EFFECT OF BUILDING ORIENTATION ON INDOOR MICRO-CLIMATE OF CLASSROOM BUILDINGS AT THE KADUNA STATE UNIVERSITY

Markus Bulus
Department of Architecture, Faculty of Environment Sciences, Kaduna State University, Kaduna-Nigeria.
Email: Markusbulus8@gmail.com

ABSTRACT

Received: 13 Dec 2017
Reviewed: 21 Jan 2018
Accepted: 8 Mar 2018

Current studies have discussed the significance of building orientation to the building indoor micro-climate and highlighted the need for more empirical research in other to establish the best orientation for buildings. Other scholars have argued that the impact of building orientation is insignificant and varies from one climatic region to another. This study, therefore, examines two prototype classroom buildings at the Kafanchan campus of Kaduna State University –Nigeria. The main purpose of the study is to determine the effect of building orientation on the indoor micro-climatic performance of two classroom buildings. Three Hobo Weather Data Loggers (HWDL) were used to collect data in the selected case-studies, and the third one was used as a benchmark. The study showed a remarkable difference in the indoor microclimatic conditions of the two buildings. The air temperature in case-study (B) is 1^{o}C to 2^{o}C lower than that of case-study (A) in all the respective time intervals. Also, 2% to 4% relative humidity difference was observed in favour of case-study (B). In conclusion, case-study (B) has demonstrated a more favourable indoor micro-climatic performance than case-study (A), and future simulation studies towards understanding the indoor micro-climatic performances of all possible building orientation options such as North-East/South-West, North-West/South-East, North/South and East/West in other to ascertain the optimum option are recommended.

Keywords: *Buildings; Indoor Micro-climatic; Orientation; Performance*

INTRODUCTION

The infrastructural deficit and most importantly the shortfall in building availability for human requirements such as housing, education, and even public services seems to be alarming especially in most of the underdeveloped countries. Even the available ones tend to have a myriad of challenges ranging from their material composition, poor workmanship, and poor micro-climatic performances due to the application of inappropriate architectural design strategies of such buildings.

The fact that most of the buildings have poor micro-climatic behaviours most especially in Nigerian hot-dry climate cannot be overemphasized (Akande 2010). In another effort to assess the micro-climatic of buildings in Nigeria subjective assessments of occupant perception on the microclimatic performance of students' hostel building located in Obafemi Awolowo University, Ile-Ife revealed was conducted. The findings revealed that more than 80% of the occupants were uncomfortable.

According to Daroda (2011), the architect must be familiar with the local climate of his proposed building site. But to understand the local climate, the site analysis is also required, and all these ingredients are supposed to be pivotal in the creative process of the architectural design. Also, the appropriate architectural design awareness as opined by Kabiru (2011) varies from one climatic region to the other and to each of the climatic region, the most suitable architectural design strategies should be the product of the mentioned ingredients. According to Markus *et al.,* (2016), the building orientation is one of the factors responsible for the poor microclimatic performance of buildings in general.

Even though the concept of building orientation may seem to be very familiar to the architects due to the fact that it has been enshrined in the architectural educational curriculum, its effect on the building microclimatic performance of the building may be far more than what the architects think or can imagine. Thus, the use of the active means for achieving a comfortable indoor microclimate in buildings rather than the passive strategies should be discouraged (IPCC 2015).

Therefore, to overcome this challenge the impact of the building orientation on the building indoor micro-climatic performance need to fully understand. The architect opinion on the building orientation at the architectural design stage should be based on empirical knowledge rather than his innovative ability or the client influence. But studies of such kind seems to be very few. As a result, a study of two classroom buildings (similar in dimensions and proportions) with different building orientation in the Kafanchan campus of Kaduna State University –Nigeria will be what this paper will seek to consider. The aim of the paper is to assess the impact of building orientation on the indoor micro-climatic performance of the two case studies.

LITERATURE REVIEW

In recent times, the researchers conducted a plethora of studies highlighting that orientation of buildings is a very important strategy for attainment of the optimum indoor micro-climatic performance of buildings. Even though each of the scholars has made his own contribution based on the perspective of his research purview, virtually all the studies were conducted by using the field measurements and simulations research methodology. Such studies include Sadafi *et al*., (2011); Meir *et al*., (1995); Berkovic *et al.,* (2012); Sthapak, (2014); and Almhafdy *et al*., (2013). Nevertheless, some other studies like Soflaei *et al*., (2016a); Akande (2010) and Soflaei *et al*., (2016b) adopted the field survey and geometrical measurement approach to accomplish their research task. Despite the disparity in their research approaches, their findings all seem to be similar.

For instance, Akande (2010), believed that the orientation is an essential design factor for passive and low energy architectural design delivery. He suggested in his study that the appropriate orientation of buildings should not be mistaken right from the design stage to the setting out of the building. Meir *et al*., (1995) in his effort to understand the microclimatic performance of two courtyard buildings in a hot-dry climatic region of Negev in Israel, revealed that the effect of shading due to building orientation has a significant impact on the micro-climatic performance of buildings, and therefore, concluded that since the building with the longest elevation facing the east has a greater percentage of shade during the morning and afternoon hours, such orientation is better for the Negev in Israel.

Sadafi *et al*., (2011) carried out their study in a terrace house in a tropical climate, the aim of their study was to investigate the thermal performance through field measurements and simulation methodology using the Ecotech software. But Autodesk has discontinued this software since March 2016. The findings revealed that the terrace house is capable of improving the cooling effects of its environment if shading by using the correct orientation of the building is not ignored. Berkovic *et al.,* (2012) also study on the thermal comfort of buildings in hot and arid climate by considering the effects of wind and shading by different orientations. The study shows that amount of shading can be small or large depending on the building orientation.

Almhafdy *et al.,* (2013) studied the impact of two critical architectural design variants such as the aspect ratio, and building orientation in the hot-humid climatic region of Malaysia. The air temperature, wind velocity, and relative humidity were measured using Portlog data weather station and the case model was constructed by using the SketchUp software, and the simulation was conducted by using Integrated Environment Solution and Virtual Environment (IES-VE) building energy software. The findings show that the courtyard geometry and orientation of the building impact its microclimatic behaviour, however, the effect of orientation as observed from the measured data revealed that the effect is less but significant. Sthapak (2014), opined that the relationship between the building orientation and the microclimate performance of buildings could not be neglected.

Soflaei *et al.,* (2016a) studied the Iranian traditional courtyard house, a field study research methodology was used and geometrical measurements of courtyard buildings with their orientations were conducted. The aim of the study was to study their orientation, dimensions, and proportions. The study shows that the orientation of such buildings was not ignored. Soflaei *et al.,* (2016b), conducted another study on the microclimatic modifying potentials of the Iranian traditional courtyard house by considering orientation, dimensions, and proportions. The study revealed that almost all the surveyed courtyards residential buildings were innovatively designed to allow orientation, dimension, and proportion to improve their potential to act as microclimate modifiers. Other research efforts on this subject include Wang (2007) and Li (2009).

All of these copious discoveries had concord to the reality of the importance of building orientation as a key strategy for mitigating cooling effects in the building. However, due to the differences that exist in the climatic regions of the world, the building orientation requirement of such climatic regions will also differ because, in some of the regions, cooling is more effective by shading while other is by air movement (ventilation) (Markus *et al*., 2017a). Furthermore, according to Almhafdy (2015), no evidence from the literature yet on the building orientation of two different locations, although, there is a general belief that orientation of buildings with the elongated side facing the north/south direction is the best option.

The Study Area

Kafanchan is located in the Southern part of Kaduna State, a north-central region of Nigeria. Geographically, it is on latitude 9^o 35'N and longitude 8^o 17'E and has 32km^2 land mass. Climatically, a tropical wet (raining) and dry climate with summer and winter seasons which is typical in Nigeria are being experienced. The wet season begins in the middle of the month of April and ends in October, while the dry season starts in the middle month of November to early April. The yearly amount of rainfall collected is within the range of 1140mm to 1204mm. Kafanchan has the yearly average temperatures range of 36.4^{o}C (BLSK, 2010). The area is noted for having large quantities of fuelwood and consumers of wood all year round (Yunana *et al*., 2014).

METHODOLOGY

The study used the inventory survey and field measurement approach to achieve its objectives. The overall research methodological procedure of this paper is illustrated in Figure 1. The justification for the choice of the research approach adopted in this study is from the literature review. The literature revealed that previous studies of this kind adopted either the field measurement approach or a combination of both the measurement and simulation (Markus *et al*., 2017b; Leng *et al.,* 2012; Sadafi *et al*., 2011; Meir *et al*., 1995; Berkovic *et al.,* 2012; Sthapak, 2014; and Almhafdy *et al*., 2015; Soflaei *et al*., 2016a & b).

Selection of the Case-Study Buildings

The Kafanchan campus of the Kaduna State University was the most preferred study area due to its numerous typologies of buildings. Two prototype lecture classrooms were selected and examined at the same time from 7:00 am to 7:00 pm. The two case-study buildings were selected based on certain requirements such as:

1. The most have a different orientation such that the longest view facing the North/South direction while the case-study building facing the East/West direction.
2. The most have the same dimensions, proportions (geometry).
3. The material component such as the floor finish, wall, roofing, doors, and windows must be the same.

The Case-Study Configuration

Figure 2 and 3 shows the pictorial view and architectural floor plan of the two case-study lecture classrooms building typologies that were selected for this study with the locations of the field measurement tools. Their geometrical dimensions, orientation, form, and height are shown in Table 1.

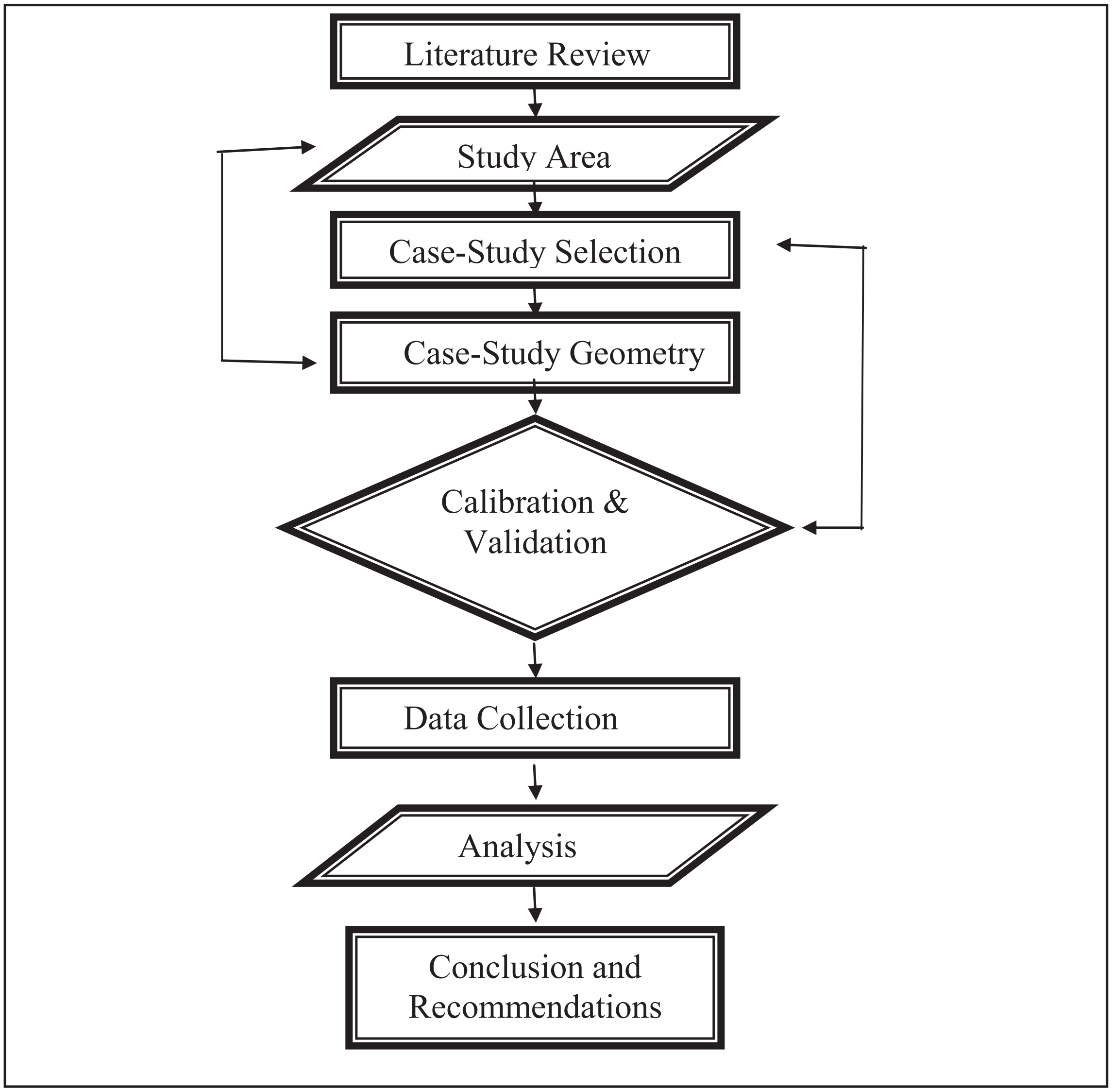

Figure 1. Summary of methodological procedures

Table 1: Characteristic of Courtyard Typologies

Typology	Area	Form	Height (m)	Orientation
Case-Study (A)	12 x 9 = 108 m^2	Rectangular	3.8	Longest view facing East/West direction
Case-Study (B)	12 x 9 = 108 m^2	Rectangular	3.8	Longest view facing North/South direction

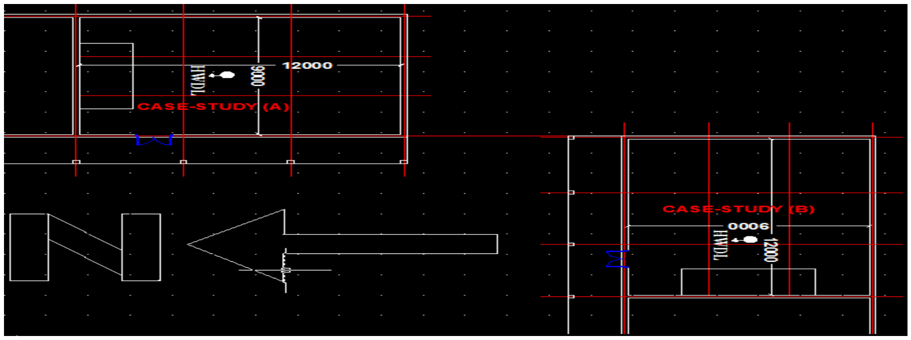

Figure 2: Floor plan of case-study (A) & (B)

Figure 3: Pictorial view of case-study (A) & (B

Tool Calibration

Earlier on, the tools were calibrated before the commencement of the field measurement. It was conducted on the 21st of March, 2017. The calibration study is the process of comparing and validating the results as obtained from the measuring tools. Academics have opined that this process is necessary when more than one measuring tools are involved in a study (Leng*, et al.*, 2012; Markus *et al.,* 2017b). Therefore, the air temperature and relative humidity parameter were used for the calibrating study. Figure 4 is a pictorial view of the measuring tools used in the two case studies.

Figure 4. A view of the measuring tools

Data Collection

Three Hobo Weather Data Loggers (HWDL) were used for the data collection. Two HWDL were placed at 1.2m above the floor level in the centre of case-study (A) and (B) while the third one was positioned in the outdoor area to serve as a benchmark. The measurement was carried out simultaneously with the doors and windows opened. The experiment started from 7.00am to 7.00pm on Tuesday, 22nd day of March 2017. The date was preferred in other to appraise the must hottest situation since it falls within the summer equinox. The HWDL was launched to record air temperature and relative humidity at 30 minutes' intervals. Then, the acquired data was read out via the HoboPro software and subsequently exported to Origin7.0 for analysis and discussion. Figure 5 is typical of the HWDL in one of the case-study.

Figure 5. A view of the HWDL in case-study (A)

RESULTS DISCUSSION

The main purpose of the study is to determine the effect of building orientation on the micro-climatic performance of two classroom buildings. Two parameters -air temperature and relative humidity, were investigated in case-study (A) and (B) with the outdoor (open-air space) as a benchmark. The three (3) HWDL were calibrated and validated to ensure their accuracy. In the following section, results of the experimental study are presented and discussed.

The Findings of the Calibration Procedure

The results show that the difference in air temperature and relative humidity at the respective 30 minutes' time interval is within the range of 0.01^{o}C to 0.02^{o}C, and 0.01% to 0.03% respectively (see Figure 6 and 7). Academics such as Almhafdy *et al*., (2015), Leng *et al.,* (2012), and Markus *et al*., (2017b) revealed that a reading difference of 0.01, 0.02, and 0.03 are very insignificant in a research of this endeavour and, therefore, the findings have verified the validity of the HWDL as tools with a high degree of precision for this study.

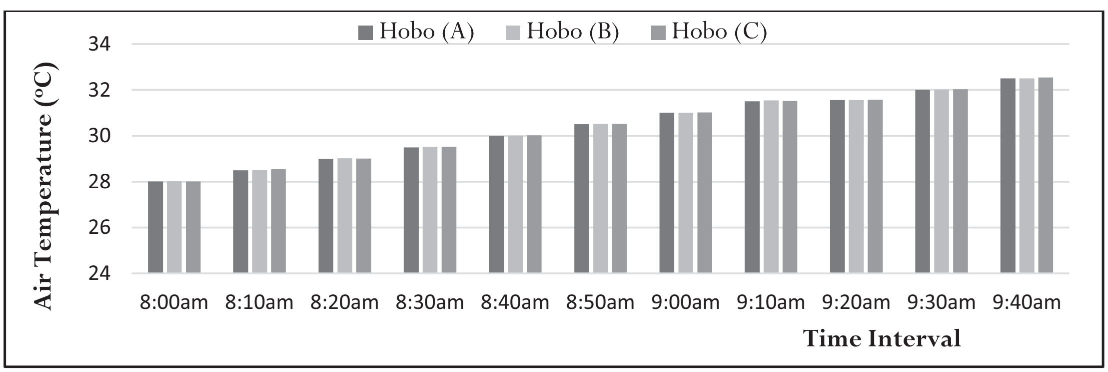

Figure 6: Air temperature of the three (3) HWDL

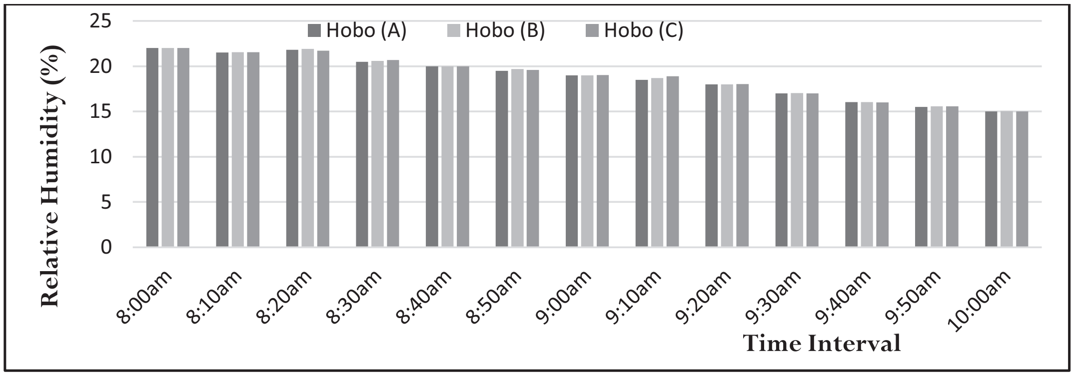

Figure 7: Relative humidity of the three (3) HWDL

The Site Measurements

Air Temperature

As revealed in Figure 8, the air temperature of outdoor (benchmark) is revealed to better off during the early and late evenings. But case-study (B) is lower at all the respective time intervals with 1^{o}C to that case-study (A). The orientation of case-study (B) tends to favour solar radiation reduction than that of case-study (A). The outdoor air temperature is seen as the worst from 10:30 am to 5:00 pm due to the fact that the solar radiation has direct access without any barrier. However, due to the natural cooling circle, the outdoor air temperature is seen to be less than the case-studies in the early morning and late evening hours. The maximum air temperature difference between the two case-study (A) and (B) is 2^{o}C, which was observed at 12:30 pm to 6:00 pm, whereas the minimum was 1ºC which was recorded almost uniformly from 8:00 am to 11:00 am.

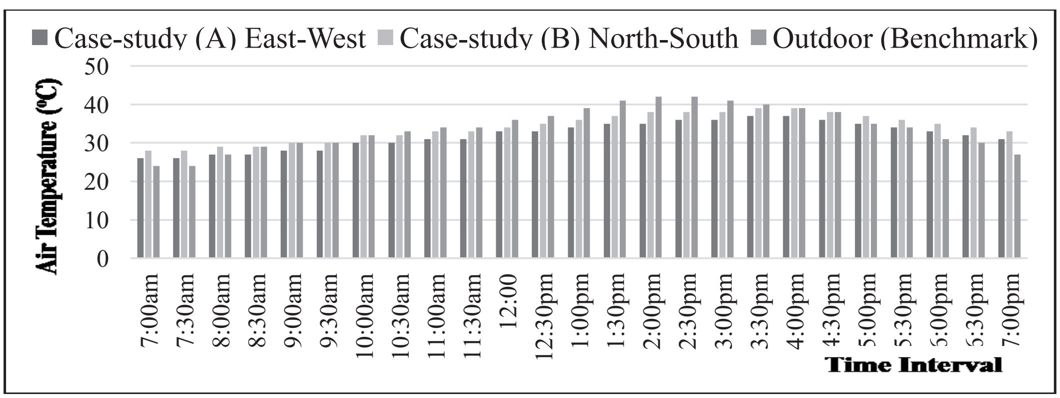

Figure 8: Air temperature

Relative Humidity

As illustrated in Figure 9, the relative humidity in the outdoor was revealed to be the worst throughout the duration of the experiment with 4% and 6% difference as compared with case-study (A) and case-study (B). But case-study (A) is lower at all the respective time intervals with 2% to that of case-study (B). The orientation of case-study (B) favours solar radiation reduction than that of case-study (A). The maximum relative humidity difference between the two case-studies is 4%, which was observed at 7:00 am, while the minimum was 2% which was recorded almost uniformly from 2:00 pm.

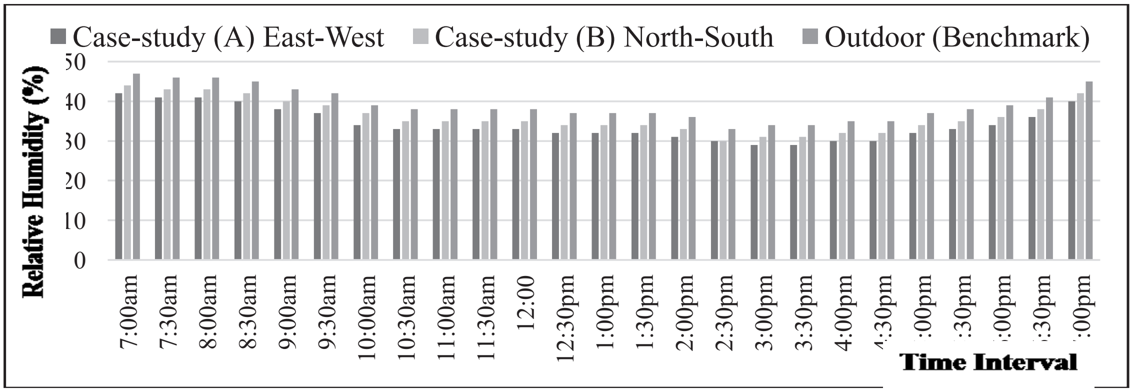

Figure 9: Relative humidity

DISCUSSION

Air Temperature

The case-study lecture classroom (A) is oriented towards the North-South orientation and its approach elevation facing the north/west direction, unlike the case-study lecture classroom (B) which have East-West orientation and its approach elevation facing east/west direction. The former reduces the access of excessive solar radiation from the sun into the building while the later exposes a larger percentage of the building to excessive solar radiation penetration from the sun to the building.

According to Almhafdy *et al.,* (2015), building orientation can reduce the effect of solar radiation on buildings or enhance air circulation as the case may be. But the choice of which of the two to consider as a major factor to determine how the building is to be oriented will definitely depend on the best strategy (Markus 2017b). According to Muhaisen and Gadi (2006), natural air circulation effect in buildings is less effective in the hot-humid climatic regions, while both the natural air circulation enhancement and solar radiation reduction design strategies are very effective in the hot-dry climatic regions such as Kafanchan.

The effect of natural ventilation (air movement) might be a major factor why the case-study (B) performed worst. The findings of air temperature discrepancies in this study concord with the assertions from the literature, however, the effect of vegetation cannot be ascertained as the scope of this study does not include it.

Relative Humidity

Unlike the air temperature performance that revealed case-study (B) as being better off than case-study (A), the relative humidity result as illustrated in Figure 9 showed a contrary result. Case-study (A) is revealed to have a lower relative humidity than that of case-study (B). But even though case-study (A) has been revealed to be the best, the conclusion of the ultimate building orientation for Kafanchan (the study area) should be based on the most impacting microclimatic factor of the climatic region to which Kafanchan belongs to (Muhaisen and Gadi 2006b). As opined by Soflaei *et al*., (2016a), the relative humidity result as revealed in this study may be due to some reasons such as the nature of the climate of the study area, the absence water bodies such as ponds and vegetation.

According Almhafdy *et al.,* (2015), the most impacting microclimatic factor in the hot-humid regions such as Malaysia and other locations around the globe that are some few distance North or South of the equator is the relative humidity and air temperature, while for the hot-dry regions the relative humidity is always lower than the air temperature. Muhaisen and Gadi (2006b), also opined that the most effective architectural design strategies for indoor air temperature are more effective in the hot-dry climatic regions while the hot-humid requires a combination of both the air temperature and the relative humidity. Markus *et al.,* (2017b), agreed with the Almhafdy assertion. Markus *et al.,* (2017b) revealed in a field measurement experiment conducted in a courtyard residential building in

Kafanchan that the outdoor air temperature is always above 23^{o}C (upper limit of air temperature comfort benchmark) during the day periods, while the relative humidity is always far less than 70%.

Consequently, the building orientation that mitigates the effect of the air temperature is more critical for Kafanchan-Nigeria than the one that favoured the relative humidity. Therefore, case-study (B) should be the most effective orientation for Kafanchan since the effect of the relative humidity is not beyond the comfort limit level.

CONCLUSION

This paper seeks to assess the impact of the orientation of building on its indoor micro-climatic performance. Two case-studies lecture classroom buildings were studied in the Kafanchan campus of the Kaduna State University. The paper concludes that a building in Kafanchan should be oriented in such a way that its longest elevation is toward the northern or southern view (case-study B). This building orientation was discovered to be the most effective in terms of the indoor air temperature performance as compared with case-study (A). On the other hand, the case-study (A) that is the building with the longest elevation facing the eastern or western view was revealed to have the best relative humidity performance because temperature humidity has an inverse relationship (Boys Law).

However, architectural design strategies that have the capacity to reduce the indoor air temperature (such as the building orientation) rather than the relative humidity are the most critical options because the relative humidity is more critical in the hot-humid climatic region than in the hot-dry of which Kafanchan belongs to.

Finally, this study has the limitation of not being able to test the different building orientation typologies due to the difficulty in selecting case-studies with such options. The methodology of the study is another factor as the required number of the HWDL tools were not enough. Therefore, the use of a simulation software plus the field measurement research methodology to validate this study and to further determine the optimum building orientation for the city of Kafanchan-Nigeria is recommended.

ACKNOWLEDGMENT

The authors would like to acknowledge The Kaduna State University, Nigeria and The Nigerian Tertiary Education Trust Fund (TETFund) for the assistance granted for this research.

REFERENCES

Abdulbasit, A., Norhati, I., Sabarinah, S. A., and Wan, M. N. (2013). Courtyard as a Microclimatic Modifier Experimental Study on Actual Site. *Applied Mechanics and Materials Online:* ISSN: 1662-7482, Vol.567, 14-19.

Abdulbasit Almhafdy, Norhati Ibrahim, Sabarinah Sh Ahmad, Josmin Yahya. (2015). Thermal Performance Analysis of Courtyards in a Hot Humid Climate Using Computational Fluid Dynamics CFD Method. *Procedia - Social and Behavioural Sciences,* 170 pp 474 – 483.

Akande, O. K. (2010). Passive Design Strategies for Residential Buildings in a Hot dry climate in Nigeria. *WIT Transactions on Ecology and the Environment 128*, 61–71.

Berkovic, S., Yezioro, A., and Bitan, A. (2012). Study of thermal comfort in courtyards in a Hot-Arid climate. *Solar Energy*, *86*(5) 1173–1186.

Bureau of Land and Survey Kaduna (2010). “Map of Kaduna State Showing the Local Government Areas”.

Farzaneh, S., Mehdi, S., & Seyed, M. S. (2016a). Investigation of Iranian Traditional Courtyard as a Passive Cooling Strategy (A Field Study on BS Climate). *International Journal of Sustainable Built Environment,* 5, pp 99–113.

Farzaneh, S., Mehdi, S., & Seyed, M. S. (2016b). Traditional Iranian Courtyards as Microclimate Modifiers by Considering Orientation, Dimensions, and Proportions. *Frontiers of Architectural Research,* 6 pp 12-13.

IPCC. (2015). *Mitigation of Climate Change* (Vol. 3): Cambridge University Press.

Kabiru, S. D. (2011). Climate Responsive Architecture: Creating greater Design Awareness among Architects. *Journal of Environmental Issues and Agriculture in Developing Countries,* Vol. 3(1) 33-39.

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 the International Annual Symposium on Sustainability Science and Management, Terengganu Malaysia.*

Li, T.-t. (2009). Study of the Original Ecology Design in the Courtyard of Traditional Dwellings in MeiZhou. Paper presented at the *Mechanic Automation and Control Engineering (MACE), 2010 International Conference.*

Markus, B. (2016). Evaluation of Courtyard Usage and its Design Requirements in Residential Buildings in Nigerian Hot-Dry Climate. *International Journal of African Society Cultures and Traditions*, Vol.4 (4), 1-12.

Markus, B., Malsiah, B. H. and Lim, Y. W. (2017a). Courtyard as a Passive Cooling Strategy in Buildings. *International Journal of Built Environment and Sustainability, IJBES* 4(1) 48-55. Markus, B., Malsiah, B. H. and Lim, Y. W. (2017b). Microclimatic Performance of Courtyards in Residential Buildings in Kafanchan-Nigeria. *International Journal of Built Environment and Sustainability, IJBES* 4(3) 220-226.

Meir, I. A., Etzion, Y. and Faiman, D. (1990). Energ>> *Aspects of Design in Arid Zones,* Desert Architecture Unit/Applied Solar Calculations Unit, J. Blaustein Institute for Desert Research Ben Gurion University of the Negev, Sede Boqer Campus & State in Israel, Ministry of Energy and Infrastructure, Research, and Development Division, Jerusalem.

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.

Sadafi, N., Salleh, E., Haw, L. C., & Jaafar, Z. (2011). Evaluating Thermal Effects of Internal Courtyard in a Tropical Terrace House by Computational Simulation. *Energy and Buildings, 43*(4), 887-893.

Swasti, S., & Bandyopadhyay, A. (2014). Courtyard Houses: An Overview. *Recent Research in Science and Technology,* 6(1).

Wang, Hui & Zhang, Yue & Sun, Hongjun, 2007, 'Embodiment of Chinese Traditional Cultural Concept in Beijing Courtyard House', *Journal of Liaoning Institute of Technology*, vol.27, no.3, pp176-189.

Yunana, M A., Siaka, S., Nale, B. Y., Simon, S., & Markus, B. (2014). Analysis of Bush Burning in the Northern Guinea Savannah of Kaduna State: Implication for Agriculture and the Environment. *International Journal of Comparative Studies in International Relations and Development*, Vol 3 No 1. Issn Print: 2354-4298, Online 2354- 4201.