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Comparative Analysis of Indoor Environmental Quality and Occupant Comfort in Federal Housing Estate Asaba, Nigeria

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ABSTRACT
The climatic conditions of warm humid zone of Nigeria in particular, are high solar radiation, high humidity levels and less effective air flow. These make it imperative for effective design of architectural openings in buildings to reduce the fluctuations of the interior temperature with respect to the variations of the exterior. However, implementing proper climatic responsive design strategies could potentially improve the openings thermal performance while significantly reducing the building's energy needs. The present study addresses the indoor environmental quality and occupant comfort under warm humid climate conditions by focusing on residential estate building. The research was conducted in the city of Asaba, Nigeria. The study explores the potential of improving the indoor environmental quality and occupant comfort in the buildings while respecting the specific characteristics of architectural openings design. Therefore, this paper reports on the analysis done using questionnaire and physical measurement with data loggers. Data on the indoor air temperature and airflow rate in five different architectural openings in purposively selected rooms were used. To achieve this goal, optimization scenarios of the building openings were examined by implementing a set of selected passive design strategies and their effect in regulating indoor air temperatures and providing comfort condition. The results demonstrate significant improvements of the indoor environmental quality and occupant comfort and a consequent decrease in indoor temperatures. Moreover, the study defines the most prominent strategies in the process of optimization of the architectural openings.

Keywords: Comparative Analysis, Federal Housing Estate, Indoor Environmental Quality, Occupant Comfort, and Warm humid climate.

I. INTRODUCTION

In Nigeria, which is the focus of this study, the building sector' energy demand is huge. According to the Federal Ministry of Housing and Power (FMHP) it corresponds to more than 41% of the national global energy consumption (FMHP, 2022). This excessive rate of energy demand is due, in part, to the social policy trends in Nigeria where the energy use is subsidised. According to Kherfah et al. (2020) the low cost of the energy bill and the lack of major financial constraints for energy supply have led to high energy consumption. Calling for a sustainable developmental strategy, the Nigeria government has set a target to reduce buildings energy demand for heating and cooling by 40% by year 2030 (Badeche et al., 2020). This constitutes a major challenge, especially in view of the available building stock, which was not designed to achieve environmental performance. In southern Nigeria where a high solar and humidity prevails, cooling living spaces is a basic need and a major priority for the residents. In these regions, where buildings are greatly dependent on artificial ventilation to provide occupants with comfortable thermal conditions, cooling requirements reach peaks of consumption during the dry season from September to May.

This paper addressed the acceptability rate of using passive opening techniques in their buildings as one as an important task of the optimisation process. The main goal of the study is to examine the potential for indoor environmental quality and occupant comfort enhancement by using architectural openings in residential buildings. Considering a sample of block of flat houses located in federal housing estate in the city of Asaba (southern Nigeria), occupant comfort conditions were analysed on the basis of questionnaire survey and physical measurements.

II. LITERATURE REVIEW

The potential of using passive architectural openings as a cooling strategy has received increasing attention as an alternative to provide occupant's thermal comfort with ensuring energy efficiency of buildings during hot periods (Abuseif et al., 2018). In this regard, a substantial amount of studies exploring various passive measures in the context of extreme climate conditions have been published. From the existent literature, authors have defined two passive cooling approaches; cross ventilation and single side ventilation. Furthermore, their applicability in the context of Asaba depends on climate conditions and architectural openings in residential buildings. By referring to Parker et al. (1998) architectural openings design is both a passive solution and a building typology that assists in reducing the cooling loads and energy demands on a building's envelope. Accordingly architectural openings can be doors, windows and vents that allow flow of air into the building and efficiently exit heat. Consequently, using an architectural opening as a passive technique can be very effective in energy-efficiency; besides being low cost, easy to install and eco-friendly, it can also decrease discomfort hours by 9–100% and reduce cooling loads by 18–93% in different climate zones (Piselli et al., 2018). Considering that people spend over 90% of their time in interior spaces, indoor thermal conditions significantly impact their health and wellbeing (Taipale et al., 2021). During the Covid-19 pandemic, time spent inside dwellings has increased, and this highlighted the importance of a ensuring well-performing buildings that satisfy occupants' comfort demand/ needs, health and productivity (Bortolini et al 2021). In warm humid climates, the exterior opening components are the most significant contributors to the comfort parameters and the energy performance of the buildings (Yu et al., 2015). In this regard, windows and doors are considered to be the main sources of overheating inside spaces. Therefore, using efficient design strategies can leads to an increase in indoor thermal comfort and a consequent reduction in ambient air temperatures that in turn results in energy saving by reducing cooling loads. In particular, applying passive cooling strategies through building had proven to be very effective in maintaining indoor well-being, controlling heat dissipation, as well as reducing cooling demand (Spanaki et al., 2011; Atolagbe, 2014).

Architectural openings in buildings can have large impact on indoor environmental quality and occupant comfort. Occupant can influence the indoor air flow by adjusting window and it would result in indoor convective cooling effect. This is one of the environmental adjustment methods occupants in the warm humid zone like that of Asaba, can apply to restore their personal thermal comfort in residential buildings. Many field studies have investigated window-use pattern based on different climates, regions and environmental stimuli. From results of those studies, the indoor and outdoor air temperatures are the main environmental factors which influence window-use pattern. A field study by Anunobi et al., (2015) in five naturally ventilated buildings in 12 weeks in during the hot season reported that 76% of window state changes were caused by variable outdoor temperature. The results of stimulus of small and large openings of windows found that the large opening was driven by outdoor temperature, while in contrast the small opening was mainly impacted by indoor air quality rather than outdoor temperature.

Herkel et al., (2008) conducted a field study in 21 individual rooms in naturally ventilated building, and then indicated that the largest opening percentage and the lowest frequency occurred in hot season, to prevent the indoor air temperature becoming over-heated. Meanwhile, cold season, window positions were changed more frequently than other seasons, which may be caused by rain or wind force; however, the frequency of windows' change, and the percentage and duration times of opening were limited, to maintain the indoor air temperature. Therefore, both the indoor and the outdoor air temperatures have important influence on indoor environmental quality and occupant comfort. Residential building stock represents a significant potential in tackling both worldwide energy and thermal built environment challenges. Actually, besides building itself, the biggest energy consumers are the inhabitants (Janda, 2011). Simply put, the way of occupying a building, humans' habits and activities explain differences between the estimated and real energy consumptions (Pannier, 2021). Consequently, the human's dimension is a key factor to be addressed when it comes to assess indoor environment quality and building energy performance (Zhang, 2018).

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Inhabitant-dwellings interactions topic, subjective post occupancy evaluation (POE) surveys together with objective building features can help in assessing indoor thermal comfort and thus building energy performance. In this regard, it is important to monitor occupant satisfaction to provide measures that can determine building performance. POE surveys seek occupant satisfaction feedback regarding their indoor environment which can help in enhancing design expertise, satisfies users' requirements and promote retrofitting process (El-Darwish, 2018). POE approaches include two complementary methods; subjective method using survey questionnaires to indicate occupant's perception in their built environment and objective method using in-situ physical measurements.

2.1 Study Area: The study area is Asaba in Delta State, Nigeria. It is located in south-eastern and Nigeria lies within 4^0N to 14^0N latitudes and 2^0E to 14.5^0E longitude. Asaba lies in Latitudes 6.2^0N of the Equator and longitude 6.73^0E of the Greenwich Meridian. It is the state capital of Delta State and located on the banks of the lower Niger Delta. The climate of Asaba is humid sub-equatorial with long wet season lasting from March to October that alternates with a shorter dry season that last from November to February. The climate is influenced by two prevailing air masses namely the south-west monsoon wind and then North-east trade wind. Annual rainfall in the Asaba area is up to 2500mm with double peak rainfall regime which takes place both in June and September. Annual average temperature is about 27^0C with no marked seasonal departure from the average. The natural vegetation of the area is rainforest with swamp forest occurring in flat-floured valleys and adjoining low lying areas that are seasonally or permanently water logged (NiMet's, 2016).

III. RESEARCH METHODOLOGY

This paper reports on the analysis using questionnaire and physical measurement with data loggers. Data on the indoor air temperature in five different architectural openings in purposively selected rooms were used. The multi-purpose Air Flow Digital anemometer (AM-4812-2-2) was used to measures air velocity, air flow, and Data logger (HTC-1) air temperature & humidity. The system collected concurrent physical data: air temperature, air flow and air velocity. The instruments were placed at 0.6m, 0.9m, and 2.1m from the floor to record the thermal comfort variables simultaneously, as the subjects filled in the thermal comfort questionnaire. The data logger was set to acquire data at 60-min intervals. The readings were recorded in separate data sheets. All the completed questionnaires and data sheet entries were given serial numbers for easy identification and synchronization. The readings were transferred onto the corresponding questionnaires at the end of every survey day. The measuring apparatus for field study and data documentation is shown in Table 1.

Table 1: measuring apparatus

Apparatus	Description
	**Air Flow Digital anemometer (AM-4812-2-2):** velocity range is between 0.4m/s- 30m/s, 1.4km/h-108.0km/h, 0.8knots- 58.3knots with accuracy of ±2% +1d at 0°C-50°C and less than 90%RH.
	**Data logger (TA298):** recording temperature from 0°C to 50°C and relative humidity from 10% to 99%. The accuracy of temperature reading is between ±1°C. The accuracy for relative humidity is ±5%RH. The reading resolution is 0.1°C for temperature and 0.3% for relative humidity.

The typical view of the Federal Housing estate Asaba are shown in plate 1, plate 2, plate 3, and plate 4 respectively.

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Plate 1: Entrance view of Federal Housing Estate Asaba (Fieldwork, 2023)

Plate 2: Tyical view of semi-detach blocks of flat apartment buildings in Federal Housing Estate Asaba (Fieldwork, 2023)

Plate 3: Tyical view of the landscape (Fieldwork, 2023)

Plate 4: Tyical view of the sitting room (Fieldwork, 2023)

3.1. Data Presentation:

This section present the data generated from the field work. The data generated from the various sources will be sorted and arranged a way that is adequately fit for statistical analysis and interpretation using tables, bar charts, graphs, frequency distributions and percentages. This measurement was carried out from October 2022 (11^{th} to 24^{th}) and during this period the outdoor temperature varied from a minimum of 21.5°C to a

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maximum of 36.1°C, with the mean daily average temperature of 27.3°C. There were large temperature fluctuations during the measuring time, which was because of high solar radiation, and the highest temperature of each day was above 30°C. However, the prevailing wind was from the south-west and the wind speed was between 0.05m/s and 5.75m/s, with an average wind speed of 1.47m/s.

Questionnaire survey: How the occupants feel with the indoor temperature

This question was asked to know how the respondents feel with the indoor temperature. The Table 4.38 shows how the occupants feel with the indoor temperature. The result has shown that about 4.30% of the respondents feel cold, 1.84% feel cool, 6.00% feel slightly cool, 2.00% feel neutral, 46.15% feel slightly warm, 10.92% feel warm and 70.61% feel hot. This shows that more of the respondents feel hot as shown in Figure 1.

Table 1: Occupant feeling with the indoor temperature

Occupant feeling with the Indoor temperature	frequency	percentage
Cold	28	4.30%
Cool	12	1.84%
Slightly cool	39	6.00%
Neutral	13	2.00%
Slightly warm	43	4.33%
Warm	71	10.92%
Hot	451	70.61%
Total	**650**	**100%**

Source: field work (2022).

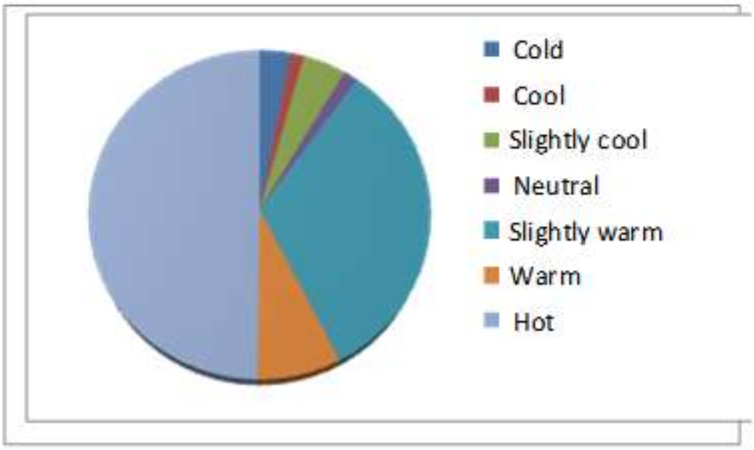

Figure 1: Occupant feeling with the indoor temperature (field work 2023).

In this investigation windows were used. In the outside facing wall the window was separated into three panes and on the corridor side there was a two pane casement window and a door. In fact, if indoor and outdoor temperature difference was small, it would mean the room was well natural ventilated. And increasing indoor air flow speed would have more influence on occupant comfort sensation rather than indoor temperature. When the window was shut the heat could not be moved out of the room and the indoor temperature would heat. When the outdoor air temperature was lower than indoor and the air flow rate was higher the indoor air temperature decreased gently when the windows were opened. Although the windows were opened in five different Window Opening State and the influence on the indoor air temperature was measured.

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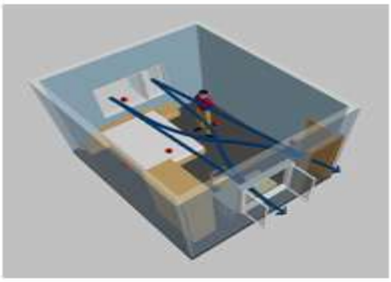
Table 2: shows the physical measurement data from field study

Window openings		East window orientation			West window orientation		
Window state 1		Max. Temp. (°C)	Average Temp. (°C)	Min. Temp. (°C)	Max. Temp. (°C)	Average Temp. (°C)	Min. Temp. (°C)
		+5.4	+0.40	-2.1	+4.0	+0.62	-1.9
Window state 2							
		+8.2	+0.66	-1.6	+4.6	+0.62	-1.9

Source: field work (2023).

Window openings		East window orientation			West window orientation		
Window state 3		Max. Temp. (°C)	Average Temp. (°C)	Min. Temp. (°C)	Max. Temp. (°C)	Average Temp. (°C)	Min. Temp. (°C)
		+4.8	+0.44	-2.3	+2.8	+0.44	-2.3

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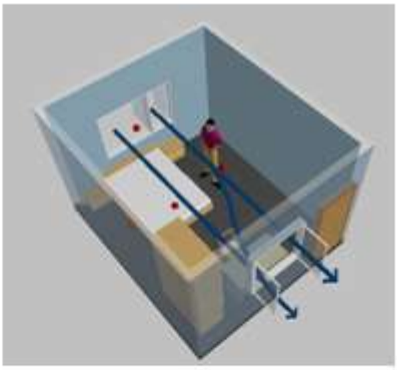
Window state 4 	+6.6	+0.41	-2.1	+3.2	+0.52	-2
Window state 5 	+3.6	+0.41	-2.1	+3.2	+0.52	-2

Source: field work (2023).

Table 2; shows the effect of architectural opening on indoor environmental quality of east and west window orientation. The air temperature variation in the rooms was close to the outdoor air temperature. This may be as a result of architectural openings on air flow rate, so the indoor heat could be moved out from the room more efficiently. The optimization analysis was carried out by implementing a set of selected passive design strategies and their effect in regulating indoor air temperatures and providing comfort condition.

IV. DISCUSSION OF RESULTS

The investigation on comparative analysis of indoor environmental quality and occupant comfort was carried out by physical measurement and questionnaire survey. The data loggers were used to obtain data on the field study. The variable measured comprises the indoor air temperature which is influenced by the indoor and outdoor temperature differences and air flow as shown in Table 2. When the wind and temperature are combined, the results show that change in temperature difference has a large impact on the air flow rate and pattern. In addition, at the directly windward and leeward side, change in temperature difference is more effective than change in wind speed. Wind speed had more impact when the incident angle was at 45° or 135° (northeast or southwest).Therefore, reducing the indoor temperature was still achievable by raising the air flow rate.

Besides, the accessibility of window was an important fact which can affect indoor environmental quality and occupant comfort. The window would not be used if it was difficult to control, subsequently, occupants would lose their opportunity to control the indoor air flow to suit their demands. It would also result in increased indoor air temperature and lost design characteristics, such as cross-ventilation. However, occupants just like to control the window which is near them or easy to reach. Thus, accessibility is an important element for design of architectural opening and this should be considered during the design process. It also affected the potential of convective cooling and occupant thermal comfort. Therefore, reducing the air volume flow rate could slow down the increase of indoor air temperature. When the air volume flow rate was higher than the required amount for cooling and also the window opening had become larger, the indoor air temperature drop was still slower than the outdoor. Gao and Lee (2011) found out that natural ventilation performance of residential units was most affected by the relative position of the two window openings followed by building orientation and doors positions. Also better natural ventilation performance can be achieved when the two openings are positioned in opposite direction or perpendicular to each other. Thus, understanding the effect of architectural openings on room temperature, and airflow is important for architects to design buildings with effective indoor environmental quality and occupant comfort.

V. CONCLUSIONS

The most effective window types should be used in naturally ventilated residential buildings in warm humid climate zone. The Analysis of Variance (ANOVA) test conducted at 95% confidence level showed that there was significant statistical difference between the rates and patterns of air flows for the different window opening state thus: F=65.555; p=.000. The Window Opening State (5) at East orientation had a mean value of maximum room temperature variation of +3.6^{o}C; Window Opening State (4) had +6.6^{o}C; Window Opening State (3) was +4.8^{o}C; Window Opening State (2) was +8.2^{o}C and Window Opening State (1) was +5.4^{o}C. The performance of window opening state in providing comfortable air flow rate is now in this order; Window Opening State (2) having optimal performance, followed by Window Opening State (4), Window Opening State (1), Window Opening State (3) and Window Opening State (5) was having the lowest performance. Although the influence of natural ventilation on indoor air temperature was very limited, high air flow speed still had a direct impact on the indoor air temperature.

However, this study shows that architectural openings can achieve a cooling purpose and improve indoor environmental quality and occupant comfort in buildings within the warm humid climate.

The research recommendations are to improve the sustainable design of residential buildings by efficient opening windows which renders optimal ventilation in single side ventilation and cross ventilation. Also energy saving strategies to be applied both in the design phase of a building and when renovating existing buildings to achieve low energy consumption and occupant thermal comfort.

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