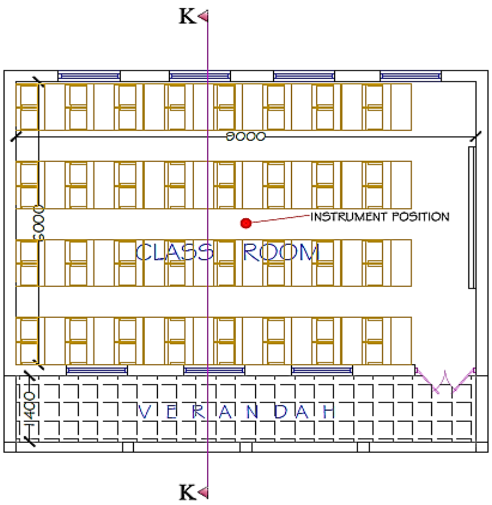

Figure 1a: Floor Plan of The Experimental Classroom

Figure 1b: Exterior View of The Experimental Classroom Building.

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Figure 1c: Interior View of The Classroom Showing Hobo Data Logger at The Centre of The Classroom.

The measuring instrument (HOBO data logger, UX100-011) was used for quantitative data collection of the classroom thermal condition which is primarily the air temperature and relative humidity. The chosen data logger has a measurement range of -20°C to 70°C with accuracy level of ± 0.21^{0}C in a temperature range of 0^{0}C to 50^{0}C. The instrument was positioned at the centre of the classroom at a height of 1.1m above the finished floor level during the lesson periods on the tested days (18, and 21st September, 2018). Table 1 summarizes the classroom building roof design characteristics with 25^0 roof angle, 0.6 m eaves projection and covered with 0.55mm thickness aluminum (ivory white coloured) roofing material having a U-value of 0.167W/m^{2}K. Further thermo-physical properties of the building is provided in Abba et al, (2020).

Table 1: Government Day Secondary School Kofar Wambai Roof Design Parameters

Name of School	Roof Design Parameters						
	Roof Material	Roof colour	Roof angle	Room Height	Eaves projection	Roof insulation	U-value
GDSS K/Wambai	Aluminum 0.55mm	Ivory	25^0	3.2m	0.6m	None	0.167 W/m^{2-}K

A range of measurement at every thirty minutes was recorded on the data logger and these measurement results were averaged in time. The averaged indoor air temperature results in 30-min intervals to allow for direct comparison with the 3-min time step simulation results.

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Thermal Simulation Model

For this study on DesignBuilder validation, the experimental airflow and temperature study which was obtained in the experiment described above is compared to the data obtained from DesignBuilder simulation results. DesignBuilder version 6.1.0.006 running on EnergyPlus 9.1.0 was used for this study. The climate data for 10years (2008-2017) of Bauchi, which is the study area, was sourced from the Nigeria Meteorological Agency (Nimet, 2018). It showed that the mean monthly maximum and minimum temperatures were 37.8^{0}C and 15.2^{0}C respectively. Relative humidity ranges from 19% to 76% .The mean monthly maximum and minimum solar radiation were 19.5 MJ/m^2/day and 13.3 MJ/m^2/day respectively. The maximum and minimum mean monthly wind speed were 4.5m/s and 2.8m/s respectively. Table 2 presents the simulation settings adopted in the simulation. While (TARP) is used in the simulation for the internal convection coefficient algorithm, the internal solar radiation distribution was calculated using the “full interior and exterior” mode.

Table 2: Simulation Parameters

Solar distribution	Full interior and exterior
Temperature Control	Air temperature
Surface convection algorithm (inside and outside)	TARP
Outside convection algorithm	DOE-2
Air mass flow exponent	0.5
Zone capacitance multiplier	50
Time step per hour	6
Sky diffuse modelling algorithm	Simple sky diffuse modelling

Results and Discussion

Figures 2a and 2b show the plot of both measured and simulated temperature data during the occupying time between the hours of 8.00am and 1.00pm. During the tested periods, the peak recorded air temperature was between 11.00am to 1.00pm with higher solar radiation when the sun was directly overhead at mid-day towards the closing hour. The air temperature was mostly over predicted on the first dataset on 18th September, 2018 as shown on figure 2a while the classroom air temperature was mostly under predicted on the 21st September, 2018 (Figure 2b). However, the simulated air temperature consistently peaked at the closing hours. On both 18th and 21st September, the highest variation between measured and simulation data was recorded at 10am and 11am with 2.0^{o}C and 1.62^{o}C respectively.

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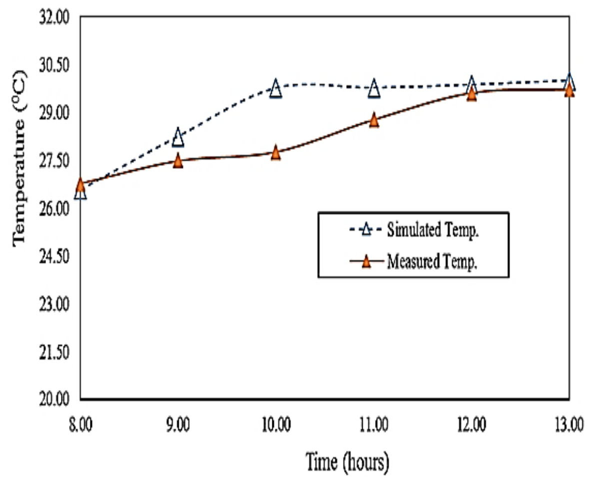

Figure 2a: Simulated and Measured Temperature on The 18th September 2018

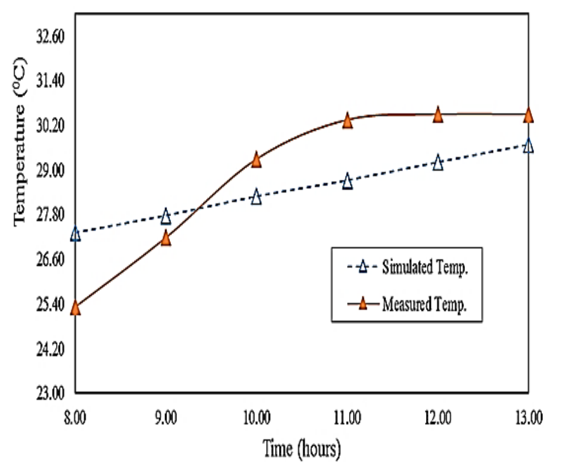

Figure 2b: Simulated and Measured Temperature on 21st September 2018

The simulation results showed somewhat good level agreement with the measured data, with an average simulation error in the classroom air temperature ranging between 0.20°C and 0.68°C during the tested dates. The periodic average maximum error of the classroom air temperature was 2.10°C. Table 3 and 4 shows the hourly measured air temperature compared to simulation results.

Table 3: Simulated vs Measured Temperature on 18th September 2018

Time	Simulated Temp.	Measured Temp.	|E| %	Error
8.00	26.58	26.779	0.75	0.20
9.00	28.25	27.49	2.76	-0.76
10.00	29.77	27.77	7.20	-2.00
11.00	29.78	28.78	3.47	-1.00
12.00	29.87	29.62	0.84	-0.25
13.00	30.01	29.73	0.94	-0.28
Mean	**29.04**	**28.36**	**2.39**	**-0.68**

Table 4: Simulated vs Measured Temperature on 21st September 2018

Time	Simulated Temp.	Measured Temp.	|E| %	Error
8.00	27.30	25.33	7.78	-1.97
9.00	27.76	27.18	2.13	-0.58
10.00	28.28	29.29	3.48	+1.02
11.00	28.71	30.34	5.37	+1.63
12.00	29.20	30.48	4.20	+1.28
13.00	29.68	30.48	2.66	+0.81
Mean	**28.49**	**28.85**	**1.25**	**+0.36**

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For the statistical evaluation of the results, indicators such as coefficient of determination (R^2), percentage margin of error (E), and mean bias error (MBE) are adopted for this study. Table 3 presents the software validation results. It was observed that the best R^2 results indicator was recorded on the 21st September with 99% of the simulated value explained with respect to the measured data, while for the 18th data showed that 75% of the simulation results was highly correlated with the measured data. A minimum 75% coefficient determination R^2 as the statistical parameter is considered desirable. Table 5 shows a statistical evaluation of the simulation validation results.

Table 5: Simulation Validation Results: Overall Statistic Indicators

Date of Measurement	R^2	Error (%)	Average Error (%)	Average bias (%)
18th September	**0.75**	**0.42**	**3.86**	**0.68**
21st September	**0.99**	**0.96**	**1.16**	**0.36**

Conclusion

This study estimated the average classroom air temperature errors that an architect can expect when simulating the thermal performance of an academic space in Bauchi, Nigeria. For this purpose, the simulation was performed using DesignBuilder that runs on EnergyPlus using typical statistical tool and approximations. The validation studies was carried out by comparing the classroom model thermal simulation results with the direct measured air temperature data during occupying periods.

The results show that, during the first one hour of the occupying period, air temperature was under predicted on both of the simulated days while air temperature was over predicted for the rest of the measured time. The differences between the averaged simulated and the measured air temperature was below 1˚C in all the tested periods while the maximum hourly difference peaked at 2.10˚C. Comparative analysis indicate that the % deviation of field measured and simulated results for the tested days (18th and 21st September, 2018) were 2.39% and 1.25% respectively.R^2 results indicated 99% and 75% correlation between the measured and the simulated temperature on the tested days. These results agreed with the recommendations of a study by (Andelkovic et al, 2016) which reported that the marginal value of R^2 for measurements and simulations validation is $R^2 \geq 75\%$. Therefore, DesignBuilder can be employed to evaluate roof thermal performance as well as predict indoor air temperature of classroom buildings.

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