Environmental Performance of Abuja's Low-Income Housing:
Understanding the current state to inform future refinement

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ABSTRACT: In times of global ecological challenges, understanding building performance to improve occupants' comfort is becoming the norm in various climatic zones and locales. Any performance evaluation should account for occupants' demands for thermal and visual comfort. However, seeking to analyse the impact of design on the two aspects of comfort simultaneously can be complicated especially when a series of parametric changes with varying impacts on either is necessary. In the Nigerian context, assessing the environmental behaviour of existing residential properties to inform future refinement is becoming far more critical due to the vulnerability of the region to the changing climate, the ongoing issue with the energy supply and the housing shortage. The method adapted in this paper following previous research can be useful for the coinciding evaluation of the thermal environment and visual comfort. The environmental behaviour of two of Abuja's common housing types, in their current state and with the addition of multiple shading elements was assessed using such methodological procedures to examine their suitability for performing a comprehensive analysis. The paper discusses the simplicity of the graphical representation utilised in displaying the changes in the cases' behaviour following the alteration. It also provides an insight into their current performance.

KEYWORDS: Housing, Comfort, Methodology, Nigeria

1. INTRODUCTION

The 2014 IPCC report on climate change predicts that temperatures in Africa are to rise faster than the global average increase. By the end of this century, temperatures over West Africa are estimated to rise by 3°C to 6°C above the mean annual temperatures of the late 20th Century. Such a hasty increase in Africa's temperatures, which is likely to occur one to two decades earlier than the global average, is the result of the small natural climate variability in the region generating narrow temperature bounds that can be easily surpassed by small climate changes [1].

It is widely accepted that conventional sources of energy for mechanical cooling, heating, and artificial lighting are among the main contributors to greenhouse gas emissions causing global warming. In Nigeria, the housing sector alone has accounted for over 58% of the electrical energy consumed in the country [2]. This figure is already alarming given the lack of housing in the region, the issue of energy supply and the uncertainty associated with climate change.

Currently, the Nigerian housing market has a deficit of about 17 million units [3]. As a country, it is the most populous in Africa, but due to its speedy urbanisation, Nigeria is not only experiencing a severe housing shortage but also struggling to maintain a secure energy supply to the growing population. Over half of the households lack access to grid supply of electricity and to for those already connected to the grid, the supply is unreliable [2]. Yet the contemporary design practice adopted in the country has contributed to inefficient energy use in the building industry. Over the years, this has led to increasing demand for active energy through various devices for both cooling and lighting [4]. Therefore, investing in low energy passive design measures as a means for minimising the reliance on mechanical systems while meeting occupants' comfort, is key for the reduction of the present and future energy use in the country.

An increasing number of recent studies have examined energy use and occupants' comfort in buildings in Nigeria. A quick inspection of their contents reveals that most publications have mainly focused on the thermal aspect of indoor comfort [e.g. 5, 6]. Obviously, solar heating is rarely desired in tropical regions, hence the need to maximise the use of daylight in spaces often receives secondary consideration in comparison to controlling solar gain to improve comfort [7]. Nevertheless, achieving a balance between the prevention of heat gain and daylight penetration is crucial for the creation of a healthy living environment. In addition, the ability to effectively assess the trade-off between daylighting and thermal comfort is essential to improve the energy efficiency of buildings, by reducing lighting and cooling loads [5].

2. MEETING COMFORT REQUIREMENTS IN ABUJA'S HOUSING

Rising concerns over energy use in buildings, climate change, and occupants' well-being have resulted in an increasing number of studies exploring the thermal and visual aspects of indoor comfort in various climates. In general, there seems to be a separation between the metrics employed by scholars for examining the visual aspect of the indoor environment and those used for assessing the quality of the thermal environment. In an effort to close the gap between assessing the requirements of the two aspects of comfort separately, Sicurella and co-authors [8] presented a *statistical approach* that aimed at measuring the frequency and intensity of thermal and visual discomfort in certain settings by using two physical parameters; the *operative temperature* and *illuminance levels*. Although in the original study, the approach was tested to examine the impact of adjusting the design of building envelope of a notional space on the internal conditions, according to the current authors' knowledge it has not yet been applied to assess the environmental performance of real buildings, including those situated within the African context and climate zone. With the objective of thoroughly assessing the internal conditions of Abuja's existing dwellings and to explore opportunities for improving their performance, a joint approach that combines the two aspects of comfort seems necessary, particularly where there is an ever-rising demand for low-income affordable housing.

This paper presents the results of assessing the environmental performance of two of Abuja's common housing types adapting a similar method to Sicurella's et al. The aim is to discuss the application of such statistical approach for the simultaneous evaluation of daylighting and the thermal environment of Abuja's low-income dwellings. The influence of utilising various shading components on the indoor comfort in the case study buildings is examined based on the prediction of the values of operative temperatures and the levels of illuminance using validated simulation and measured data.

3. PERFORMANCE EVALUATION MODEL: INDICATORS

The method employed included a calculation of the following set of indicators:

Hours of Thermal Discomfort (HTD), Frequency of Thermal Discomfort (FTD), the Intensity of Thermal Discomfort (ITD) (which is derived from the areas under the curve as illustrated in Fig. 1), *Hours of Visual Discomfort (HVD)*, *Frequency of Visual Discomfort (FTD),* and *the Intensity of Visual Discomfort (IVD).* A detailed description of each metric is given in [8]. Due to the lack of regional comfort guidelines, the ASHRAE standard 55-2013 adaptive model for thermal comfort in naturally ventilated buildings [9] is used to define the thermal comfort boundary in the study. Similarly, the evaluation of visual comfort is based on the recommended illuminance values given by the Illuminating Engineering Society of North America (IESNA) for generic types of activity in interior spaces [10].

HTD is a measure of hours within a given time period during which the indoor thermal comfort conditions are not accomplished. FTD is the percentage of time within a given period during which the indoor thermal comfort conditions are not accomplished [8]. The values of both metrics can be delineated by defining the upper and lower limits of the acceptable temperature range, T_{over} and T_{under}. A satisfactory level of comfort is to be achieved when the operative temperature in a room is greater than T_{under} and less than T_{over}. Temperatures greater than the upper limit T_{over} might cause occupants to suffer from hot sensation while those dropping below the lower limit T_{under} might cause a cold sensation.

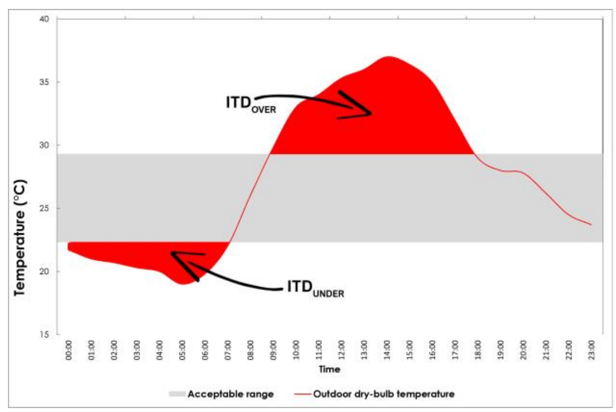

Figure 1: Definition of Intensity of thermal discomfort

The values for T_{over} and T_{under} are calculated in compliance with the adaptive thermal comfort criterion specified in section 5.4 of the ASHRAE standard-55, using the following equations:

T_{over} (°C) = 0.31 x Tpma +21.3 (1)

T_{under} (°C) = 0.31 x Tpma +14.3 (2)

Where: *T_{pma} is the prevailing mean outdoor air temperature, which is the arithmetic mean of all the mean daily outdoor air temperatures for no fewer than 7 and no more than 30 sequential days prior to the day in question.*

Typical daily tasks undertaken in a domestic setting are not limited to desks and display screens, therefore it should be noted that there is uncertainty regarding the preferred upper limits for thermal comfort in residential properties [11].

The traditional as well as the contemporary architecture of Nigeria favour limiting solar heat gain through windows over allowing higher levels illuminance indoors. Thus, the upper limit and lower limit for preferred daylight illuminance used for this research are 500lux (for the performance of visual tasks of high contrast and small size) and 100 lux (for spaces where simple visual tasks are performed), as prescribed by the IESNA standard [10]. Similar to thermal comfort, occupants are likely to feel visually comfortable when the average daylight illuminance across the working plane in the room is between the two limits.

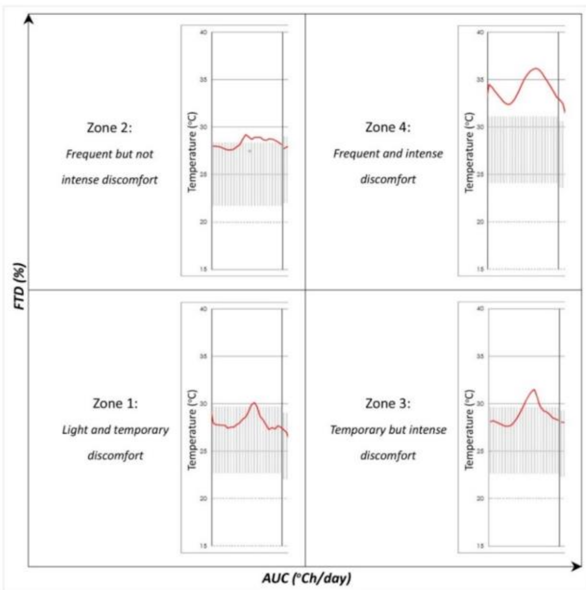

Figure 2: Zones of discomfort based on frequency and intensity

Depending on the quality of the indoor environment, an occupant's experience of comfort in a certain setting can be classified following Sicurella's et al approach into four categories. These are (a) *a modest level of discomfort for a short period* (b) *a modest level of discomfort for a long period* (c) *intense discomfort for a short period* and (d) *intense discomfort for a long period*. The zones were classified based on the severity of the conditions examined and for the ease of analysis and comparison are presented on a single graph as illustrated in Figures 2 and 8.

However, the paper by [8] did not define standard thresholds for each zone either in terms of the intensity of thermal or visual discomfort. Thus, in the current work, the threshold between temporary and frequent discomfort is 50% whereas the threshold between light and intense thermal and visual discomfort are 25^{o}C•h/day and 12500Lux•h/day respectively. These thresholds are based on the examination of multiple buildings within the context of the study.

4. CASE STUDY BUILDINGS AND URBAN CONTEXT

The case study buildings selected for this study include a two-bedroom house in a four-storey block of flats and a four-bedroom detached house. The former was constructed in 1983 while the latter was constructed in 2003 (Fig. 3 and 4).

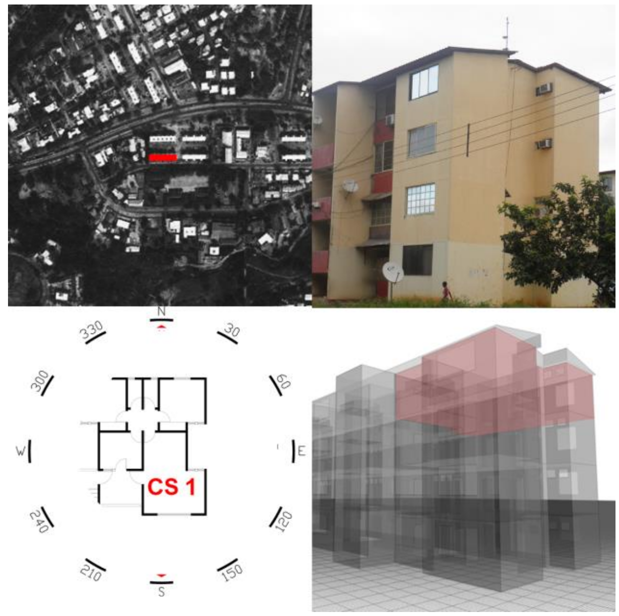

Figure 3: Location, photograph, plan of Cases study building 1 and the selected room (CS 1).

Figure 4: Location, photograph, plan of Cases study building 2 and the selected room (CS 2).

Both buildings are examples of the common prototypes for residential buildings developed by the government over the last three decades in Abuja. A room was selected from each house for the analysis presented in this paper. The physical attributes of the selected rooms and thermal transmittance of the buildings' materials that were collected during the fieldwork and utilised in the simulation modelling are given in Table 1. Even though both buildings were developed years apart they have similar materiality and internal finishes because their construction were carried out using the same style and standard that have been adopted for mass housing by the government in Nigeria for four decades.

Table 1: Physical characteristics of case study buildings

Room		**CS 1**	**CS 2**
Volume (m^3)		54.5	66.4
Floor area (m^2)		21.4	23.4
External wall area (m^2)		34.2	31.6
Window area (m^2)		3.8	3.6
Orientation		S	NE
U-value (W/m^2K)	Wall	2.15	2.15
	Windows	5.22	5.22
	Roof	3.79	3.79
	Floor	2.38	2.38

5. CLIMATIC CONTEXT

The quality of the indoor environment of the rooms was evaluated during the Dry season, which is the hottest period of the year, normally extending from November to April. The midday sun is at its lowest angle in the south during the first three months of the season (around 57° in December) and there is often very little cloud cover over the city. Thus, the level of direct solar radiation reaching Abuja during this period is high. The average hourly solar radiation in the city in December is about 509 watts per hour per square metre (Wh/m^2) leading to temperatures as high as 35°C [12]. The nearly vertical location of the sun in March combined with the absence of cloud cover further raises the average daytime temperatures to above 37°C [12]. However, over the course of the Dry season, the gap between the daytime and night-time temperatures in the city is wide, especially during the first three months. Temperatures around dawn can be 15-17°C lower than those recorded during the middle of the day [13]. This is the result of the dissipation of daily solar radiation beyond the atmosphere due to the lack of cloud cover [14].

Given the significance of the diurnal temperature change on the thermal experience of the occupants this paper reports the daily performance of the case studies. Consequently, the thermal and visual conditions in each room were assessed on the fifteenth day of each month during the Dry season. The operative temperatures in the rooms were simulated for 24 hours, and the illuminance levels between 7am and 6pm. On-site measured data was used in validating the simulated values, details of the validation method used were given in a separate publication [15].

6. THERMAL AND VISUAL PERFORMANCE ANALYSIS

According to the results (Fig. 5) it is anticipated that the frequency of thermal discomfort (FTD) in CS1 and CS2 will be 64% and 72% for the period assessed. Moreover, the ITD in both rooms are around 41°C•h/day and 45°C•h/day respectively. On other hand, the frequency of visual discomfort (FVD) in CS1 and CS2 will be 72% and 54% for the period assessed (see figure 6), while the IVD in the room is predicted to be 23032Lux•h/day and 14113Lux•h/day respectively.

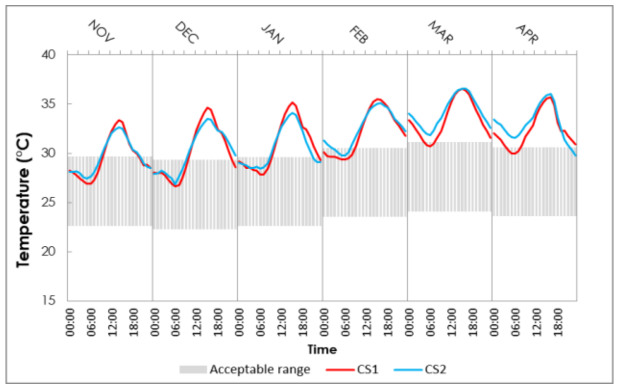

Figure 5: The acceptable temperature range and operative temperatures in CS1 and CS2 on the 15th of each month during the dry season

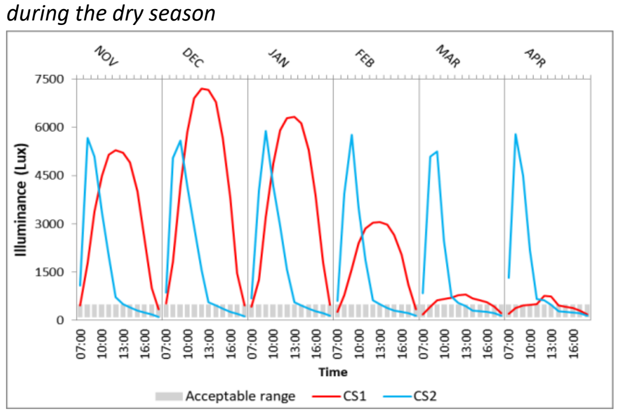

Figure 6: The acceptable illuminance range average daylight illuminance levels on the working plane of the living room in CS 1 and CS2 on the 15th of each month during dry season

Based on the application of the four categories of assessment presented, the thermal discomfort conditions in both rooms can be described as frequent and intense (Fig. 8). On the days during the first three months of the Dry season the operative temperature in both rooms are within the acceptable range for a few hours in the morning but rise to about 35°C in the afternoon. By March 15th, the operative temperatures in the rooms are constantly above the acceptable range and the maximum temperatures are above 35°C. Likewise, on April 15th, there are only 4 hours in CS1 and 2 hours in CS2 during which the temperatures indoors are within the acceptable range.

The visual discomfort conditions in CS1 can also be categorised as frequent and intense due to the high illuminance levels (above 1000lux) that are expected to occur most hours on the days assessed during the first four months of the dry season. On the 15th of March and April the room receives minimal direct sunlight, thus there are 8 hours of visual discomfort on March 15th and only 3 hours of visual discomfort on April 15th. Moreover, the illuminance levels during these hours are below 1000lux. In contrast, the visual discomfort status of CS2 can be classified as light and temporary. This is the results of the eastern orientation of the room only receiving high levels of illuminance for a couple of hours around sunrise.

6. PARAMETRIC IMPROVEMENTS

Mapping the data on a single figure /sheet across the various zones, as stated above, is intended to assist with the visual inspection of the results providing a quick but an informative standardised way to compare and choose between various scenarios. Thus, the impact of adding two shading features on the rooms' as-built performance was examined for comparison. The composite shading devices used are 300mm and 900mm deep consisting of an overhang above the window and fins on either side of the window (Fig. 7).

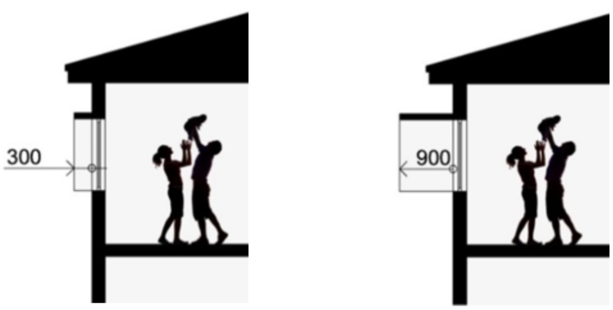

Figure 7: Composite window shading

As illustrated in Figure 8, the use of shading effectively reduces the frequency and intensity of thermal and visual discomfort. Although the thermal discomfort conditions for both rooms remain frequent and intense the FTD of CS1 and CS2 is reduced from 64% to 54% and 72% to 58% respectively with the 300mm shading components. The FTD with the 900mm shading components is about 52% and 56% in CS1 and CS2 respectively. Furthermore, the ITD in CS1 and CS2 is reduced from 41°C•h/day to 34°C•h/day and 45°C•h/day to 35°C•h/day respectively with the 300m shading components, while the 900mm shading reduces the ITD to 31°C•h/day and 32°C•h/day in CS1 and CS2 respectively. The results indicate that the addition of even minimal shading elements can be almost as effective as large shading elements for blocking unwanted solar radiation indoors in Abuja's climate. On the other hand, the increase in shading depth has a more significant impact on the visual environment in both cases. The FVD in CS1 and CS2 is reduced from 72% to 58% and 54% to 40% respectively with the 300m shading components. The FVD in CS1 and CS2 is further reduced to 13% and 25% with the 900m shading components added to the windows. Likewise, the IVD in CS1 and CS2 is reduced from 23032Lux•h/day to 16548Lux•h/day and 14113LuxC•h/day to 6925Lux•h/day respectively with the 300m shading components, while the values are about 563Lux•h/day and 1265Lux•h/day with the larger shading components.

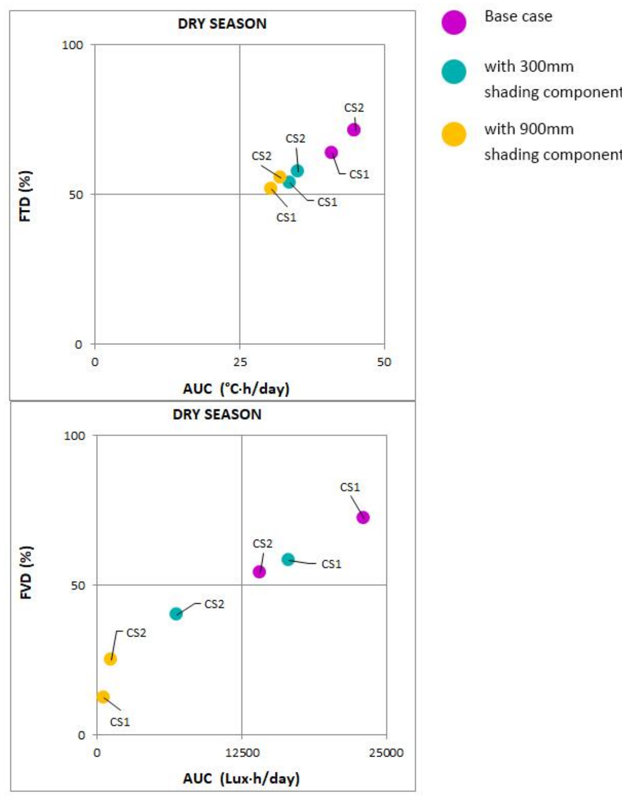

Figure 8: The zonal classification of the rooms assessed with 900mm shading (yellow), 300mm shading (blue) and without shading (purple) on the 15th of each month during the dry season

The impact of the shading elements on the zones of discomfort is illustrated in Figure 8. As clearly shown in the figure, the addition of shading elements can change visual discomfort from frequent and intense (zone 4) to light and temporary in both rooms (zone 1). Even though the frequency and intensity of thermal discomfort in both rooms are reduced the conditions in the rooms remain within zone 4. That said the zone diagram offers a simple and clear indication of the trend of discomfort with the addition of shading elements. Whereas the analysis presented in the paper is only limited to a few scenarios, the data mapping approach explained can be easily adjusted to identify the trend for other parameters or a range of multiple parameters.

7. OVERVIEW ON KEY FINDINGS

The evaluation tool adapted in this study following previous research work seems to offer an efficient informative way to assess buildings performance considering occupants' thermal as well as visual comfort demands. The simplicity of the data-mapping template presented can help designers quickly assess ways to optimise a building's design for comfort without sifting through cumbersome data. To manage such an analysis of the thermal and visual environments in residential settings, the tool only requires hourly operative temperatures and hourly average daylight illuminance. These data can be generated using reliable simulation packages or measured and collected on site. This can happen during the design phase for both new and existing buildings. However, the threshold for the zones established is dependent on the context of the study.

According to the results the two examined rooms are likely to be thermally uncomfortable for over half of the period assessed (64% and 72%) over the hottest part of the year. They are also expected to be visually uncomfortable for about 65% and 47% over the same period. Likewise, the intensity of thermal discomfort and visual discomfort are also high. With the exception of the visual condition in CS2, the visual and thermal conditions in the rooms can be classified as frequent and intense. However, it was found that the use of rigid shading components could potentially reduce the frequency of thermal discomfort in the rooms by 8.5-19.5%, as well as reducing the visual discomfort by 22-53%. In comparison to the as built-case, the intensity of thermal discomfort after the addition of shading devices reduced by as much as one-fifth and that of visual discomfort by as much as one tenth of the initial value. Shading devices (such as verandas) have long been recognised as the KEY design feature in the traditional residential architecture of Nigeria. Yet, most of Abuja's low -income contemporary dwellings are lacking the use of shading. Thus, responsive shading could not only act as a desired passive design measure but also as a cue bringing back some of the traditional architecture features to the image of the city.

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