OPTIMUM MICROCLIMATE EFFECT OF FULLY-ENCLOSED COURTYARD RATIOS AND ORIENTATION IN NIGERIAN TEMPERATE HOT-DRY CLIMATE

Markus Bulus[1, 2*]
[1]Department of Architecture, Faculty of Environmental Sciences, Kaduna State University. Kaduna-Nigeria
[2]Department of Architecture, Faculty of Built Environment, Universiti Teknologi Malaysia

* Corresponding author:
markusbulus8@gmail.com

ABSTRACT

The courtyard is being considered as a strategy for modifying microclimate of its immediate environment and thereby, enhancing thermal comfort conditions in buildings. Scholars have opined that this claim need to be confirmed. The aim of this study is to determine the effect of courtyard ratios and orientation on the microclimate of a fully-enclosed courtyard in a temperate hot-dry climate of Nigeria. The paper used a combination of the field measurement and simulation approach. During the field measurement, two study variables such as the air temperature and relative humidity were recorded while the Integrated Environmental Solution-Virtual Environment (IES-VE) simulation software was used for the simulation investigations starting with a validation procedure and then, the simulation experiment. The findings confirm that the courtyard ratios and orientation influence not only the microclimate of the semi-enclosed courtyard as revealed by Abdulbasit, et al., (2013) but, the fully-enclosed courtyard is also influenced by such variables. IES-VE simulation software has been proved to be a valid tool suitable for research of this kind. The paper concludes that further simulation experiment in order to understand whether such impact also applies to the indoor microclimate of the fully-enclosed courtyard residential building in Nigeria is required.

Keywords: *Fully-enclosed Courtyard; Courtyard ratios; Orientation; microclimate; Simulation*

1. INTRODUCTION

According to history, the courtyard is an ancient concept used in buildings for numerous purposes such as domestic, communal, religious and cultural usage (Markus 2016a). Even though Edward, et al., (2006) opined that its application in buildings cannot be stated when exactly it started, Berkovic, et al., (2012) has stated that it was during the earliest days of the Mesopotamian civilization in Ur. Ayhan and Neslihon, (2011) have also concord that the ancient courtyard house was located in Ur. Thereafter, the courtyard concept spread all around the world (Fatma, et al., 2016).

Numerous scholars have developed interest in conducting research on the courtyard as a space in the building envelope, and each of such scholars has defined the courtyard in his own way (Fatma, et al., 2016; Ok, et al., 2008; Yang, et al., 2012; Sozen, 1999; Ghaffarianhoseini, et al., 2015). Markus, et al., (2016b) has reviewed their definitions and concluded that the courtyard can be defined as “a space enclosed within a building with open walls”.

The courtyard is made-up of two basic typologies such as the semi-enclosed and the fully enclosed (Saeed, 2007). Meir, et al., (1995) has opined that the semi-enclosed courtyard typology has the most favorable potentials for modifying its microclimate than the fully-enclosed. But Markus, et al., (2017a) in his effort to determine the best typology used the field measurement approach to compare the microclimatic performance of the two typologies in Nigeria and concluded that the fully-enclosed is better-off. For the courtyard to be habitable, its microclimate should be conducive, and to achieve such task the knowledge of certain design variables such as the courtyard ratios and orientation are required (Reynolds, 2002). Other academics have also concord that the knowledge of the courtyard ratio, must be understood otherwise the courtyard space may be too unconducive for the users of such space(s) (Al-Masri & Abu-Hijleh, 2012; Muhaisen and Gadi, 2006a).

The issue of the courtyard microclimate is so important that scholars such as Muhaisen and Gadi, (2006b); Rajapaksha, et al., (2003); Tablada, et al., (2005); Markus et al., (2017b); Manio and Oral (2015) have contributed. They studied its behavior in order to understand how it can be further optimized for optimum microclimatic performance. Muhaisen and Gadi, (2006b) studied the impact of the courtyard ratios on courtyard thermal comfort in three climatic zones. Three case-studies were selected such as Rome, Kuala Lumpur and Cairo to represent the temperate cold, hot-humid and hot-dry climatic regions. The study shows that manipulating the courtyard height has a significant impact on shading in the courtyard, nine (9) meters, six (6) and three (3) meters were the courtyard height recommended for the hot-humid (Kuala Lumpur), hot-dry (Cairo) and temperate cold (Rome).

Manio and Oral (2015) studied the effect of courtyard ratio and orientation on heating and cooling load in a hot-dry climate of Turkey. They investigated the impact of manipulating the length and width of the courtyard form on its cooling/heating deficits. The study defined the relationship between the width and the length lines of an equilateral courtyard form as the Courtyard Shape Factor [CSF]. Numerous CSFs were studied. The studies show that as the courtyard form changes to the square shape the effect of shading is reduced due to orientation factor. The smaller the courtyard form, the lesser solar radiation received in the courtyard. The study concluded that the smaller CSF performed better irrespective of their orientation while the courtyards with larger CSF performed worse, but their orientation can impact on their cooling/heating load.
Markus, et al., (2017b) studied the microclimatic performance of a fully-enclosed courtyard residential building in Nigeria. In their first study, a comparison of the semi-enclosed with the fully enclosed courtyard form was conducted using the field measurement methodology. It was discovered that the fully-enclosed performed better. A further comparison of their indoor microclimate was conducted in their second study. Their findings also confirmed that the fully-enclosed courtyard residential building performed better than the semi-enclosed courtyard residential building.

In most of the courtyard and courtyard building studies conducted so far, the field measurement and simulation methodology were used to accomplish the research objectives of such studies. According to Bagneid, (2006), the validation procedure of the simulation software prior to the simulation experiment will produce ultimate and acceptable solutions. This is because the validation helps to check the discrepancies between the field measurement acquired data and simulation results of the simulation software and, thereby, confirming whether such tool is suitable for the study or not (Leng, et al., 2012).

For instance, Abdulbasit, et al., (2013) conducted a study that follows the validation and simulation procedures. The study provided both numerical and experimental proofs. The impact of courtyard ratio and orientation on the microclimate of the courtyard was investigated. Their purpose was to study how different courtyard ratio and orientation scenarios affects the performance of the courtyard microclimate in a hot-humid tropical climate in Malaysia. A semi-enclosed courtyard building was selected as the case-study for field measurement. The case-study was used to construct the base-case model by using a modeling software, SketchUp Version 8 and the IES-VE simulation software was adopted in the study. It was confirmed that changing the courtyard form and its orientation influences its microclimate. The optimum courtyard ratio was not confirmed but the study concluded with a recommendation for a similar study with a different courtyard typology such as the fully-enclosed courtyard and in a different climatic zone.

This paper, therefore, seeks to fill the gap as revel by Abdulbasit, et al., (2013). The fully-enclosed courtyard in a residential building was chosen for field measurement study by examining two types of design variants such as the courtyard ratios and orientation. The aim is to study their effect on the microclimate of a fully-enclosed courtyard in a temperate hot-dry climate of Nigeria.

2. Methodology of the Study

The methodology of this paper consists of two stages –the field measurement and the simulation stage. The following sections below explain the details of the two stages.

2.1. Field measurement

The field measurement was conducted in the temperate hot-dry climatic region of Nigeria. Nigerian temperate hot-dry climate has the characteristics of a moderately high temperature, moderate-high relative humidity, and rainfall during the raining season. A fully-enclosed single storey courtyard residential building located in Kaduna-Nigeria was selected as a case-study. The building is situated in the Malali area of Kaduna metropolis. It is on 9° 3' N latitude and 6° 11"E longitude. The detail characteristics of the fully-enclosed courtyard shape are illustrated in Table 1.

Table 1: Characteristics of the Fully-enclosed Courtyard Investigated

Courtyard Typology	Total Area	Shape	No. of storey
Fully-enclosed Courtyard	36m^2	Four sided rectangular	One-storey height

During the field measurement exercise, only two climatic parameters were recorded -air temperature and relative humidity. It was conducted using two Hobo Weather Data Loggers (HWDL). One HWDL was positioned in the center of the fully-enclosed courtyard at 1200 mm above the natural ground level and, launch at 30 minute time intervals as shown in Figure 1. The second HWDL was located outside (outdoor) the building. The field measurement lasted for twelve (12) hours, starting from 7:00 am to 7:00 pm on Monday 3rd of April 2017. The date was select due to the fact that it falls within the equinox period (the hottest days) in the tropic of cancer. Thereafter, the HWDL was readout via the HOBO-pro software and subsequently exported to Microsoft Excel 2013 for analysis.

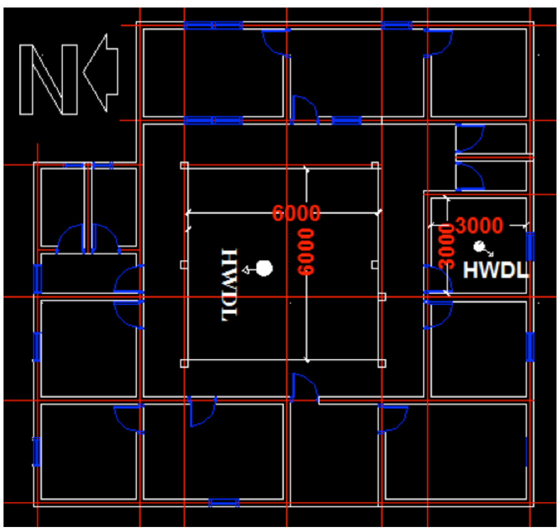

Figure 1: Case-study of Fully-enclosed Courtyard Residential Building

2.2. Simulation Investigations

IES-VE is a complete simulation software often used for simulation investigations in buildings. The microclimatic performance of a courtyard space in a building could be experimented through continuous adjustments of certain design variables. The IES-VE software can achieve such task through its APACHE application by using a weather data input of the study location. The Kafanchan weather data file was acquired and used for the simulation because it is the nearest weather data file. The acquired weather file was linked to the IES-VE software APlocate. Two major procedures such as the construction of the base-case model and validation of the simulation software preceded the simulation experiment.

2.2.1. The Base-case Model

A base-case model is the physical scaled three-dimensional drawing of the case-study building. The drawing is required for the validation experiment and other subsequent investigations. Thus, prior to the field measurement, an inventory of the case-study building was carried out in order to obtain the required information for constructing the base-case model. The obtained information was the courtyard dimensions and proportions, its orientation and building components. Then, the base-case model was constructed using the Model-It application of the IES-VE simulation software. As illustrated in Figure 2, the base-case model is typical of the actual fully-enclosed-courtyard residential building. The building components were the same.

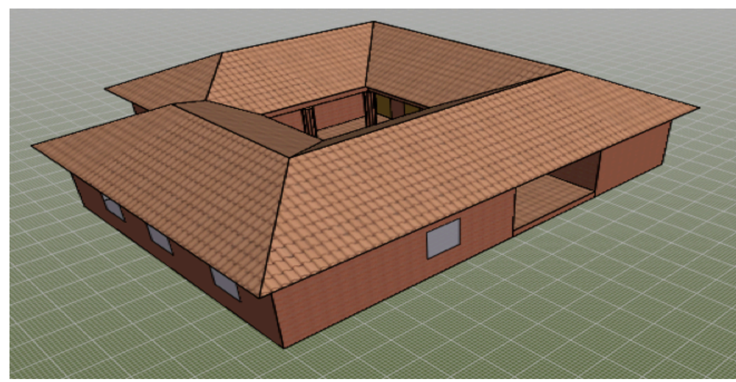

Figure 2: The Base-case Model

2.2.2. Validation of the Simulation Software

After the base-case model construction, the IES-VE simulation software was validated. The validation procedure was carried out by comparing the discrepancies between data obtained during field measurements and the base-case model simulation results. The benchmark used by scholars such as Leng, et al., (2012); Prasanthi et al., (2011); Maamera et al., (2006) was also used in this paper for the validation. Only air temperature and relative humidity were used.

2.2.3. Simulation Investigation of the courtyard ratios and orientation

Abdulbasit, et al., (2013) has confirmed that the courtyard ratios such as aspect ratio and orientation affect the courtyard microclimate of a semi-enclosed courtyard. This paper confirms whether the impact is the same in a fully-enclosed courtyard or not. Apart from the base-case model, the results of varying the courtyard height to 6m, and 9m was performed. The 6m and 9m were selected because fully enclosed courtyard residential buildings in Nigeria are within the range of one, two and three-storey height (Markus et al., 2017).
To determine the impact of orientation on the microclimatic performance of the fully enclosed courtyard, the best from the three courtyard ratios scenarios tested earlier (the base-case model, 6m, and 9m heights) was used for the experiment. Four different orientation scenarios were experimented such as the north/south, east/west, north-east/south-west and the north-west/south-east respectively. This paper studied 7 scenarios all in all, and a comparison of their microclimatic performances was performed. Table 2 illustrate the courtyard scenarios investigated.

Table 2 : Showing the Studied Variables Scenarios

Studied Variables	Scenarios	Code
Base-case model	The actual case-study fully-enclosed courtyard	B1
Courtyard heights	Six meters (6m) courtyard height	B2
	Nine meters (9m) courtyard height	B3
Orientations	North/South	B4
	East/West	B5
	North-East/South-West	B6
	North-West/South-East	B7

3. FINDINGS AND DISCUSSION

3.As earlier stated, two microclimatic parameters such as air temperature and relative humidity were measured during fieldwork in a fully-enclosed courtyard of a residential building for one day. This section, therefore, presents and discussed the results of the field measurement, IES-VE software validation, and simulation investigations.

3.1. Field Measurement (Air Temperature and Relative Humidity)

A fully-enclosed courtyard is a rectangular form. It has an east-west orientation with the longest axis facing the north direction. A comparison of air temperature and relative humidity between the fully-enclosed courtyard and the outdoor environment was conducted. Figure 3 show the air temperature and relative humidity results. A difference of 1 to 4 degrees (air temperature) and 1 to 10 percent (relative humidity) was observed. The fully-enclosed courtyard shows a better microclimate than the outdoor. The result concord with Markus, et al., (2017a) findings. The maximum and minimum air temperature in the fully-enclosed courtyard and outdoor environment was 33oC, 22oC, 37 oC and 18 oC at 7:00 am and 4:00 pm respectively. Whereas the maximum and minimum of relative humidity in the fully enclosed courtyard and the outdoor environment was 66%, 33%, 77% and 43% at 7:00 am and 4:00 pm respectively. The air temperature rises from 7:00 am and reach its peak at 4:00 pm and began to decline as the sunsets, but the relative humidity pattern reflects a type of temperate hot-dry climate and behaves contrary. The highest relative humidity was recorded at 7:00 pm while the lowest at 4:00 pm.

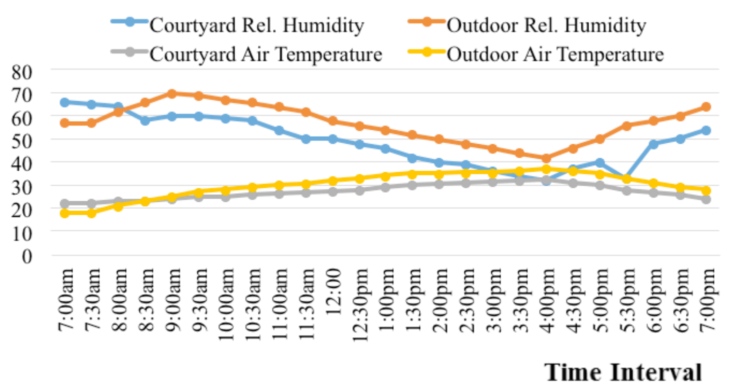

Figure 3: Field Measurement of Air Temperature and Relative Humidity

3.2. The Validation Results

According to Abdulbasit, et al., (2013), a comparison between the field measurement conducted on the actual site and the simulation of the base-case model is required for validation purpose in order to check for the suitability of the software for further simulation investigations. The validation procedure was achieved by comparing the air temperatures data obtained from field measurement in the fully-enclosed courtyard with that of the base-case model simulation via the IES-VE software. Only the air temperature results were used.

The findings show that the maximum and minimum discrepancies between the air temperature in the fully-enclosed courtyard and the IES-VE simulation of the base-case model as 4.5% and 3.6%. The discrepancies are within the accepted benchmark of 0-20% as reveal by scholars (Leng, et al., 2012; Prasanthi et al., 2011; Maamera et al., 2006). The correlation coefficient was 97.3%. A difference of 2 degrees was observed especially between 9:00 am until 4:30 pm, see Figure 4. The discrepancies may be due to the microclimate of the case-study building and weather condition on the day of the study. However, the validation findings confirmed that the IES-VE software is valid, reliable and suitable to be used for further simulation investigations for the courtyard scenarios.

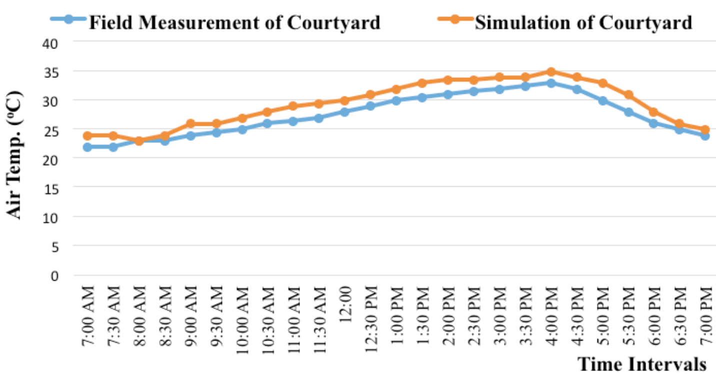

Figure 4 : Validation of IES-VE Simulation Software

3.3. The Simulation Investigations

As discussed in the methodology, the simulation investigation focused on the impact of changing two courtyard variables such as height and orientation. Therefore, the simulation findings are presented and discussed.

3.3.1. The effect of Courtyard Height on Air Temperature and Relative Humidity

To study the effect of courtyard ratio (courtyard height) on the microclimatic performance of the fully-enclosed courtyard, a comparison of the three courtyard height scenarios which represent the three typologies of fully-enclosed courtyard residential buildings in Nigeria was made through simulations. Besides the case-study building which is typical of one-story, two courtyard models of six meters and nine meters height each were also investigated. Figure 6 and 7 shows the effect of the studied variables on air temperature and relative humidity in the fully-enclosed courtyard.

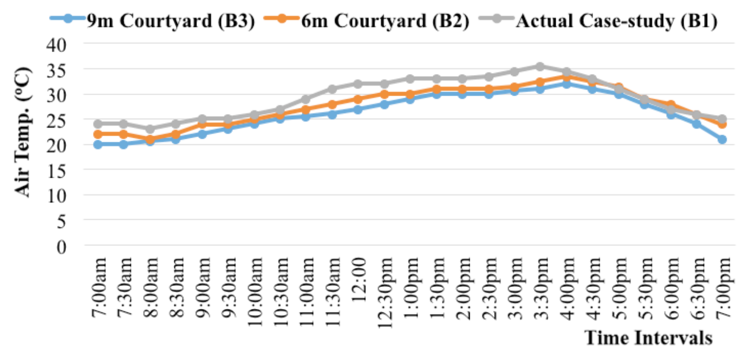

Figure 5: Effect Courtyard Height on Air Temperature

The air temperature is significantly influenced by the courtyard height as shown in Figure 5. The three height scenarios of the courtyard show discrepancies of 2 degrees. The B1 scenario which is three meters height (base-case model) has the worse air temperature. But the B3 which represent nine meters height performed better, then followed by B2. The B3 performance was due to increase in the shaded portion of the courtyard which is a major strategy for comfort in buildings in the temperate hot-dry climate (Muhaisen and Gadi 2006a).

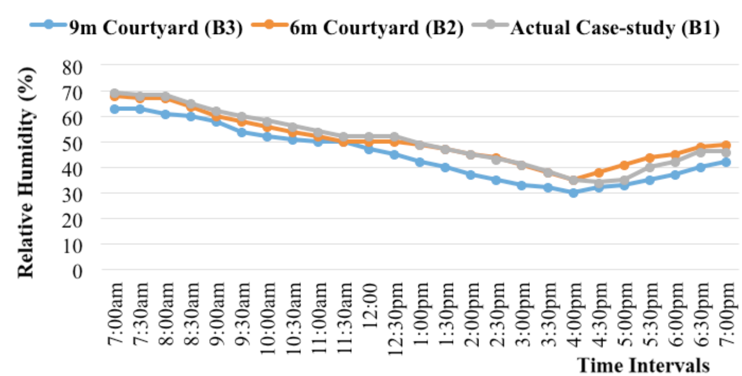

Figure 6 : Effect Courtyard Height on Relative Humidity

On the relative humidity, the conditions in the three scenarios are not different as compared to the air temperature. Just as in the air temperature, the relative humidity is considerably influenced by the courtyard height as revealed in Figure 5. A discrepancy of 1 to 3 percent is revealed in the three scenarios. Scenario B1 the base case model was the worse while the B3 (nine meters height) performed well, then next to it is B2.

3.3.2. The effect of orientation on Air Temperature and Relative Humidity

As discussed earlier, the best courtyard height scenario in section 3.3.1 was selected to further investigate the effect of orientation. Courtyard scenario B3 with nine meters height was further studied to evaluate the effect of orientation. Four orientation scenarios such as north/south, east/west, north-east/south-west and north-west/south-east were investigated.
The findings show that orientation could be an important factor influencing the courtyard microclimate. As illustrated in Figure 7, the east/west (B5) orientation was the best followed by north-east/south-west (B6). The north/south (B4) and north-west/south-east (B7) were worse, both having the same microclimates. The fully-enclosed courtyard has 36m2 with a geometric characteristic of a square form, meaning that any orientation should not have any impact on its shading performance, but the effect of orientation on wind direction most have given the east/west orientation the advantage. In Nigeria, the north-east trade wind blows on the north/south direction. Even though Muhaisen and Gadi (2006a) opined that shading effect has more impact on the courtyard microclimate (in the hot-dry climatic region) than ventilation, the findings of this study have proof contrary. Therefore, the north/east orientation has proved to be the best orientation.

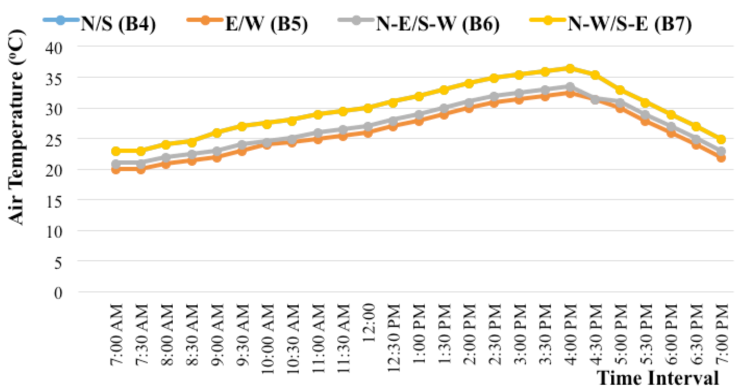

Figure 7: Effect of Orientation on Air Temperature

Figure 8 is the results of the relative humidity. The E/W (B5) orientation has the most favorable relative humidity condition, then followed by the N-E/S-W. Both N/S and N-W/S-E have the same conditions. Consequently, the E/W orientation can be considered as the most suitable orientation for fully-enclosed courtyard buildings in Kaduna-Nigeria. Both in terms of the air temperature and the relative humidity, the N/E orientation has demonstrated a better microclimate than the others.

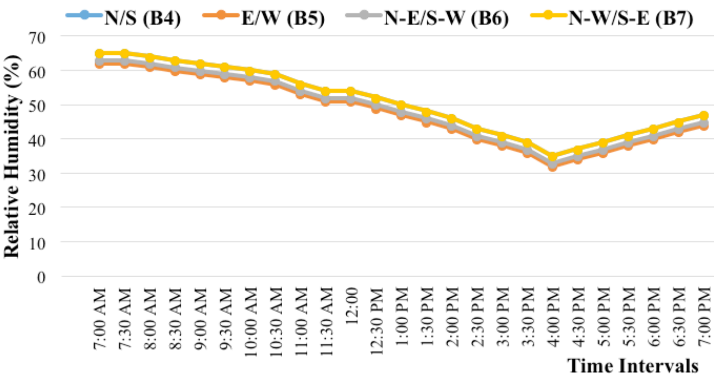

Figure 8: Effect Orientation on Relative Humidity

4. CONCLUSION

This study has confirmed that the microclimate of a fully-enclosed courtyard can be enhanced for a better performance only when the effect of the courtyard ratios and orientation are fully understood. Increase in the fully-enclosed courtyard height betters its air temperature and relative humidity. The orientation of the fully-enclosed courtyard also affects its microclimate significantly.

The purpose of the study was to confirm whether Abdubasit, et al., (2013) assertion that the courtyard ratios and orientation have a tremendous influence on the semi-enclosed courtyard microclimate also applies to the fully-enclosed courtyard. The indoor microclimate of the courtyard residential building was not considered in this study. Also, the effect of the courtyard shape factor was not discussed. The literature reveals that manipulating the courtyard shape factor could enhance the courtyard microclimatic performance. Therefore, further simulation investigations in this regard are required. This paper has proof that the simulation software is a powerful tool for prediction of microclimate performance of the fully-enclosed courtyard. The validation procedure has also confirmed that the IES-VE simulation software is valid and suitable for such study.

ACKNOWLEDGEMENTS

The Kaduna State University and the Nigerian Tertiary Education Trust Fund (TETFund) are two major institutions that the author must acknowledge in this study. Also, Mr. Bruno Lot Tanko has contributed in the course of this research endeavor.

5. REFERENCES

Abdulbasit, A., Norhati, I., Sabarinah, S. A., Josmin, Y. (2013). Courtyard Design Variants and Microclimate Performance. *Procedia - Social and Behavioral Sciences,* 101(2013), 170 – 180

Al-Masri, N., & Abu-Hijleh, B. (2012). Courtyard Housing in Midrise Buildings: An Environmental Assessment in Hot-arid Climate. *Renewable and Sustainable Energy Reviews,* 16(4), 1892-1898.

Ayhan, B., & Neslihan, D. (2011). The Influence of Climate and Privacy on Indigenous Courtyard Houses in Diyarbakır, Turkey. *Scientific Research and Essays,* 6(4), 908-922.

Bagneid, A. (2006). *The creation of a courtyard microclimate thermal model for the analysisof courtyard houses*. University Microfilms International, P. O. Box 1764, Ann Arbor, MI, 48106, USA.

Berkovic, S., Yezioro, A., & Bitan, A. (2012). Study of Thermal Comfort in Courtyards in a Hot Arid Climate. Solar Energy, 86(5), 1173–1186.

Edwards, B., Sibley, M., Hakmi, M., & Land, p. (2006). *Courtyard Housing: Past, Present and Future:* Spon Press.

Fatma, A., Ismail, L. H., & Solla, M. (2016). A Review of Courtyard House : History Evolution Forms, and Functions. *Engineering and Applied Sciences* 11(4), pp 2557–2563.

Ghaffarianhoseini, A., Berardi, U., & Ghaffarianhoseini, A. (2015). Thermal Performance Characteristics of Unshaded Courtyards in Hot and Humid Climates. *Building and Environment,* 87(2), 154–168. http://doi.org/10.1016/j.buildenv

Leng, P., bin Ahmad, M. H., Ossen, D. R., & Hamid, M. (2012). *Investigation of Integrated Environmental Solutions-Virtual Environment Software Accuracy for Air Temperature and Relative Humidity of the Test Room Simulations*. Paper Presented at the UMT 11th International Annual Symposium on Sustainability Science and Management, Terengganu, Malaysia.

Maamari, F. (2006). Experimental Validation of Simulation Model for Bi-directional Transmission Properties at the Delighting Performance Level. *Energy and The building,* 38(2006), 878-889.

Markus, B. (2016a). A Review of Courtyard Design Criteria in Different Climatic Zones. *An International Multi-disciplinary Journal, Ethiopia AFRREV,* 10(5), 181-192.

Markus, B. (2016b). A Review of Courtyard House in Nigeria: Definitions, History, Evolution, Typology, and Functions. *International Journal of Science and Technology (STECH)*, 5(2), 103-117.

Markus, B., Malsiah, B. H., & Lim, Y. W. (2017a). Microclimatic Performance of Courtyards in Residential Buildings in Kafanchan-Nigeria. *International Journal of Built Environment and Sustainability Ijbes*, 4(3), 220-226.

Markus, B., Lim Y. W., & Malsiah, H. (2017b). Microclimatic Performance of Courtyard Residential Buildings in Kafanchan-Nigeria. *Journal of Advanced Research Design,* 37(1), 16-25.

Meir, I. A., Pearlmutter, D., & Etzion, Y. (1995). On the Microclimatic Behavior of two Semi-enclosed Attached Courtyards in a Hot-dry Region. *Building and Environment*, 30(4), 563-572.

Muhaisen, A. S., & Gadi, M. B. (2006a). Effect of Courtyard Proportions on Solar Heat Gain and Energy Requirement in the Temperate Climate of Rome. *Building and Environment,* 41(3), 245-253.

Muhaisen, A. S., & Gadi, M. B. (2006b). Shading performance of polygonal courtyard forms. *Building and Environment,* 41(8), 1050-1059.

Ok, V., Yasa, E., & Özgunler, M. (2008). An Experimental Study of the Effects of Surface Openings on Air Flow Caused by Wind in Courtyard Buildings. *Architectural Science Review,* 51(3), 263–268. http://doi.org/10.3763/asre.2008.5131

Prasanthi R. Vangimalla, (2011). *Validation of Autodesk Ecotect Accuracy for Thermal andDaylighting Simulations*. Proceedings of the 2011 Winter Simulation Conference. U.S.A: IEEE.

Rajapaksha, I., Nagai, H., & Okumiya, M. (2003). A Ventilated Courtyard as a Passive Cooling Strategy in the Warm Humid Tropics. *Renewable Energy,* 28(11), 1755-1778.

Reynolds, J. (2002). *Courtyards: aesthetic, social, and thermal delight:* Wiley.

Saeed, T. A. (2007). *Studies on the geometrical properties of courtyard house form considering natural ventilation in hot-dry regions*. Unpublished 3492493, Illinois Institute of Technology, United States -- Illinois.

Sosen Randhwa, T. (1999). *The Indian Courtyard House*. Prakash Books Pvt. Limited.

Tablada, A., Blocken, B., Carmeliet, J., De Troyer, F., & Verschure, H. (2005). The Influence of Courtyard Geometry on Air-flow and Thermal Comfort: CFD and Thermal Comfort Simulations. *Energy and Buildings,* 36(2), 114.

Yang, X., Li, Y., & Yang L. (2012). Predicting and Understanding Temporal 3D Exterior Surface Temperature Distribution in an Ideal Courtyard. *Build Environ;* 57(1), 38-48.