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Indoor Thermal Comfort of Residential Buildings in the Hot-Humid Climate of Nigeria during the dry season

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Abstract: The indoor thermal conditions in residential buildings in two locations in Abuja, Nigeria were investigated to understand the ideal conditions of occupants in this hot-humid climate. Understanding these conditions helps give an insight into what people are experiencing in their houses and how they adapt to the high temperatures. The study seeks to fill the gap in research of occupants' thermal comfort in this area by providing empirical thermal comfort data from a city in the tropical region. During the study, 86 households responded to a post occupancy questionnaire to evaluate their building and how they adapt to high temperatures. A comfort survey questionnaire was administered to occupants of four low-income residential households to assess their perception of their thermal environment. These included two air conditioned and two naturally ventilated buildings with the questionnaires having over 80% return rate. Simultaneously, physical measurements were taken in the living room, bedroom and outdoor spaces to evaluate the actual building performance and thermal environment. Most occupants in the residential buildings in this climate experienced thermal discomfort and were uncomfortable with their thermal environment as suggested by the results of the study. The data further suggest the preferred conditions are operative temperatures above 28°C.

Keywords: Thermal comfort, Residential buildings, hot-humid Climate

Introduction

The current high indoor temperatures experienced in residential buildings, especially those in the big cities like Abuja in Nigeria are thermally uncomfortable for a substantial period (Adunola and Ajibola, 2012). Unfortunately, the housing condition in the country is of extreme worry as it is largely of poor quality and standard in both rural and urban centres. The increase in the quantity of housing needed has led to a major and evident concern about the quick deterioration of the current housing stock leading to a shortage of housing units (Olayiwola et al., 2005). Hence, because of the rush to meet demand, builders tend to focus more on quantity rather than quality therefore compromising standards and indoor comfort. Most occupants now rely on mechanical cooling: mostly, fans and air conditioning, to achieve thermal comfort.

Mechanical cooling is largely dependent on electricity in Nigeria of which the residential buildings sector consumed 53.3% of electricity generated as seen in the Federal Government of Nigeria's 2009 vision 2020 report in (Oyedepo, 2014; Adaji et al, 2015). However, due to the lack of a reliable and continuous power supply from the national grid, mechanical cooling systems in residential buildings are not dependable to provide cooling. Also, these cooling mechanisms (like air conditioning) require lots of energy to run and maintain. Hence, relying on the continuous running of air conditioning is not feasible and sustainable (Adaji *et al*, 2015). In addition to the lack of a constant power supply, people frequently turn to generators as a back-up power supply for their electrical appliances especially for mechanical cooling.

A thermal comfort study was carried out in Abuja, with a view to understanding the conditions of residents in buildings across two different residential neighbourhoods in the city, during the dry season. This paper tries to understand the ideal and preferred conditions of thermal comfort in low-income buildings in Abuja, Nigeria. Furthermore, monitoring of air temperatures and humidity was carried out to determine the maximum, minimum, average values and the way people adjust to achieve thermal comfort in buildings located in this area to understand what residents are experiencing. Studies such as this could also assist the improvement and recommendations of diverse levels of tropical comfort considerations required in the standards (Djongyang et al. 2010).

Study area and case study description

The study area Abuja, lies at latitude 9° 07 ’N and longitude 7° 48’ E, at an elevation of 840 m (2760 ft.) above sea-level. The area now designated the Federal Capital Territory (F.C.T.), Abuja, Nigeria’s capital, falls within the Savannah Zone vegetation of the West African sub region with Patches of rain forest. As it is in the tropics Abuja experiences two weather conditions annually; the rainy season ranging from 305 to 762 mm (12–30 in.) which begins in April and ends in October and the dry season (the equivalent of summer in a temperate climate) which begins in November and ends in March, but within this period, there is a brief interlude of Harmattan, a period when the North-East Trade Wind moves in with the main feature of dust haze, intensified coolness and dryness. Fortunately, the high altitudes and undulating terrain of the FCT act as a moderating influence on the weather of the territory. Temperatures can rise to 40°C during the dry season with dry winds lowering the temperature to as low as 12°C (Abubakar, 2014).

Four case studies in two locations (Lugbe and Dutse Alhaji) in Abuja were identified to investigate the thermal comfort of occupants with their means of ventilation (natural ventilation and air conditioning), purpose of construction (for low income group) and building type (low rise building) as the main selection criteria.

Case study 1, Lugbe (LGH1) (see figure 1), is in a low-middle income area (though designated a low-income area) called Light Gold Estate just off the express way linking the international airport in Abuja to the city centre. It’s a 3-bedroom, north facing detached bungalow, built with sandcrete blocks, has aluminium roofing with no insulation and is naturally ventilated.

Case study 2, Lugbe (LGH2) (see figure 1), is in a low-middle income area in Lugbe and is in the same location as the first house only not in the same estate but north of the first case study, called Trade Moore Estate. It’s an air conditioned north east (East by North) facing, 2-bedroom north facing semi-detached bungalow, built with sandcrete blocks and has aluminium roofing with no insulation.

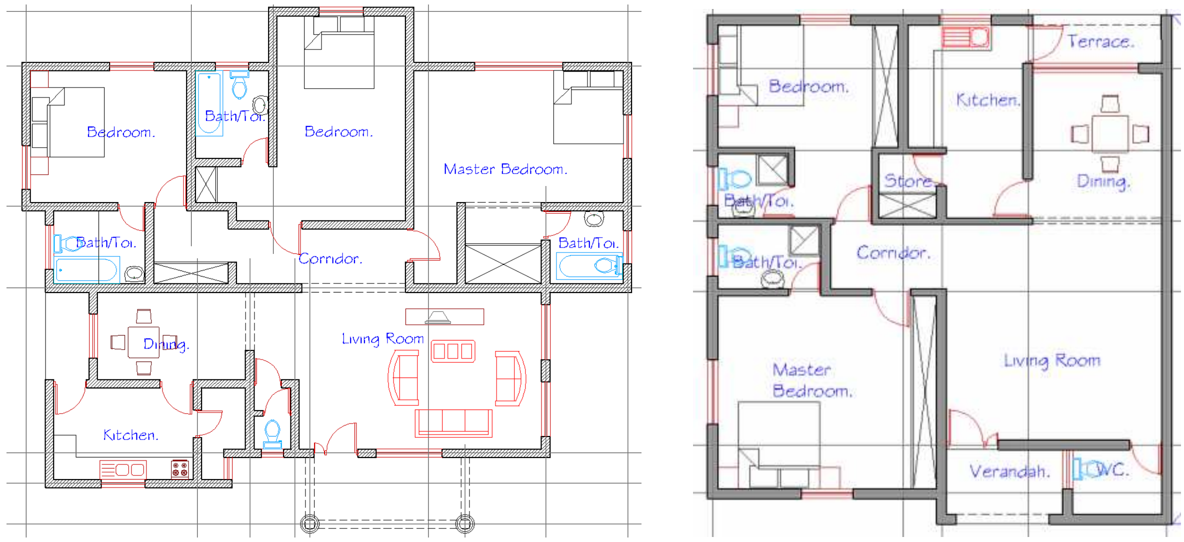

Figure 1: Floor plan of the Case Study 1 (left) and Case study 2 (right) in Lugbe, Abuja.

Case study 3 (DAH1) (see figure 2), in Dutse Alhaji, is in a low-income, high density area. The building is naturally ventilated and has a painted exterior. It is roofed with iron sheets with no insulation. Finally, Case study 4 (DAH2) is in the same area and is a 1-bedroom air conditioned flat attached to DAH1 (see figure 2).

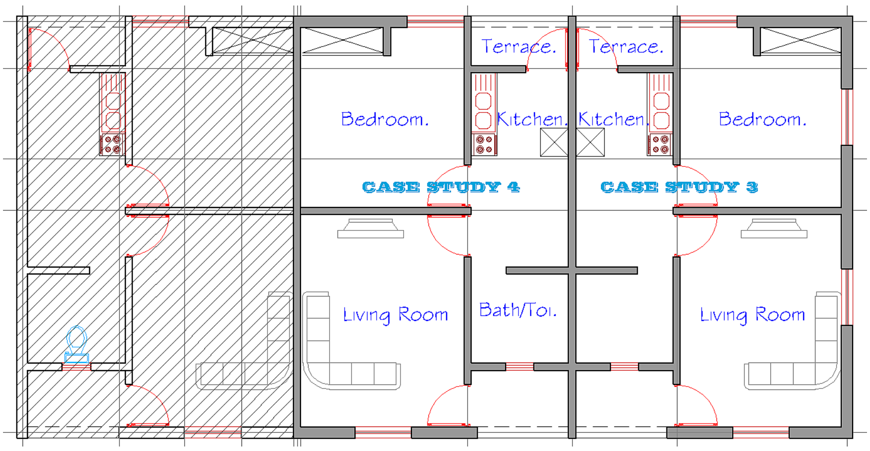

Figure 2: Floor plan for Case study 3 and 4 in Dutse Alhaji, Abuja

Research methods and techniques used for this research

The methodology for the survey included environmental monitoring, post-occupancy and comfort surveys. These surveys were aimed at obtaining a comprehensive understanding of occupants' thermal comfort sensation within the buildings and occupant's energy demands and use. The Post-occupancy studies are basic to evaluating the thermal condition in buildings, while the comfort surveys help to understand and in addition analyse the nature and occurrence of occupants' complaints of experiencing warmth or feeling hot through the day that can't be acquired during thermal investigations (Nicol and Roaf, 2005; Adekunle and Nikolopoulou, 2014).

Post-occupancy survey: This survey focused on dwellings other than the case study buildings but situated in the same areas. They add breadth and support the results from the individual case studies. Each questionnaire in the current study has 31 questions, divided into three main sections: Section A, includes background information about their location, gender, age, socio-economic status, educational and occupancy status; Section B, asks about building attributes and energy consumption including house type, number of rooms in the building and duration of occupancy; Section C, considers indoor thermal conditions and looks at how residents make themselves comfortable by opening and closing windows or doors, and clothing type. Overall 100 questionnaires were distributed, 90 (90%) were returned and of these 86 (86%) were correctly completed. All the questionnaires were self-administered.

Comfort survey: Thermal comfort questionnaires were issued to the occupants of the dwellings monitored. They were asked to complete the questionnaires three times per day to assess their thermal comfort state, (using the seven-point ASHRAE thermal sensation scale and a five-point preference scale). Further information on clothing insulation and activity was also collected. The comfort survey was designed as a daily diary evaluating occupants' responses to discomfort and how they achieve comfort at various times of the day (morning, afternoon and evening) for a week. These data were used to support the physical data collected at the same time.

Environmental Monitoring: The field survey was conducted during the dry season from 11/03/15 to 18/04/15. Air temperature and relative humidity were recorded using HOBO Temperature and Relative Humidity sensors installed on the internal walls at a height of 1.1m above the ground floor level. Four dwellings were monitored in Abuja, with two spaces representing the living room area and bedroom area monitored in each case study. The outdoor environmental conditions measured were air temperature and relative humidity using Tiny Tag T/RH sensors inside a radiation shield and global solar radiation on the horizontal. Data was recorded every 15 minutes.

Data analysis

Analysis of Post-Occupancy Survey:

Lugbe had 43 questionnaires returned, of which 26 (60.5%) were from male and 17 from female (39.5%). Dutse Alhaji had 43 questionnaires returned with 33 (76.7%) male and 10 (23.3%) female responses.

The warm part of the scale in the dry season, had a much greater response across all the respondents of the case studies, with 74.4% of occupants feeling 'warm' or 'hot' at Lugbe and 86.1% at Dutse Alhaji. The mean thermal sensations for Lugbe and Dutse Alhaji (Table 1) in the dry season were around the 'slightly warm'. The overall thermal sensation results across the two case studies show that 80.2% felt either 'warm' or 'hot' during the dry season.

The thermal satisfaction was measured on a 7-point scale with 1 for very dissatisfied to 7 for very satisfied. In Lugbe, 37.2% were satisfied with their thermal environment compared to 90% of respondents of Dutse Alhaji that were either 'very dissatisfied', 'dissatisfied' or 'slightly dissatisfied'.

Table 1: Post occupancy survey mean responses for the overall thermal sensation, thermal satisfaction, overall thermal comfort in the dry season

Case study	Overall Thermal sensation	Thermal satisfaction	Overall thermal comfort
Lugbe	5.8	3.9	3.6
Dutse Alhaji	6.0	2.1	5.3

A 7-point scale (from 1 for very uncomfortable to 7 for very comfortable) was used for the overall thermal comfort. There was an almost even distribution of the comfort votes in Lugbe where 49.5% were dissatisfied, i.e. only slightly skewed towards discomfort. However, 81% of the respondents in Dutse Alhaji indicated they were uncomfortable with their thermal environment. These results suggest that the thermal environment has been influenced by the air conditioning in these buildings, as houses in Lugbe have more air conditioning compared to those in Dutse Alhaji.

Analysis of Comfort Survey:

105 questionnaires were administered during the dry season and 71 were received (67.6% response), while 105 were administered during the rainy season and 55 were received, (52.4% response).

The comfort surveys show most of the occupants were feeling warm with most of the distribution of votes varying from 'slightly' warm' to 'hot'. The results suggest that 50% of the time the occupants in Lugbe LGH1 felt 'warm' while 25% of the time occupants in Lugbe LGH2 felt 'warm'. Also, 76.9% of the time the occupants in Dutse Alhaji DAH1 felt 'warm' compared to 25% of the time in Dutse Alhaji DAH2. The 25% warm votes recorded in Lugbe LGH2 and Dutse Alhaji DAH2 can be attributed to the use of air conditioning in these dwellings, though the 'slightly warm' votes in Lugbe LGH2 and Dutse Alhaji DAH2 were 53.6 and 56%.

Most of the residents spent 12 hours inside the house per day and most of the participants from the survey had lived in the case study buildings for over 36 months. The residents in Lugbe owned the properties they live in while the occupants in Dutse Alhaji lived in rented buildings. More than 70% of the spaces monitored in all case studies recorded temperatures above the comfort range.

Table 2: Thermal comfort survey mean responses for the thermal sensation in the dry season

Case study	Overall Thermal sensation
Lugbe (LGH1)	5.4
Lugbe (LGH2)	5.0
Dutse Alhaji (DAH1)	5.8
Dutse Alhaji (DAH2)	5.0

The thermal sensation analysis shows a distribution clustered above the central categories with more than two-thirds of the responses feeling 'uncomfortably warm' with a moderately even distribution of votes varying between 'neutral' and 'warm' (See table 2).

Linear regression analysis was used to calculate neutral and preferred temperatures (See Figure 3), which were in a range of 28°C to 30°C. This showed that occupants in this region of Abuja have a potential to adapt to high temperatures. Occupants in Lugbe showed more adaptation potential, with a higher neutral temperature of 29.6°C and preferred temperature of 28.3°C, compared to a neutral temperature of 28.2°C and a lower preferred temperature of 25.4°C in Dutse Alhaji.

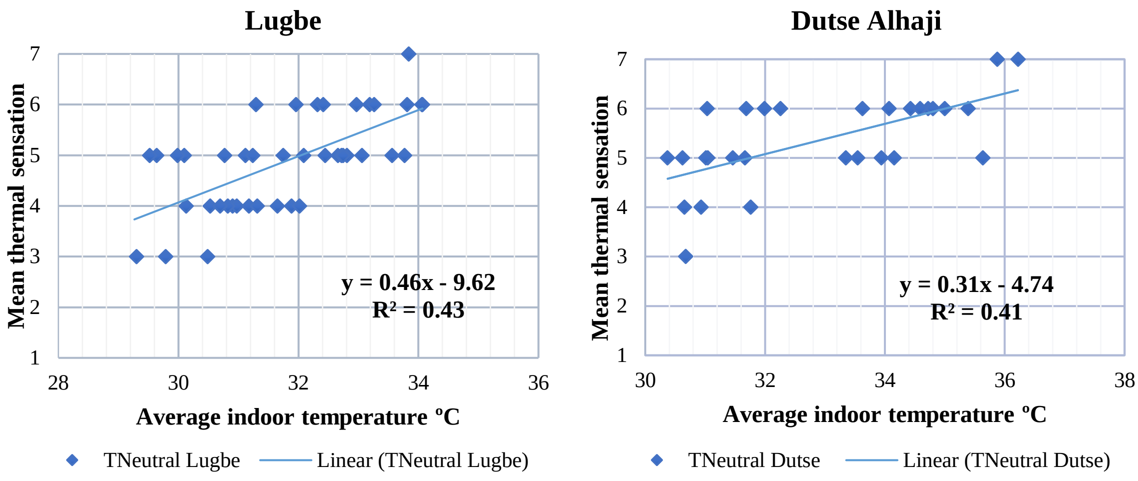

Figure 3: Relationship between the thermal sensation and the average indoor temperature at Lugbe (left) and Dutse Alhaji (right) during the dry season

Analysis of Environmental Survey:

The outdoor temperature recorded in Lugbe during the dry season varied from 23.5°C on 21/3 to a maximum of 41.1°C on 19/3, with a relative humidity varying from 19% on 19/3 to a maximum of 91% on 21/3, and an average of 56%; while the outdoor temperature in Dutse Alhaji varied from 23.0°C on 15/4 to a maximum of 38.4°C on 14/4, with a relative humidity varying from 10% on 17/4 to a maximum of 93% on 11/4 and an average of 37% throughout the monitoring period.

The measured outdoor temperature had a running mean temperature, $T_{rm,}$ as defined by BSENI 15251 (BSI, 2008), varying from 32.1°C on 23/3 to a maximum of 33.3°C on 21/3 in Lugbe and 30.8°C on 11/4 and a maximum of 31.4°C on 17/4 in Dutse Alhaji during the dry season monitoring. The results suggest that Lugbe had the hottest month of the year (March), with an average indoor temperature of 32°C and a maximum outdoor temperature of 41.1°C.

The average indoor temperature between 08.00 and 22.00 in the monitored living areas in Lubge was 32°C for the living rooms and 32°C for the bedrooms. The living room space recorded the hottest temperature in the building with a mean of 32.5°C and a maximum temperature of 36.2°C. The average temperature between 23.00 and 07.00 was 31.3°C for the living rooms and 31°C for the bedrooms. The living rooms were also the hottest space in the building with a mean temperature of 31.1°C and a maximum temperature of 34.6°C. There is a positive relationship between the indoor and outdoor temperatures and the living room temperatures in the two case studies are much higher and warmer than the bedroom spaces because of their higher occupancy throughout the day.

In Dutse Alhaji, the average temperature between 08.00 and 22.00 in the monitored living areas was 34.4°C for the living rooms and 31.1°C for the bedrooms. The living room space recorded the hottest temperature in the building with a mean of 34.5°C and a maximum temperature of 36.8°C. The average temperature between 23.00 and 07.00 was 32.7°C for the living rooms and 31.3°C for the bedrooms. The living rooms also were the hottest space in the building with a mean temperature of 32.9°C and a maximum temperature of 34.8°C.

The results indicate the living room is the hottest monitored space in the building and occupants in Dutse Alhaji experienced a higher temperature compared to the occupants in Lugbe. The indoor relative humidity was 21% - 76% for Lugbe and 15% - 66% in Dutse Alhaji, which is outside the comfort limit of 40% - 60% for the associated temperatures.

Conclusions

The results from the post occupancy, environmental monitoring and comfort survey from different residential low-income buildings in two locations in Abuja, Nigeria were presented in this paper.

Across the different locations examined during the post occupancy evaluations, 80% reported being warm and hot on the thermal sensation scale with most reporting being 'not satisfied' with their thermal indoor environment. At least 50% were uncomfortable with the thermal conditions. This further suggests that occupants perceived higher indoor temperatures during the dry season.

The thermal comfort survey showed occupants' adaptability to high temperatures with a neutral and preferred temperature range of 28.2°C – 29.6°C and 25.4°C – 28.3°C respectively with most of the occupants in the naturally ventilated building experiencing higher temperatures compared to those in air conditioned buildings. The linear regression analysis to calculate neutral and preferred temperatures confirm the higher adaptation potential at Lugbe compared to the lower temperatures recorded in Dutse Alhaji. However, the difference in temperature between the air conditioned and naturally ventilated building was only about 2°C. Upon further investigation, it was clear that most of the occupants of air conditioned buildings did not use their air conditioners for cooling frequently owing to power cuts being very common in this area during the survey. Most of the occupants didn't find their thermal conditions acceptable and more than 70% of the spaces monitored in all case studies recorded temperatures above the comfort range.

Based upon the results from these four case studies and the wider survey of 90 other dwellings, the results suggest that most residents in the study areas of Abuja are not satisfied with their thermal environment and there is discomfort among occupants in residential building. Occupants prefer to be much cooler during the dry season, therefore there is a high dependence on air conditioning to improve their indoor thermal condition.

This prevalence of thermal discomfort highlights the need to explore the possibilities of reducing internal temperatures, particularly by passive means (fabric, shading, etc.) given the need to avoid or reduce the need for air conditioning. This paper has reported on four case study dwellings, but six further dwellings have since been monitored in detail and will be reported in the future.

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