Application of Integrated Environmental Solutions Software for Thermal Simulation in a Courtyard Residential Building

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Abstract

The study was concerned with validating the suitability of IES-VE Software for simulation of indoor micro-climatic variables such as the air temperature and relative humidity in a fully enclosed courtyard residential building in Kafanchan. Two Hobo Weather Data Logger (HWDL) were instrumental during the one-day data collection in the test-room and outdoor environments of the selected case-study building. The data were obtained through field measurement and compared with the IES-VE simulated results. The findings show the minimum and maximum percentage discrepancy between the simulation and field measurements results of the indoor (test-room) and outdoor (environment) as 3.3%, 4.9% and 2.7%, 4.3% for air temperature, while 4.5%, 14.3% and 1.9%, 1.9% for relative humidity respectively. The percentage discrepancies were less than 0-20%. Also, the R^2 values were 1, 1, 0.99 and 0.96 respectively. Consequently, it is concluded that the IES-VE software is applicable for further simulation experiments of indoor air temperature and relative humidity in a fully enclosed courtyard residential building in Kafanchan. The software is recommended for Architects to adopt in professional practice, in order to enable prediction of building microclimatic performance, from onset.

Keywords: *IES-VE Software, Validation, Air Temperature, Relative Humidity.*

Introduction

The application of scientific technology for mitigating the global environmental related challenges such as carbon dioxide (Co^2) emission from buildings, energy consumption in buildings, and many others are major challenges of this century (Schatzmann and Leitl, 2011). Some studies (Akande, 2010; Kabiru, 2011; Markus, *et al.,* 2017a) have stressed on climate-responsive architecture or even passive architectural design strategies and discouraged the overdependence on the active means for achieving thermal comfort in buildings. On the contrary, Blocken *et al.* (2012) encouraged the application of technological inventions for solving challenging issues, and most particularly the built environment thermal related issues. One of such contemporary technological innovations for the built environment is the application of building energy simulation software.

According to the United States Department of Energy (DOE 2010a), there were 374 building energy simulation soft wares. Because of the advancement of scientific discovery and innovations, the figure improved to 407 in two years (DOE 2012). Numerous simulation tools were designed for diverse simulation purposes such as heat, day-lighting, insulation thickness, air conditioning load calculation, heat loss, heat gain, life cycle assessment, solar shading and many other purposes. One of the most common simulation tools is the Integrated Environment Solution –Virtual Environment (IES-VE). The IES-VE building energy simulation software is a multi-facet energy tool which can be used for efficient energy building analysis (Abdulbasit *et al.*, 2013; Al-Masri and Abu 2012; Muhaisen & Gadi 2006a; Leng, *et al.,* 2012). The software has many applications such as the Modil-It, SUNcast, Apache, Radiance, and Vesta-Pro. Such applications are used for different types of simulation investigations. And according to Attia (2009), the IES-VE has a friendly interface and offers a tremendous assistance to the architectural design of energy-efficient buildings.

Even though the tool has been revealed to be efficient, scholars such as Maamera, *et al.,* (2006); Prasanthi, *et al.,* 2011); and Leng, *et al.* (2012) emphasized that its validation is required. Consequently, the validation of IES-VE software for simulation experiment is necessary for Nigeria. The paper explored the application of IES-VE Software for indoor air temperature and relative humidity simulation. The main objective being to equate the data obtained from field measurements and IES-VE software simulation data in other to verify the applicability of the software for further simulation studies in a fully-enclosed courtyard residential building in Kafanchan, Nigeria.

Literature Review

Oberkampf and Trukano (2002) opined that building energy simulation software has been in use for more than five decades. The application of such software has been implicit; and academics, engineers, and architects have resolved that it is cheaper, precise and contribute positively to the design process (Laouadi and Atif, 1998; Ji and Cook, 2007; Wang *et al.*, 2009). Particularly to the architectural profession, the tool enables the conceptualization of intelligent energy efficient building by allowing scientific prediction of the performance of the building microclimate and thermal related issues such as air temperature, relative humidity, wind velocity, air quality, solar intensity, energy efficiency, and many others.

Since the difference between the outdoor and the indoor thermal parameters such as air temperature, relative humidity, and wind speed are the major cause of thermal distress in buildings, then, the prediction of such parameters at the design stage can contribute positively towards mitigating the challenge (Hadi, 2016).

Academics have emphasized why the architectural proposal of buildings with very low energy requirements for the end users' thermal comfort is important (Markus *et al.*, 2017b; Akande 2010; Olutoa 2015). In the developed countries, for instance, buildings consume more energy toward sustaining a comfortable living condition for the end users (WBCSD 2009). In the United States of America in particular, the building sector is accountable for 40% of energy consumption, carbon dioxide (CO^2) emissions 39% and only 13% of water consumption per year, thereby making the concept of energy efficient building a serious challenge (USGBC 2010). Also, the required energy for space heating accounts for 12% of energy consumption in commercial buildings, energy for space cooling 8% and lighting for 18% (DOE 2010b).

Consequently, the overall thermal loads can be reduced by curtailing heating and cooling loads through the use of simulation software in architectural design.

Despite the numerous advantages of the building energy simulation software, the users of such tools should understand some of the issues embedded thereof. The question of the viability, confidentiality, accurateness, and acceptability of the simulation results produced by such tools need to be understood clearly. According to Foruzanmehr (2008), the answer to the above question is in the validation of such simulation tools. Validation, therefore, is the scientific research procedure of using a range of accepted standard as a benchmark to make a comparison between the simulated results obtained from a prototype case-model of a case-study building with the field measurement result of the same case-study building (Fawaz *et al.*, 2006).

Recently, scholars have contributed that the validation procedure helps to ensure the reliability and practicality of the simulation results (Casey and Wintergerste, 2000; Dalgliesh and Surry, 2003; Franke *et al.*, 2004, 2007). These scholars all agreed that the validation of the software prior to the simulation experiment is very vital, and most particularly, the IES-VE software validation. Numerous scholars conducted research by using the IES-VE tool, such as; Abdulbasit *et al.,* (2013); Muhaisen and Gadi (2006); Al-Masri and Abu (2012); Leng *et al.*, (2012). Their studies revealed that the IES-VE tool is valid for simulation studies on energy efficient buildings. Most of the studies however did not show how the software was validated but revealed the discrepancies and correlation coefficients only. Hence, a comprehensive validation study on the IES-VE is considered to be very few.

Some of the available few include Leng *et al.* (2012); Attia, (2009). In a study to validate the IES-VE software, Leng *at al.* (2012) made a comparative study of the discrepancy between the field measurement and the simulated base-case model of the case-study results. Leng's study adopted Prasanthi *et al.* (2011) method of validation that compare the result between the field measurement and the simulation and applied the equation below to calculate the percentage of the discrepancy.

PD = [(SM-FM)/FM] x 100 ......equation (1)
Where;
PD = Percentage Discrepancy,
SM = Simulation Measurement
FM = Field Measurement

The discrepancy range of 0-20% (as adopted by Summer *et al.,* 1989; Maamera *et al.,* 2006 and Prasanthi *et al.,* 2011) was used as a benchmark for interpreting the results. The result revealed a discrepancy of 6.99% to 13.62% and 0.002% to 14.90% for air temperature and relative humidity respectively.

The study concluded that since the validation results show that the percentage differences were within 0-20%, therefore, recommended that the IES-VE can be considered as a valid simulation software for the prediction of micro-climatic performance for energy-efficient buildings.

However, since the method adopted by Leng *et al*. (2012) only shows the discrepancies of maximum and minimum of the parameters, the correlation coefficient, and R^2 values are also necessary. According to Lim (2014), the Pearson Correlation equation is another approach used by scholars to determine the correlation between the field measurement result and the simulation result. The greatest results are the ones closer to the value of 1. The Equations for calculating the Correlation is as shown below.

Pearson Correlation

$$r = \frac{(\Sigma lm)-[(\Sigma l)(\Sigma m)]n}{\sqrt{[n\Sigma l^2-\frac{(\Sigma x)^2}{n}][n\Sigma m^2-\frac{(\Sigma m)^2}{n}]}} \quad ....2$$

Where, l = measured value, m = simulated value and n = number of measurements.

Therefore, since the use of equation 1, and 2 have been suggested and adopted by numerous scholars, the same shall be used in this study.

Methodology

The methodology was made up of two phases; the field measurement and the simulation phase. The details of how the study was performed are discussed in the sub-sections below.

The Case Study Building

The study was conducted in Kafanchan city of Kaduna State. The selected building is a fully-enclosed courtyard house located close to the Kafanchan campus of the Kaduna State University. The case-study building has an orientation of East/West direction with the longest side of its elevation facing the North direction. An inventory study of its dimensions and proportions and a field measurement was conducted in the number 13^{th} room (test-room) of the building for one-day (Figure 1).

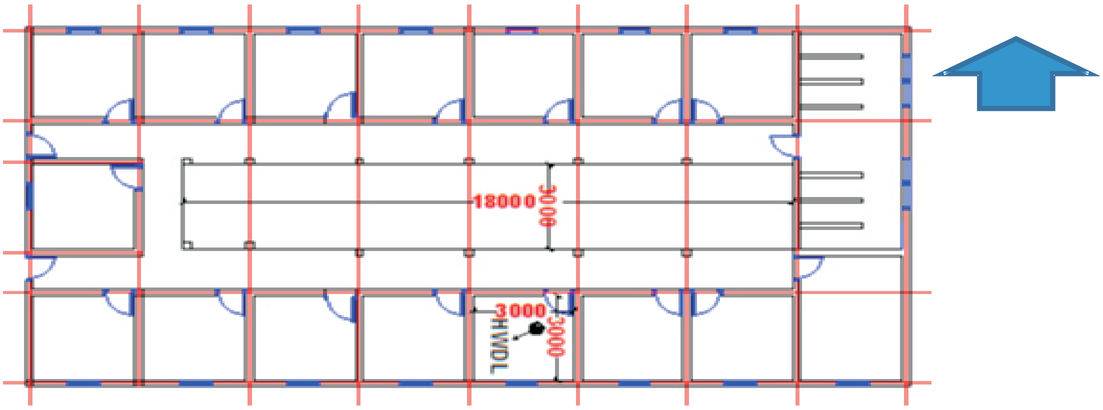

Figure 1: Floor Plan of the Case-Study Building Showing the HWDL in the Test-room

Field Measurement and Inventory

The case-study shown in Figure 1 was used to collect data during the hours of 7:00 am - 7:00 pm, on 21st March 2017. The choice of the date was to conform to Lim's (2014) opinion that it should be during the equinox or solstice period. But because the study area is located in tropic of cancer, the equinox date of 21st of March was chosen. The HWDL were calibrated. This procedure was for the purpose of checking the precision of the tools. The choice of HWDL was due to its sensing micro-climatic ability. It can record air temperature and relative humidity of -20° to 70°C and 5% to 95%. This procedure followed Leng *et al.* (2012) study which suggested that the calibration of the measurement tools is also necessary. So, the micro-climatic variables measured were; the indoor air temperature and relative humidity.

An HWDL was fixed at the center of the test-room (room 13) as shown in **Figure 2**, but the other HWDL was fixed at a distance of 500m away from the case study. The tools were both set to record data at 30 minutes time intervals at a distance of 1.2m above floor level. Afterward, the tools were read out by using the HOBO-Pro software.

Figure 2: HWDL in Test-Room

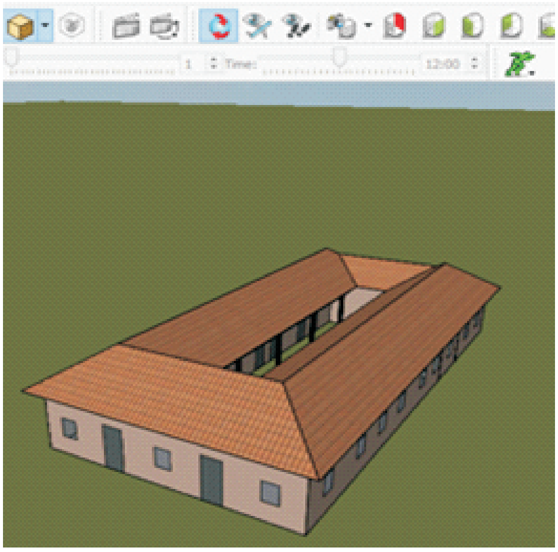

Figure 3: The Base Case Model

The Simulation Stage

Base-Case Model and Simulation Setting

The Model-IT application of IES-VE software was used to construct a base-case model. The model is a similar representation of the case-study building. The record of the inventory of the building conducted during the field measurement was used to build the base-case model and subsequently simulated. **Figures 3** and **4** illustrate the base case model and the simulation setting.

The simulation was set at 30 minutes interval (as in the HWDL during the field measurement). All surface texture, construction, and thermal templates were created and assigned in the base-case model. The building was modeled as natural ventilated. The Kafanchan weather data file was acquired and incorporated into the IES-VE Weather/Location Data Base (APlocate) for the simulation investigations.

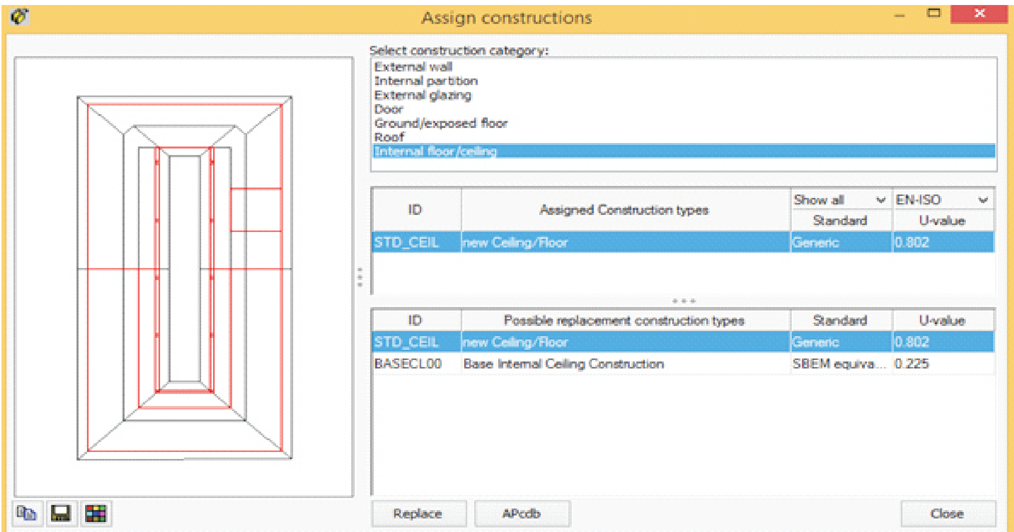

Figure 4: IES-VE Simulation Settings

Results and Discussion

The Air Temperature.

The comparison of the field measurement and IES-VE simulation of indoor (test-room) and outdoor (environment) was done. The indoor air temperature obtained through field measurement on the 21st of March 2017 reveals that the maximum and minimum air temperature in the indoor (test-room) and outdoor (environment) were 33.10ºC, 26.11ºC, 41.21ºC and 24.13ºC at 4:00 pm and 7:00 am respectively, while the simulation results are 34.20ºC, 27.41ºC, 42.32ºC and 25.17 ºC at 4:00 pm and 7:00 am respectively. The minimum and maximum discrepancy values for the indoor and outdoor are 4.9%, 3.3%, 4.3%, and 2.7% respectively, see **Table 1**. The R^2 was equal to 1 in both cases.

Table 1. Showing the Analysis of Air Temperature

	Test-Room		**Outdoor Environment**	
	Field Measurement	Simulation	Field Measurement	Simulated Kaf. Weather Data File
Max. Air Temp. (^OC)	33.10	34.20	41.21	42.32
Time	4:00pm	4:00pm	4:00	4:00
Min. Air Temp. (^OC)	26.11	27.41	24.13	25.17
Time	7:00am	7:00am	7:00am	7:00am
Max. Discrepancy	3.3%		2.7%	
Min. Discrepancy	4.9%		4.3%	
R^2	1		1	

All discrepancies are within the acceptable discrepancy-limit of 0-20%. Although the field measurement and simulation results of the indoor test-room are the primary purpose for the validation study, the outdoor environmental performance of the study area (Kafanchan) is required for the validation procedure (Leng, *et al.*, 2012). As shown in **Figure 5**, both the indoor and outdoor scenarios are close to each other. The indoor air temperature condition was not better than that of the outdoor in the early morning hours of 7:00 am to 8:30 am, however, a remarkable difference was observed from 9:00 am to 7:00 pm in the evening.

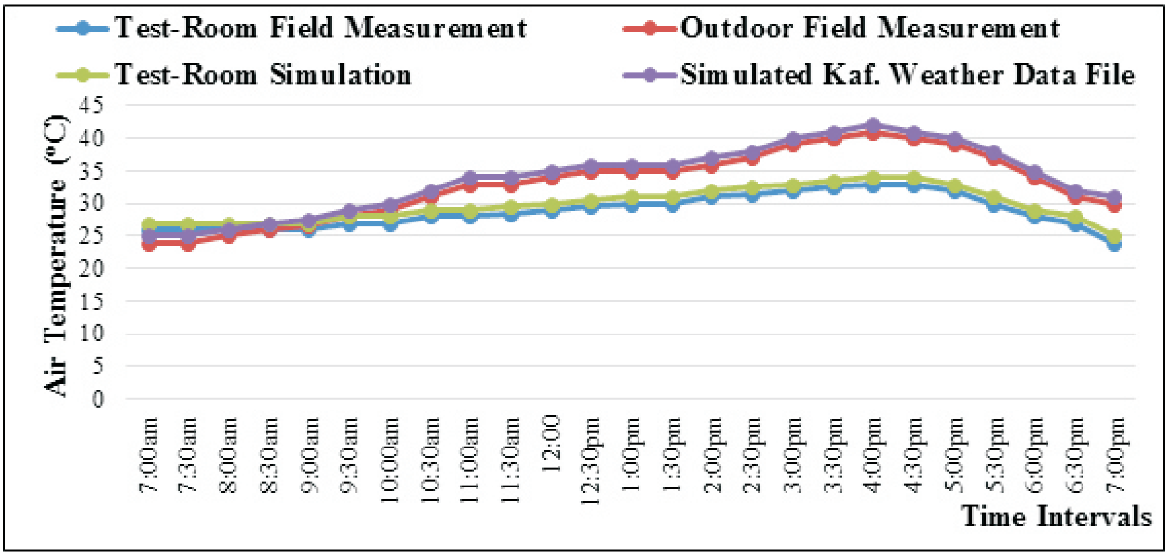

Figure 5: Comparison of Simulation, Field Measurement and Outdoor Air Temperature in the Test-Room

Additionally, both of the scenarios have the same graphical pattern which further confirms that the field measurement and the IES-VE software simulation results did not exceed the 0-20% range. **Figure 6 and 7** shows that both have the same linear equation of $y = x + 1$, and R^2 of 1 respectively.

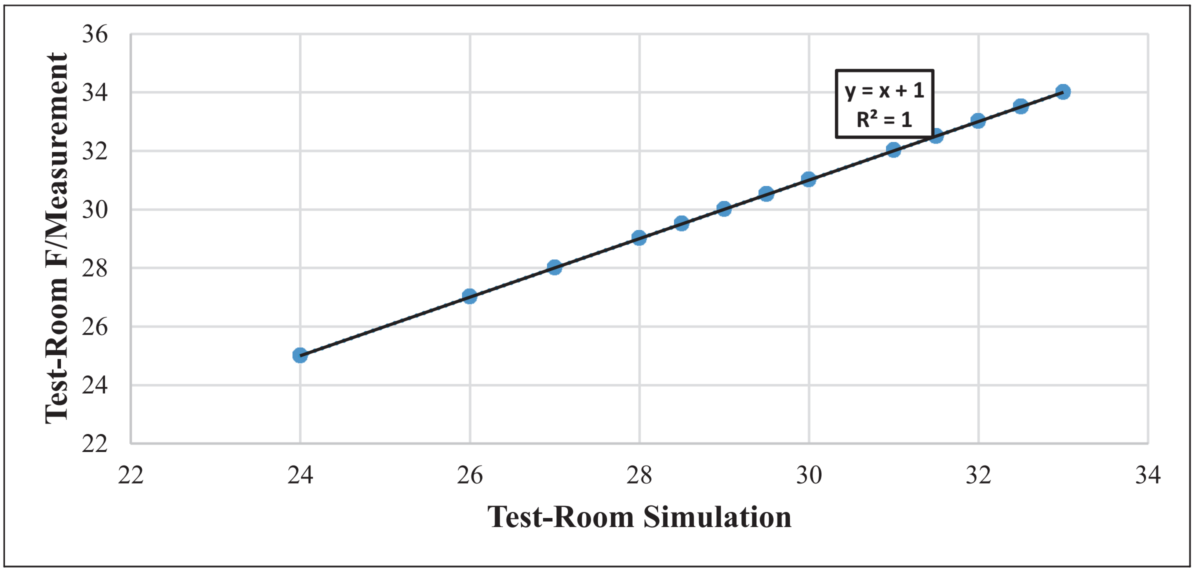

Figure 6: Correlation between IES-VE Simulation and Field Measurement Indoor Air Temperature in the Test-Room

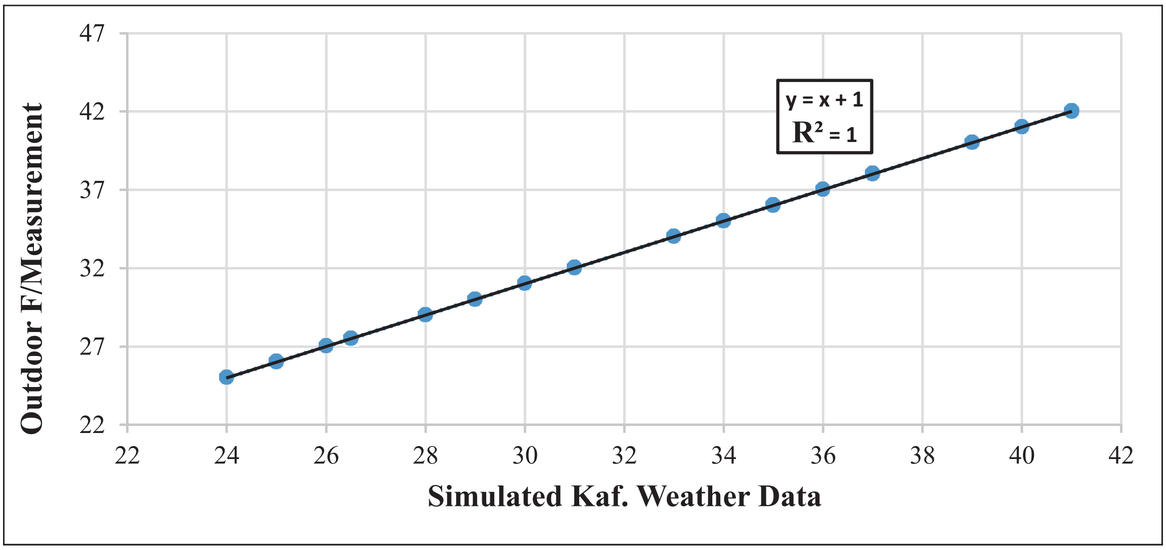

Figure 7: Correlation between IES-VE Simulated Kafanchan Weather Data File and Outdoor Field Measurement

The Relative Humidity

The comparison of the relative humidity of the indoor (test-room) and outdoor (environment) of the case study building obtained through field measurement and the simulation experiment was conducted. The data indicates that the maximum and minimum relative humidity in the test-room and outdoor were 44%, 28%, 56%, and 41% at 7:00 am and 4:00 pm respectively, while the simulation results revealed 46%, 32%, 57% and 42% at 7:00 am and 4:00 pm respectively. The minimum and maximum discrepancies are 4.5%, 14.3, 1.9 and 1.9%, and at the same time, see in **Table 2**. Both the two scenarios have R^2 of 1 each.

Table 2. Showing the Analysis of Relative Humidity

	Test-Room		**Outdoor Environment**	
	Field Measurement	Simulation	Field Measurement	Simulated Kaf. Weather Data File
Max. Rel. Humidity (%)	44	46	56	57
Time	4:00pm	4:00pm	4:00pm	4:00pm
Min. Rel. Humidity (%)	28	32	41	42
Time	4:00 pm	4:00 pm	4:00 pm	4:00 pm
Max. Discrepancy	4.5 %		1.9%	
Min. Discrepancy	14.3%		1.9%	
R^2	0.99		0.96	

The discrepancies did not exceed the limit of 0-20%. As shown in **Figure 8**, the result of field measurement and IES-VE simulation relative humidity in the indoor and outdoor have a similar graphical form. During the early morning hours starting from 7:00 am to 8:00 am, the relative humidity was higher in the indoor (test-room) than in the outdoor (environment). This condition may be due to the natural law that state that "temperature is inversely proportional to relative humidity" (Boyles Law).

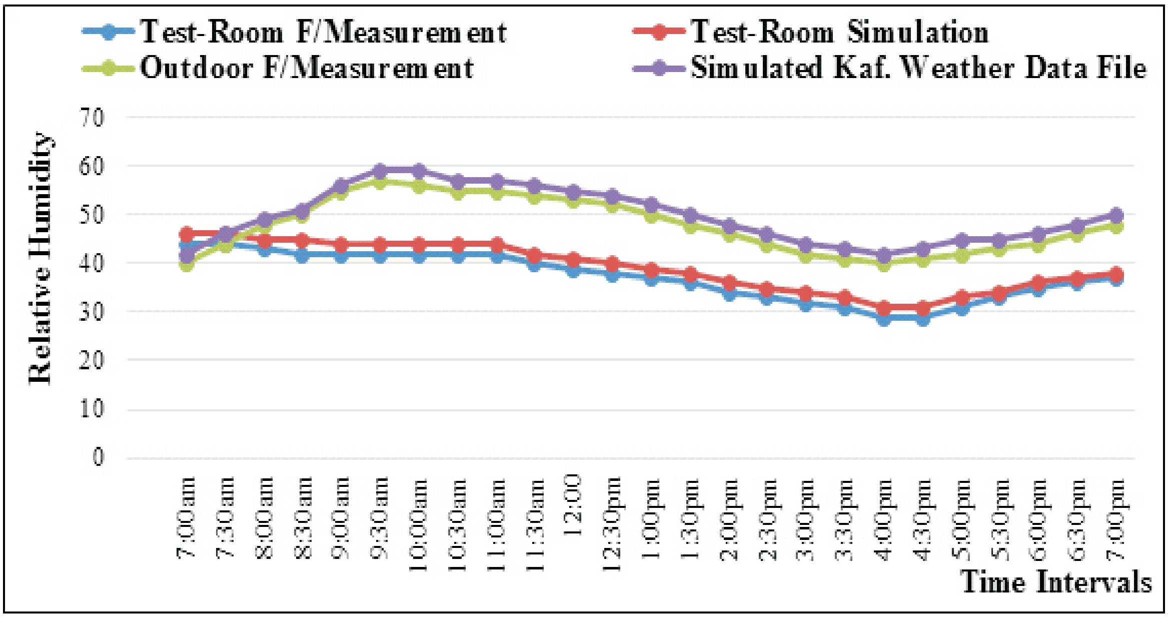

Figure 8: Comparison of Simulation with Field Measurement of Relative Humidity

So also, the R^2 values for the field measurement and IES-VE simulation of relative humidity in the test-room and outdoor were 0.99 and 0.96, as shown in **Figure 9 and 10**. The strong R^2 value suggests a strong correlation. The IES-VE software is, therefore, valid for further simulation of relative humidity in a fully-courtyard residential building in Kafanchan and environs.

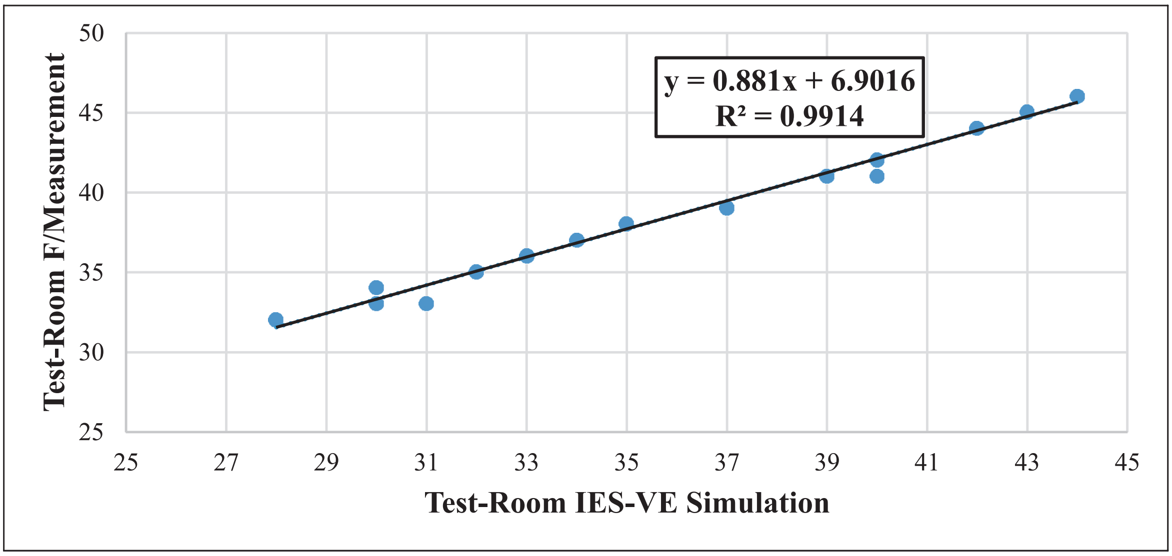

Figure 9: Correlation between Simulation and Field Measurement Relative Humidity in the Test-Room

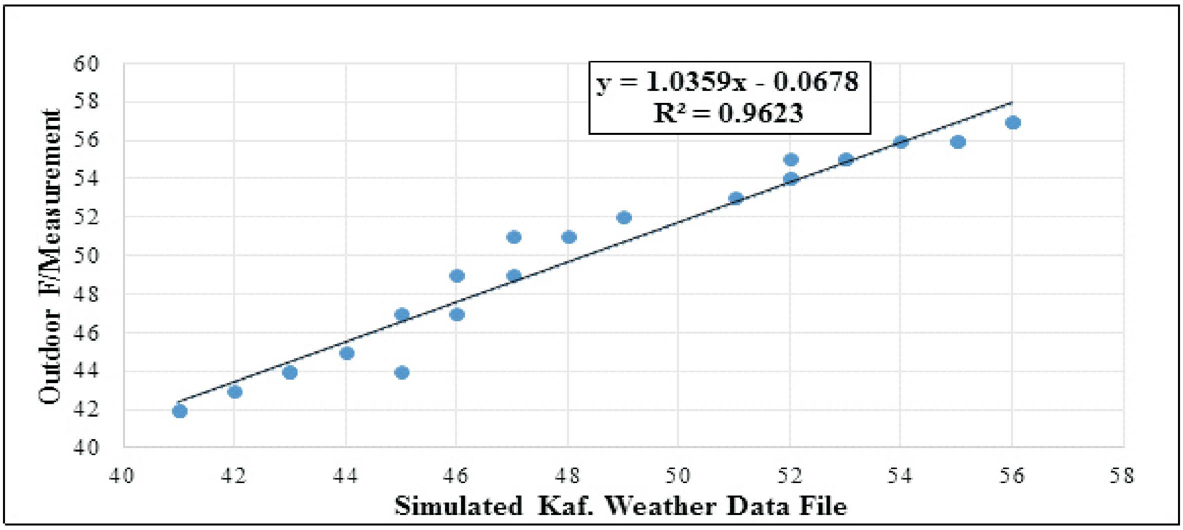

Figure 10: Correlation between IES-VE Simulated Kafanchan Weather Data File and Field Measurement Relative Humidity in the Outdoor Environment

Conclusion

Validation of the result of building energy simulation software is an important procedure in any research methodology that intended to use the simulation approach to achieve its research objectives. It is vital because the discrepancies in the results and the R^2 values will justify whether to go ahead and use the simulation software or to change to another one.

In the research, the discrepancies between the field measurement and the IES-VE software simulation results were very close. The findings revealed that IES-VE simulation software performed almost the same with the field measurements. The percentage of discrepancies are within the acceptable range of 0-20%. Also, the R^2 values are all equal to one (1) which connote a strong correlation. As a result, the study concludes that IES-VE simulation software is valid and can be adopted for further simulation of air temperature and relative humidity in a fully-enclosed courtyard residential building in Kafanchan, Nigeria. The professional architects should also acquire and use such building energy simulation software in their architectural design schemes because the thermal performance of their proposals can be predicted from onset.

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