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Microclimatic Performance of Courtyards in Residential Buildings in Kafanchan-Nigeria

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ABSTRACT

Recent studies have emphasized the importance of the courtyard microclimate to the building and the need for a comparative study on their typology in other to ascertain the best alternative. Also emphasizing that the architect choice of the courtyard typology to be adopted in his architectural design schemes should be based on performance rather than his mere intuitive choice. Therefore, an investigational study of two different courtyard forms with the same perimeter, and material finished -the fully enclosed internal central courtyard and the semi-enclosed courtyard has been carried out in two existing residential buildings, in the city of Kafanchan-Nigeria. The main purpose of the study is to compare their climatic performances in other to ascertain the best option. The study employed the experimental methodology. Three Hobo Weather Data Loggers (HWDL) were used to collect data in the courtyards, and the third one was positioned in the outdoor area as a benchmark. Only two climatic variables, namely air temperature, and relative humidity were examined as these variables have not been investigated in a single research on the courtyard in Nigeria. The results showed a definite difference in the microclimatic conditions of the two courtyards. The fully enclosed internal courtyard is seen to have a better air temperature difference of 1oc to 3oc at the time intervals, and the relative humidity difference of 1% to 6%. In conclusion, the fully enclosed internal courtyard has demonstrated a more favorable microclimatic performance than the semi-enclosed, and future simulation studies towards its optimization are recommended.

1. Introduction

One of the most important and contemporary discussions in the built environment, architectural practice, theory, and procedures is “Passive Architectural Design Strategies [PADS]” (Markus *et al*., 2017). And it is becoming more and more difficult to ignore the issues of microclimatic performance of the architectural design space(s). Recent studies in PAD have emphasized that the courtyard is a passive design element, and its microclimatic performance should be investigated (Tablada *et al*., 2005; Akande 2010; and Markus 2016a).

The Courtyard is a worldwide architectural design element which has been accepted and put into practice for many centuries of years in the entire globe and most particularly in residential buildings. And scholars have developed a research interest in recent times on the courtyard subject. The scholars have conducted studies on the courtyard from a different perspective of the courtyard in buildings and each of them had defined what the courtyard is all about in his own point of view. And some of the definitions are as follows: Chen (2012), “Said that the courtyard is an empty space for specific use (somehow all connected with a domestic function) are arranged”. Taleghani and van den Dobbelsteen (2012), “refers to the courtyards as, unique spaces that are external yet almost internal, open to the sky, usually in contact with the ground, but bordered by rooms”. Also, Wazeri (2014), “asserted that a courtyard is a covered outdoor or semi-outdoor space surrounded by buildings and open to the heavens”. The definitions can go on and on, but Markus (2016b) in his research effort to make a review of Courtyard definitions concluded that the courtyard is an open space bounded by walls of a building.

The courtyard is indeed an enclosed space surrounded by a building and exposed to the heavens (Edward *et al.*, 2006). Its application originated from the primordial architecture of the Arabs, initial Europe, and other past civilizations (Reynold 2002). The courtyard is the primogenial architectural expression that has been adopted in buildings by people. It could be found in residential or in municipal buildings that offer pockets of meeting space(s) that stimulate communal and family oriented activities such as gardening, cooking, working, playing, sleeping, or keeping of animals (Adeyemi 2007). All through the centuries, this basic architectural design form has been enhanced to mitigate various environmental features such as topography, site constraint, and purposed to generate a different form of courtyard such as U, L, T or Y (Das 2006). According to Meir *et al*., (1995), the courtyard is classified into two major typologies, that is, the semi-closed [three sided], and the fully enclosed [four or more sided] courtyard.

The courtyard has numerous of benefits. Its benefits cut across enhancing the microclimatic performance of the building and thereby adding to the building durability, and secondly, the thermal comfort of the end users (Farzaneh *et al.,* 2016a). According to (Adeyemi 2007), the courtyard in a typical Nigerian traditional house concept makes provisions for domestic functions such as: provision for playing ground; provision for women cooking area within the internal central courtyard space; laundry space; space for traditional craftwork; family and communal gathering space; for celebrations and feasting (for example), child naming, dedications and funeral occasions as required by the people's norms and traditions; receiving guest and settling disputes. A perfect example of Nigerian ethnic groups that enjoy the above-mentioned courtyard benefits are; the Yoruba ethnic group in the south-western region of Nigeria, the Igbo ethnic group in the eastern region of Nigeria; the Asante, Ekwere and Calabar in the South-Eastern region of Nigeria; the Hausa in the Northern region of Nigeria and other minority groups in the middle belt region of Nigeria such as: Bajju, Ham, Kataf, Idoma, Tiv, Tarock, Angas, Brom, and so on (Adeyemi 2007).

Numerous studies have established that the courtyard is a microclimate modifier (Aldawoud 2008; Abdulbasit *et al*., 2014). Consequently, this comparative study attempts to study the microclimatic performance of two different courtyard forms with the same dimensions, proportions and material finish -the fully enclosed internal central courtyard and the semi-enclosed courtyard, in two existing residential buildings located in the city of Kafanchan-Kaduna in the north central region of Nigeria. The main purpose of the study is to compare their microclimatic performances in other to ascertain the best option, and thereby justifying the choice of the courtyard typology to be used in an ongoing research work on the courtyard optimum ratio for microclimatic performance in buildings.

2. Theoretical Background

The fact that the present state of depletion of the ozone layer is far beyond what we can think or imagine may not be untrue. As reported by the Intergovernmental Panel on Climate Change (IPCC) (2015), "preventive climate change would have need of significant and continuous reductions in conservatory gas emissions in other to reduce climate change threats. The report continued that, outside air temperature is anticipated to move up over the 21st century under all assessed emission situations, the report goes on and on". But the fundamental question is that if outdoor air temperature will continue to be on the increase, what then should be the main approach of the architect towards his architectural design scheme and practice? Those the architect has any contribution to offer towards mitigating the global challenge of ozone layer depletion caused by environmental pollution as buildings design by architects tend to depend completely on the mechanical means for achieving occupants thermal comfort, or should he continue in his intuitive contemporary design approach that depends on the post-modern concept that completely ignores the traditional design concept of buildings that offers cooling, and thereby adding to the lingering challenge of greenhouse gas emissions, as use of electric generators remain the only sure source of power in Nigeria and in most underdeveloped countries in Africa and the world generally, or still, should a shift to passive strategy for architectural design be considered as an option?

Recently, the research effort in Passive Architecture design (PAD) have highlighted the need for passive architectural design approaches. And the application of the courtyard as a Passive Architectural Design Strategy (PADS) may be one among the most suitable approaches. Tablada *et al*., (2005) has suggested that passive architectural design strategy is a major approach for mitigating cooling effects in buildings and recommended the application of the courtyard. Akande (2010), has also agreed in his studies on "Passive Design Strategies for Residential Buildings in a Hot Dry Climate in Nigeria". He recommended that the use of certain passive design strategies such as; courtyards in buildings, and building orientation could improve cooling naturally and bring to a minimum reduction in the amount of energy required for cooling in buildings.

Amongst the many passive architectural design elements which may be found in all buildings in the tropical climatic regions of the entire world is the courtyard. It consists of the fully internal enclosed, and the semi-enclosed (Meir *et al*., 1990). The application of these courtyards typologies in architectural design is often accredited to the complimentary microclimatic conditions such spaces can offer (Koenigsberger *et al*., 1980). Over the past three decades, there is quiet an increasing number of research efforts that have made more emphasis on the courtyard as a passive design strategy, emphasizing on their optimization for a more favorable performance (Moore, 1983; Roaf, 1990; Dunham, 1990, Markus 2016b).

But, the social and functional benefits of the courtyard, for instance, seclusion and security, lighting and air circulation within the courtyard and the building, seems to be of greater significance than the problem of microclimate performance, as revealed by Markus (2016c), and other scholars such as Muhaisen and Gadi (2006a), Muhaisen and Gadi (2006b). They argued that the courtyard microclimatic performance should be more paramount than its social benefits. Meir *et al*., (1995) concluded that it is possible for the internally fully enclosed courtyards to add to the thermal distress condition of the building due to the lack of the knowledge of its microclimatic behavior and improper application of the design variants. Thus, while available information seems to be very deficient on the microclimatic behavior of the fully internal enclosed courtyard, there is only a little or not at all research effort towards understanding the microclimatic potentials of the semi-enclosed courtyard (Meir and pearlmutter*,* 1992). This may be owing to an exaggeration of its exceptional microclimatic behavior. Even with these uncertainties, the courtyard can constitute a huge portion of the entire building envelope depending on the architect intuitive ability. Therefore, the courtyard has a great innate ability for outdoor activities in diverse climatic zones, as long as that inappropriate design deficit by architects does not reduce their potential to contribute meaningfully (Abdulbasit *et al*., 2013)

The degree of thermal distress in the courtyard space(s) is determined by the climatic factors acting on it, most particularly those of radiation and wind. The effect of these factors may be measured with respect to the courtyard's dimensions and proportions such as the height to width ratio, the sky view factor, and the orientation of the courtyard as well-defined by its longest axis or by the course to which it opens (Muhaisen 2005).

Radiation is the sum total of solar energy immersed within a space such as a courtyard throughout a given period. It occurs due to the diffusion of shortwave radiation into the courtyard space and by the albedo of the courtyard surface, and its reflectance factor. While the albedo of the courtyard surface is basically a task of the material ability to reflect shortwave radiation, both the courtyard and the albedo are being affected by the courtyard's co-ordination (orientation) and size.

For the courtyard shading performance, a greater height to width ratio will cut down direct contact of all the courtyard surfaces to the level that direct radiation will be directly vertical to the courtyard ground level (Muhaisen and Gadi 2006b). Because of inside reflection, however, a greater height to width ratio has a tendency to drop the albedo, and consequently, proliferate the amount of penetrating radiation which is immersed (Terjung and Louie 1973). The sky vault is the major determinate of the extent to which a given surface is cooled at night-time. It then means that the courtyard with a big height to width ratio, or a narrow sky view factor, will tend to cool more gradually because of its restricted radiative condition. This phenomenon has been revealed to be a fundamental factor in the increase of air temperatures within the courtyard (Oke 1981).

Based on measurements and hypothetical contemplations, nevertheless, Givoni (1989) and others have recommended that the earlier described means of heating could be changed in hot dry zones. In high buildings, however, it is stated that the radiation will take place at the roof shells which, if very reflective, can generate undesirable radiation equilibrium. Based on this idea, air at rooftop level will tend to be cooler and heavier than that at the natural ground level and will descend into the courtyard space.

For the wind effects, the impact of air drive through the courtyard is very important in achieving thermal distress, both in the case of air flow in connection with the human skin and in the case of air from outside the courtyard space. The pattern of wind speed in the courtyard is defined by the orientation of the courtyard, and the creation of eddies air speed directly perpendicular to the direction of the wind (Chandler 1976). Such flow configurations are influenced by the courtyard's size and form (Muhaisen 2005). If the distance between the courtyard surrounding is somewhat wide in the path of the wind, such that the height to width ratio is less than 0.5, moderately small regions of unstable air are created with a free movement through the courtyard. When the height to width ratio is larger, about 0.65, more eddies are created. Even though air velocity is generally lesser when space between successive building are very close to each other, such as when the height to width ratio is more than 0.65, the courtyard is seen to be well sheltered from the direct influence of the wind. Obviously, this situation offers the highest shelter to occupants from unwanted wind, but on the other hand, it may also impede on the ventilation effect of the courtyard.

3. The Study Area

The study area is sited in the Southern part of Kaduna State, North Central region of Nigeria. It is positioned geographically between latitude 9^0 35'N and longitude 8^0 17'E and has a total land area of 32km^2 (Google Earth, 2016). The population of Kafanchan was projected to be 30,407 people (BLKS 2010). It has a tropical wet and dry climate which is typical of Nigeria. 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 46.4 ^{0}C (BLSK, 2010). The area is noted for having large quantities of fuel wood and consumers of wood all year round (Yunana *et al*., 2014).

4. Methodology

This research adopted site measurement methodology, and Figure 1 illustrates the research procedures.

Selection of courtyards: Out of the numerous courtyard residential buildings in Kafanchan-Kaduna, two different forms of courtyard typologies were selected and examined concurrently throughout daytime along with additional outside area as a benchmark. The courtyard was selected based on the following characteristics: the same orientation such that the longest view facing the North/South direction, the courtyards have the same dimensions, proportions and floor finish as 18000mm x 3000mm, and of sand screed floor finish respectively.

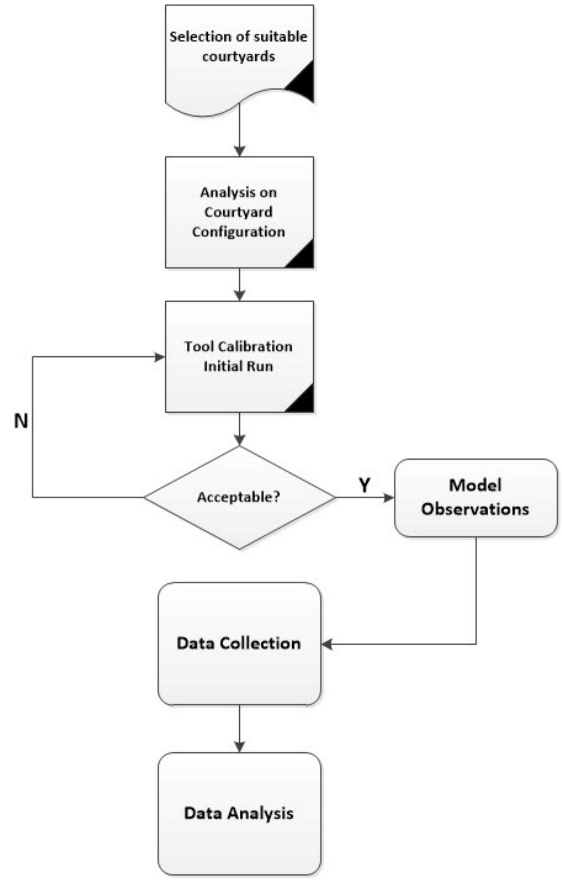

***Figure 1:** Method of Study*

Tool Calibration: Before the commencement of the site measurement, a calibration study was done to compare the results of the three HWDL used in other to check for precision differences so as to validate their accuracy. According to Leng, *et al.*, (2012), such procedure is compulsory even as more than one Hobo Weather Data Logger is required. Therefore, the air temperature and relative humidity parameter were used for the calibrate study. Figure 2 is a pictorial view of the three HWDL used.

***Figure 2:** A View of the Hobo Weather Data Loggers (HWDL)*

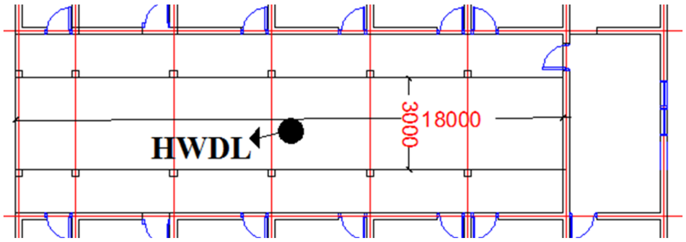

Figure 3: *Floor Plan of the Semi-Enclosed Courtyard House*

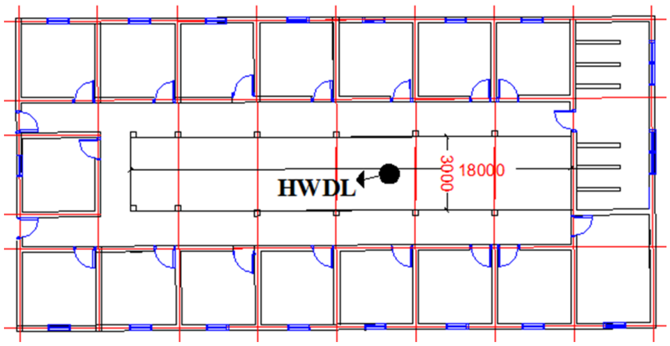

Figure 4: *Floor Plan of the Fully Enclosed Courtyard House*

Table 1: *Characteristic of Courtyard Typologies*

Typology	Area	Form	No. of Floor	Orientation
Fully enclosed	18 x 3 = 54 m^2	Rectan-gular	1	Longest axis facing North/ South direction
Semi-enclosed	18 x 3 = 54 m^2	Rectan-gular	1	Longest axis facing North/ South direction

Figure 3 and 4 illustrates the two different forms of courtyard building typologies that were selected for this study. Their dimensions and proportions, orientation, form, and a number of floors are shown in Table 1.

Data Collection: This comparative study was conducted to examine the microclimatic conditions of two different courtyard forms with the same perimeter, and material finished -the fully enclosed internal central courtyard and the semi-enclosed courtyard. The measurement was conducted in two existing residential buildings, in the city of Kafanchan-Kaduna in the North Central region of Nigeria. Three Hobo Weather Data Loggers (HWDL) were used to collect data in the courtyards, and the third one was positioned in the outdoor area as a benchmark. They tools were calibrated a day before the real measurement in order to guarantee accuracy. The uninterrupted measurement was carried out simultaneously at the courtyards between 6.00am and 6.00pm on Tuesday, 22nd day of April 2017. The HWDL was placed at the center of each courtyard as illustrated in figure 5. The data were measured at 30 minutes intervals and recorded at 1.2m above the natural ground level. At the end of the exercise, the acquired data was read out via the HoboPro software and subsequently exported to Origin7.0 for interpretation and analysis.

5. Results and Discussion

As stated earlier, two different typologies of courtyard forms in residential buildings have been considered for the purpose of comparing their microclimate performances. Two physical parameters

Figure 5: *The Semi-Enclosed (above) and Fully Enclosed Court-yard House (below)*

-air temperature and relative humidity, were investigated in the courtyards along with the outdoor (open air space) as a benchmark. Before the commencement of the investigations, the tools were calibrated to ensure their accuracy. In the following section, results of the experimental study are presented and discussed.

5.1 Calibration of Tools HWDL

The calibration of the Hobo Weather Data Loggers (HWDL) was done for the three tools. The results show that the difference in air temperature and relative humidity readings at each 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). According to Abdulbasit et al., (2014), a reading difference of 0.01, 0.02, and 0.03 are very

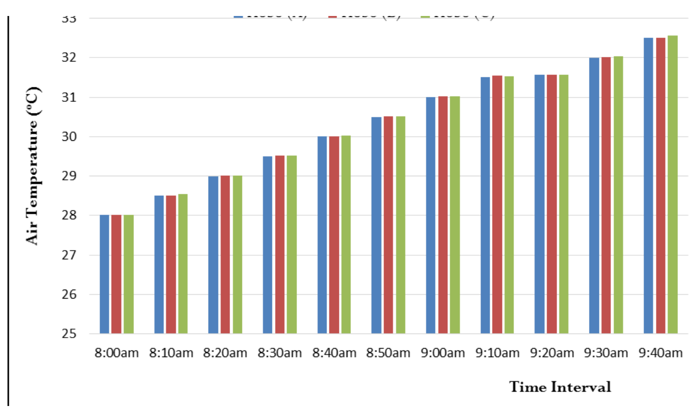

Figure 6: Air Temperature of the three HWDL

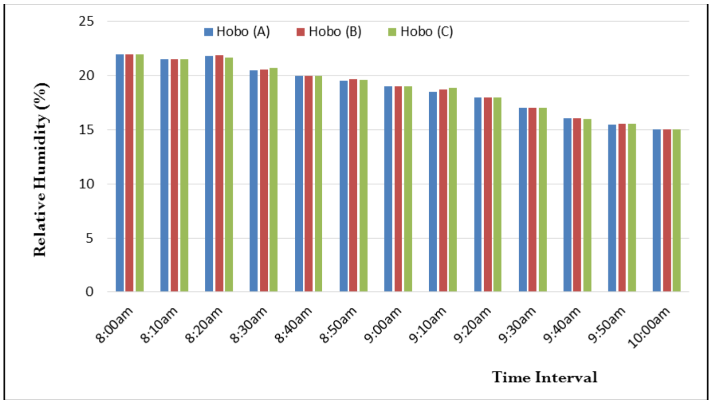

Figure 7: *Relative Humidity of the three HWDL*

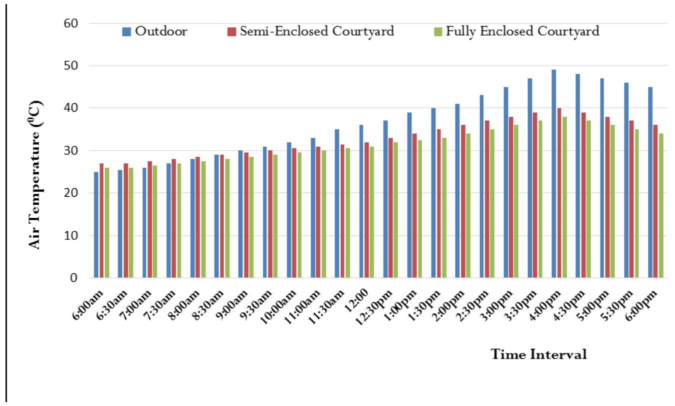

Figure 8: *Air Temperature*

insignificant in a research of this endeavor. Therefore, the results have verified the validity of the Hobo Weather Data Loggers to be used for further measurements.

5.2 Site Measurements

5.2.1. Air Temperature

The semi-enclosed courtyard is rectangular in form, oriented towards the east-west direction and opened to the western side. This kind of configuration encourages catching of excessive solar radiation from the western side which has more effect on temperature rise then the early solar radiation from the eastern side. The air temperature in the two courtyards was compared with the overall outdoor air temperature. As shown in figure 8, the air temperature inside the courtyards was lower at all times, between 0.4 to 3 degrees difference compared to the outdoor temperature.

Also, the fully enclosed internal courtyard has better air temperature than the semi-enclosed courtyard form. The maximum difference of temperature between the fully enclosed internal courtyard and the semi-enclosed courtyard were 2 ^{O}C recorded almost uniformly at all the different time interval. Whereas, the minimum difference of air temperature was 1ºC, recorded almost uniformly at the 8:00 am to 11:00 am. The fully enclosed internal courtyard is fully surrounded and has no advantage for natural ventilation from all the sides, while the semi-enclosed courtyard form is not fully enclosed but surrounded by 3 walls and opened to the western direction which does not favor natural air circulation. Thus, according to Meir*,* (2000), the orientation of the courtyard in the building may have affected the microclimatic performance of the semi-enclosed courtyard negatively. The differences in the air temperature as observed in the study could be due to different reasons such as the building orientation, the courtyard configuration, (Rajapaksha *et al.*, 2003; Doris and Kubota 2015; Muhaisen and Gadi 2006(a) and (b); Abdulbasit *et al.*, 2014; and Markus *et al.*, 2017). As asserted by Manio and Oral (2015), in their study to investigate the influence of the courtyard shape on the building microclimatic performance in Turkey revealed that the courtyard with an area of 100m^2 will need a lesser amount of heating for cooling, but when compared to that of 200m^2 area. The conclusion was that large courtyard shape is more critical than the smaller ones in the hot and dry climate of Turkey. Doris and Kubota (2015), contributed in their study on buildings thermal comfort that the small courtyards were more effective to cooling in buildings.

Also, Markus *et al.*, (2017) in their effort to investigate the courtyard as a cooling strategy in buildings, concluded that the courtyard can be very effective in achieving cooling in buildings if the appropriate courtyard geometry is understood and applied. Thus, the subject of the influence of the courtyard ratio on the building microclimatic performance has been discussed in recent time.

Therefore, the observation of air temperature discrepancies in the studied case-studies concord with the assertions made by the above-mentioned scholars. However, the effect of orientation, vegetation, and building material finishes cannot be ascertained as all the respective case -study buildings had the same orientation and material finishes, but none has any kind of vegetation. But the effect of solar radiation in the semi-enclosed courtyard due to its opening facing the western direction where the sunset may be a major factor for the discrepancies in air temperature observed in the courtyard. The solar radiation intensity is very high when the sun is setting as compared to when the sun is rising (Muhaisen and Gadi 2006a). So, the direction of opening of the semi-enclosed courtyard has a tremendous influence on the microclimatic performance of the courtyard open space(s).

5.2.2. Relative Humidity

While on the other hand, the relative humidity had a converse relationship with the air temperature. As revealed in Figure 9, the relative humidity was greater in the semi-enclosed courtyard form than in the fully enclosed internal courtyard form. The maximum difference in relative humidity between the fully enclosed internal courtyard and the semi-enclosed courtyard was 20 % recorded at 6:30 am and 5 % at 3:30 pm. whereas, the minimum difference of the relative humidity is 2

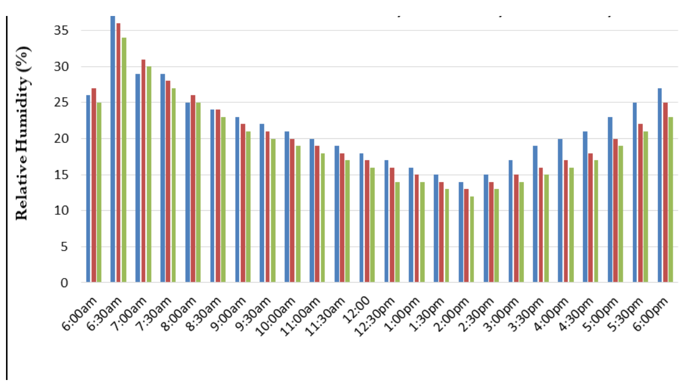

Figure 9: *Relative Humidity*

% at 5:00 pm. The semi-enclosed courtyard has a direct contact with the ambient microclimate than the fully enclosed. According to Bekovic *et al.,* (2012), the degree of the courtyard sky-view factor has a direct relationship with the amount of relative humidity, the higher the courtyard exposure to the open air environment the higher the amount of relative humidity. Therefore, the high amount of relative humidity in the semi-enclosed courtyard in this study has concord with Bekovic findings. But the relative humidity inside the courtyards was lower at all times as compared to the outdoor open air.

Also, the measure of relative humidity as revealed in this study may be due to some causes ranging from the climate of the study area, the absence water bodies such as ponds and vegetation (Farzaneh *et al*., 2016a). In a research effort to investigate the Iranian traditional courtyard house (a typical of hot-dry climate), Farzaneh *et al*., (2016b) revealed that the central courtyard with the appropriate physical and natural parameters could aid the effectiveness of the courtyard to act as a passive cooling element in the building.

Therefore, the absence of the physical and natural parameters has worsened the microclimatic performance of the studied courtyards, and application of such could better both their outdoor performances and even their indoor thermal performances.

6. Conclusions

This study is another research effort that aimed at investigational two different courtyard forms with the same dimensions and proportions, orientation, and material finished -the fully enclosed and the semi-enclosed courtyards in two existing residential buildings, in Kafanchan, the northern central region of Nigeria-Africa. The primary objective of the study is to compare their microclimatic performances in other to ascertain the best option to adopt for further studies in an ongoing Ph.D. research effort and to make recommendations for the professional architects in practice. The study, therefore, concludes as:

- A comparison of the calibration study revealed that the HWDL has an insignificant difference of 0^{O}C to 0.02, and 0.01% to 0.03 % for air temperature and relative humidity respectively. Therefore, the Hobo Weather Data Logger (HWDL) has a very good degree of precision and is recommended for future research of this kind.
- The fully enclosed courtyard performs better than the semi-enclosed with a difference of 0 ^{O}C to 2 ^{O}C, and 0 % to 5 % for air temperature and relative humidity respectively, as observed in the time intervals. And so, a further simulation study on its optimum ratio for a better performance should be investigated.
- The open air outdoor space (environment) is revealed as the worst scenario, with an air temperature and relative humidity difference of 3 ^{O}C to 4 ^{O}C, and 2 % to 4 % difference at each time interval. And therefore, the courtyard is a good passive architectural design strategy in the hot-dry climate of Nigeria.

Finally, the fully enclosed internal courtyard has demonstrated a more favorable microclimatic performance than the semi-enclosed. But the field measurement research methodology seems to have its own limitation of not being able to test different courtyard typology options due to the difficulty in selecting case-studies with the same dimensions and proportions, orientation, and availability of the Hobo Weather Data Loggers tools, but on the other hand, the simulation methodology has the advantage of testing many options as far as the validation of the simulation software is confirmed to be positive. Therefore, the simulation research methodology may be the best research approach to this kind of research in future. So also, further simulation studies towards determining the optimum courtyard ratio for optimum microclimatic performance of the fully enclosed courtyard residential buildings in every particular geographical location (for instance Kafanchan in Nigeria) is required. And the professional architects should endeavor to adopt the use of the simulation tool in their architectural design schemes and practice due to its potency of positive contribution to the realization energy efficient architectural design of buildings.

Acknowledgement

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