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Thermal comfort of occupants during the dry and rainy seasons in Abuja, Nigeria

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Abstract

The paper presents the results of a recent study on the thermal comfort of occupants in four low-income residential buildings, at two different locations, within the hot-humid climate of Abuja. A comfort survey questionnaire was administered to occupants of four case studies to assess their perception of their thermal environment. Simultaneously, the indoor temperatures and relative humidity of the living room and bedroom spaces were monitored as well as outdoor parameters to evaluate the actual building performance. To support the comfort survey, a post-occupancy survey was carried out to evaluate an additional 86 buildings nearby in the case studies areas. The paper focuses on analysing the thermal conditions of respondents of the post-occupancy survey, the comfort survey and indoor monitoring findings from the case studies. The maximum daytime average temperature of the naturally ventilated buildings was only 2.0°C more than in the air-conditioned buildings. The maximum indoor air temperature in the living spaces during the dry season was 36.8°C (and 26.4% RH) and the minimum 28.4°C (and 66.6% RH), while during the rainy season these were respectively 35.9°C (and 43.7% RH) and the minimum 24.3°C (and 75.5% RH). The results suggest that there was significant thermal discomfort in the low income residential buildings.

Keywords: Thermal comfort; hot-humid climate; low-income residential buildings

1 Introduction

Dry season temperatures in residential buildings in tropical regions like Nigeria are becoming a major concern. High levels of solar radiation influence the heat produced in this region which increases the heat intensity felt by residents within the building as seen in high indoor temperature levels. These indoor temperatures can be a health hazard and as global temperatures are expected to rise, they can also be life threatening to occupants. Also, Indoor activities, rural urban migration, industrial process and deforestation contribute to the increase of these high indoor temperatures (Adunola, 2012).

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 of time (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 needs has led to a major and evident concern about the quick deterioration of 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. This in turn creates buildings with poor thermal properties i.e. buildings that allow high levels of solar gain into the building fabric, subsequently increasing discomfort to occupants and increasing the energy use especially that meant for cooling the indoor environment. Comfort levels are usually poor, as a result of the construction or lack of ventilation in the roof. These building can't last for longer periods before they start deteriorating. As a consequence, most occupants now rely on mechanical cooling mostly, fan 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 reliable and continuous power supply from the national grid, mechanical cooling systems in residential buildings are not really dependable to provide cooling. Also these cooling mechanisms, like air-conditioning require lots of energy to run and maintain. Hence, the continuous running of air-conditioning is not feasible and sustainable (Adaji et al, 2015). In addition to the lack of constant power supply, people tend to turn to generators as a back-up power supply for their electrical appliances especially for mechanical cooling.

The construction and building sector may also be a contributing factor to the problem of indoor heat gain. There's little or no regard to thermal comfort concerns and local climate when designing and constructing buildings. Most materials used in construction today, especially the sandcrete blocks for walling, made of sand, cement and water mix, don't have sunlight reflection and insulation qualities. Also, they don't have an effective shield or insulation between the building interior and the outdoor environment. As a result, the building through its opaque fabric, experiences high level of solar gain. This also causes thermal discomfort to occupants of these buildings given the hot climate of Nigeria (Adaji et al, 2015).

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 and rainy seasons. This paper tries to understand the ideal and preferred conditions of thermal comfort in low-income (in the lower half of the income spectrum) buildings in Abuja, Nigeria. Furthermore, monitoring of air temperatures and humidity was carried out to determine the maximum, minimum and average values and also the way people adjust to achieve thermal comfort in buildings located in this area in order 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).

2 Conditions for achieving thermal comfort in buildings

Thermal comfort can be described as satisfaction with thermal sensation felt within an indoor climate; the occupants in their indoor environment should be satisfied with their indoor climate of the time (de Dear and Brager, 2002). For people to find a building thermally comfortable, building designers should provide certain thermal comfort standards to attain or improve indoor climates. Occupants should be thermally comfortable in a building and its sustainability should be increased by reducing its energy consumption potential (Nicol and Humphreys, 2002). In ASHRAE standard 55 (1992), it describes attaining thermal comfort as when the 'indoor space environment and personal factors produce a thermal environmental condition acceptable to 80% or more of the occupants within a space' (ASHRAE 1992; de Dear and Brager, 2002). In thermal comfort quality for residential buildings; the materials used, nature of building, the variations to the building structure and installation in all situations are very important options to use when relating the influence of changes to building, which must be maintained at all times (Peeters *et al.,* 2009).

3 Thermal comfort in a Hot-humid climate

Attaining thermal comfort is crucial for health and efficiency for the people in the building. Researchers have used indoor thermal measurements such as ISO 7730 and the ASHRAE standard 55 (ASHRAE, 2004) to determine indoor thermal comfort and expression of satisfaction by that condition of mind with the thermal environment. The results and analyses from these experiments have created thermal comfort templates, definitions and standards which are used in temperate regions; after all it was developed to serve the temperate climate.

There have been many studies carried out in hot humid climates with most results showing a wide range of temperatures at which people feel comfortable (comfort or neutral temperature) measured in air-conditioned (AC) and naturally ventilated (NV) buildings as seen in Table 1 below

Table 1: Neutral temperature results from field experiments conducted in hot-humid climates

Year	Researcher	Building	Location	Neutral temperature of subjects	
1990	J.F Busch	Office	Bangkok, Thailand	24.5°C (ET) for AC buildings	28.5°C (ET) for NV buildings
1991	R.J. de Dear, K.G. Leow *et al.*	Residential and office	Singapore	24.2°C for AC buildings	28.5°C for NV buildings
1994	R.J. de Dear, M.E. Fountain	AC Office	Townsville, Australia	24.2°C for AC buildings	24.6°C for NV buildings
1998	T.H. Karyono	Office	Jakarta, Indonesia	26.7°C for AC buildings	
1998	W.T. Chan *et al.*	Office	Hong Kong	23.5°C for AC buildings	
1998	A.G. Kwok	Classroom	Hawaii, USA	26.8°C for AC buildings	27.4°C for NV buildings
2003	N.H. Wong *et al.*	Classroom	Singapore		28.8°C for NV buildings

Source: Hwang *et al.* (2006) in Akande and Adebamowo, (2010)

Furthermore, studies in sub-Saharan Africa have shown most neutral temperatures are above 26.0°C as seen in Ogbonna and Harris (2007), a study carried out on naturally ventilated buildings in Jos, Nigeria achieved an operative temperature of 26.1°C, though the neutral temperature was 25.06°C. Also a study in Lagos, Nigeria by Adebamowo, (2007) achieved a neutral temperature of 29.1°C. In Akande and Adebamowo, (2010) a study on naturally ventilated residential buildings in Bauchi, Nigeria, gave a neutral temperature of 28.4°C. In Cameroun, Djongyang and Tchinda, (2012) did a survey in an inter-tropical climate in a naturally ventilated building, the thermo neutral temperature range from this experiment was 24.7°C – 27.3°C.

From the results of studies conducted by different researchers around the world, it shows that neutral temperatures have exceeded the higher range of comfort temperature, 26.0°C prescribed by Fountain et al. (1999) and the ISO EN 7730 (1994) standard. Though the studies have proven to be important, their findings have yet to be widely recognized as a comprehensive way for naturally ventilating buildings in the tropics (Adebamowo, 2007). As a result of previous research suggestions, the wider range of comfort conditions in reality is where occupants have the sensation of feeling comfortable. Also their environment is affected by several factors like physiological adaptations (experiences, acclimatisation), psychological adaptations (expectations) and behavioural adjustment (modifications made by a person consciously or unconsciously) which could contribute to occupants adapting to changes (Adebamowo, 2007; Peeters et al., 2009).

Regarding human thermal comfort, there has been much documented material worldwide from physiological, adaptive and social hypotheses but throughout sub-Saharan Africa especially the tropic regions, there have been few literature reports on comfort of occupants and residential thermal environment. The tropics may require a different level of comfort parameter in the standard, besides the current standards are almost based on experiment across a variety of climatic zones including temperate, hot-humid and cold regions (Djongyang et al. 2010). Furthermore, there is little or no literature reported on indoor comfort for residential occupants in Abuja.

This paper is aimed at filling this gap by investigating the indoor thermal comfort for occupants and their thermal environment.

4 Study Area

The study area falls within latitudes 7º 20′ and 9º 20′ north of the Equator and longitudes 6º 45′ and 7º 39′. 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 which begins in April and ends in October and the dry season which begins in October and ends in April, 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 cool and dryness. Fortunately, the high altitudes and undulating terrain of the FCT act as moderating influence on the weather of the territory. The maximum daytime air-temperature ranges from 28°C to 35°C and a minimum night-time temperature ranging from 18°C - 23°C (World climate guide, 2014); (Abubakar, 2014).

4.1 Case Study Description

Four case studies in two locations (Lugbe and Dutse Alhaji) in Abuja were identified in order 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 their main criteria.

All the roofs of the buildings selected for this study were unventilated but had a ceiling between the roof space and the rooms. Roof overhangs were in the range of 0.6m - 0.7m. The floor to ceiling height was between 3m - 3.2m. The buildings were all ventilated using operable windows and none of the external windows had shading devices. The walling material comprises mainly sandcrete blocks, which have a dimension of 45cm x 23cm x 23cm for external walls and 45cm x 15cm x 23cm for internal partitions walls like toilets and bathrooms.

The case studies are located in low and low-middle income areas, which can be defined as an area where residents earn the minimum wage of N18,000.00 (GBP 45.00 at N400.00 = GPB 1.00) to four times the minimum wage (Ekong and Onye, 2013). Most people in this area have more than one job and tend to save over time to build or rent better houses, therefore the façade of some of these houses might look like those meant for the middle income areas, but most often, they are not usually built to the recommended standard set by the housing authorities in Abuja.

Case study 1, Lugbe (LGH1), (Figures 1, 2 and 3) is located in a low-middle income area (officially 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 north facing, 3-bedroom detached bungalow, built with sandcrete blocks, has aluminium roofing and is naturally ventilated.

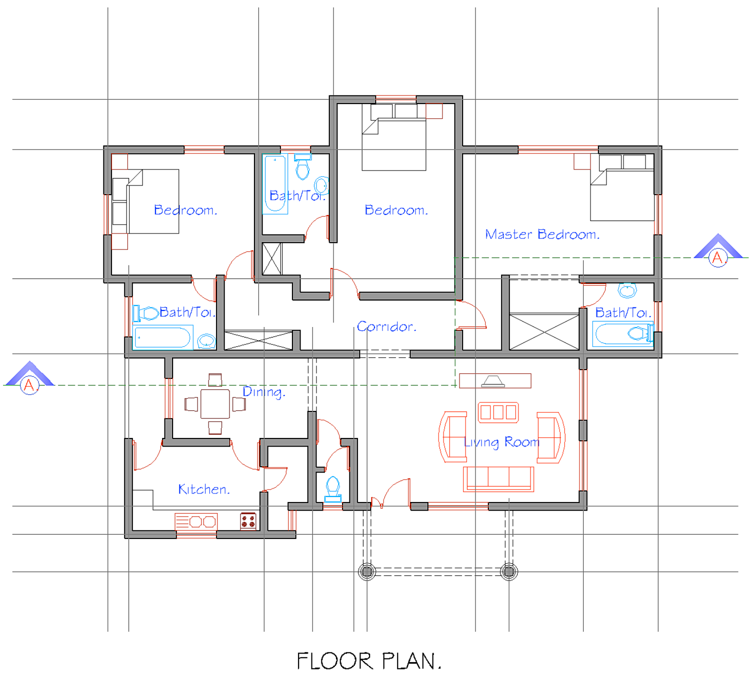

Figure 1: Floor plan of Case Study 1 in Lugbe, Abuja

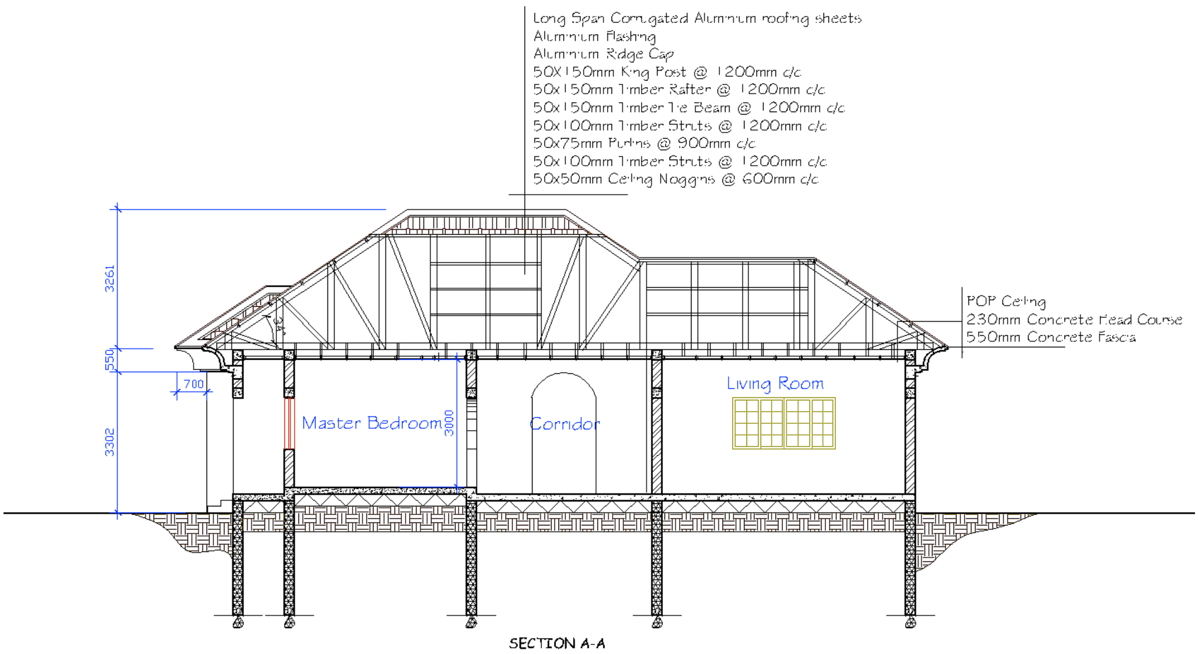

Figure 2: Section A-A of Case Study 1 in Lugbe, Abuja

Figure 3: Front view of Case Study 1

Case study 2, Lugbe (LGH2), (Figures 4 and 5) is located in a low-middle income area in Lugbe and it's 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 facing 2-bedroom semi-detached bungalow, built with sandcrete blocks and has aluminium roofing.

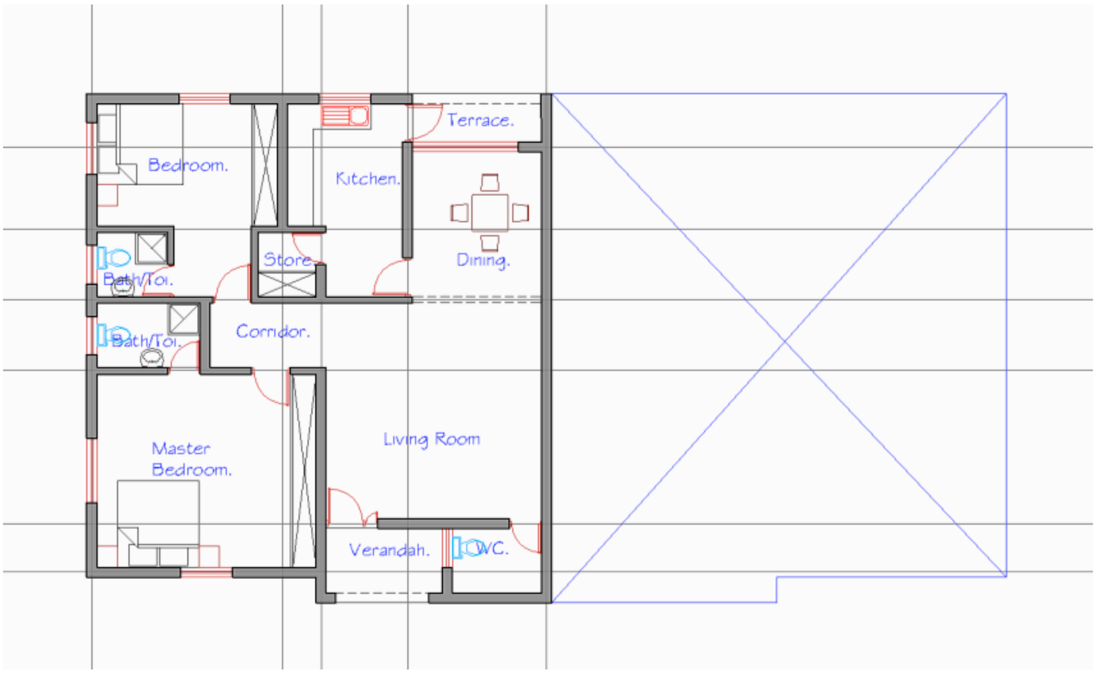

Figure 4: Floor plan for Case study 2 in Lugbe, Abuja

Figure 5: Main building, Case study 2

Case study 3 (DAH1) in Dutse Alhaji, (Figures 6, 7 and 8) is located in a low-income, high density area. The building is naturally ventilated and has a painted exterior. It is roofed with iron sheets and built with sandcrete blocks. It's in a sound state, although it needs some minor repairs. Finally, Case study 4 (DAH2) (Figures 6 and 8) is located in the same area and is a 1 bedroom flat attached to DAH1. It is air conditioned and it's also in a sound state but needs minor repairs too.

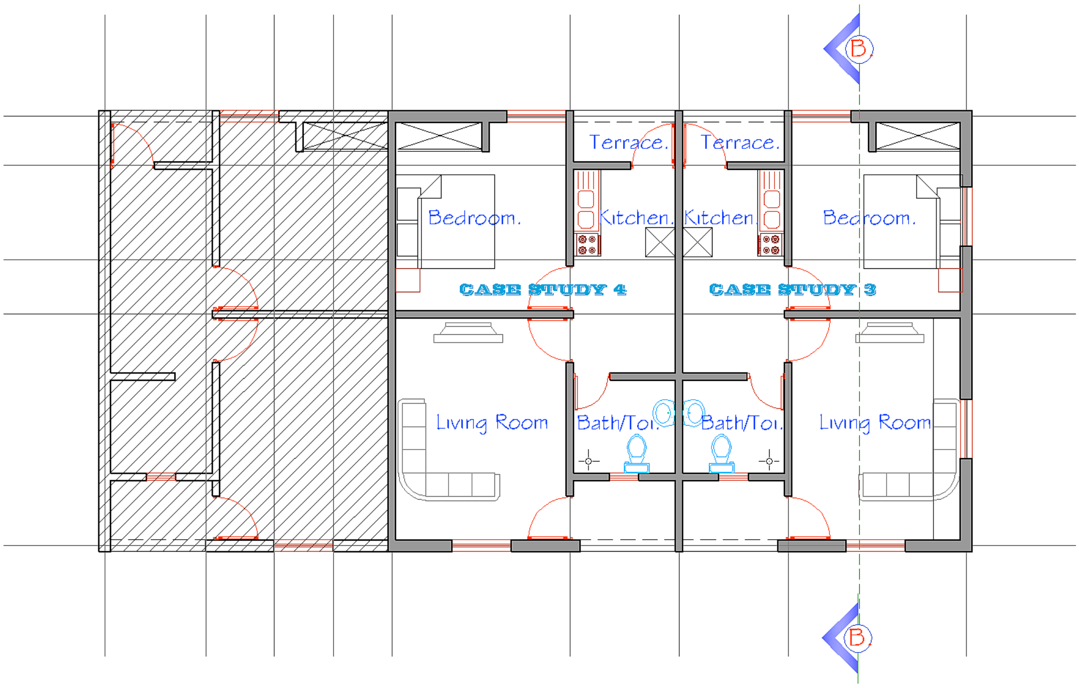

Figure 6: Floor plan for Case studies 3 and 4 in Dutse Alhaji, Abuja

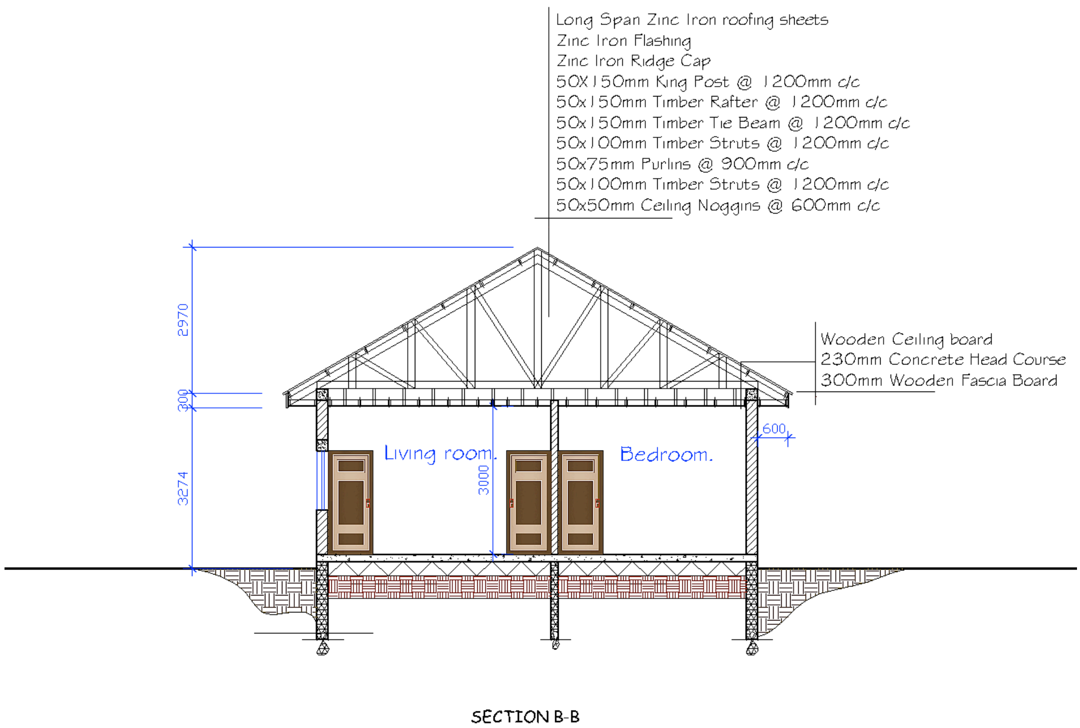

Figure 7: Section B-B of the Case Study 3 in Dutse Alhaji, Abuja

Figure 8: Main building, Case studies 3 and 4 in Dutse Alhaji, Abuja

5 Research methods and techniques used for this research

The methodology for the survey included environmental monitoring, with post-occupancy and comfort surveys. These surveys were aimed at obtaining a comprehensive understanding of occupants' thermal comfort sensation within the buildings and occupants' energy demands and use.

5.1 Post-occupancy Survey

Post-occupancy surveys help understand and compare the nature and frequency of occupants' views that cannot be measured during surveys, especially why they feel warm or hot. That's why they are critical in increasing the value of the thermal environment, (Nicol & Roaf, 2005); (Adekunle and Nikolopoulou, 2014). This survey focused on dwellings other than the case study buildings but situated in the same area. They add breadth and support the results from the individual case studies. Each questionnaire in the current study has 31 questions, requiring 8-10 minutes to complete. Questions on overall thermal comfort and thermal satisfaction in different seasons were asked for respondents to evaluate. The questionnaire was 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 109 questionnaires were distributed, 100 (92%) were returned and of these 86 (79%) were correctly completed. The questionnaires were self-administered and survey visits were conducted between 6.30am and 18.00pm (Figure 9).

Figure 9: Post occupancy survey

5.2 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.

5.3 Environmental Monitoring

The field survey was conducted during the dry and rainy seasons from 18/03/15 to 18/04/15 and 17/06/15 to 12/07/15 respectively. 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 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. Data was recorded every 15 minutes (Figure 10).

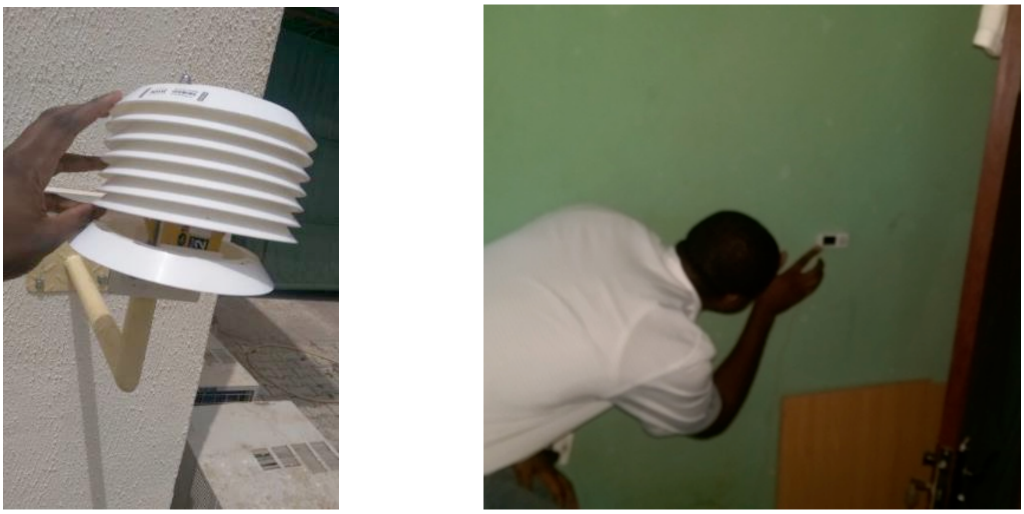

Figure 10: Installation of Tiny Tag outdoor logger and indoor Hobo T/RH sensors

6 Data analysis and Results

6.1 Analysis of Post-Occupancy Survey

Lugbe had 43 valid questionnaires returned (79% response), of which 26 (60.5%) were male and 17 female (39.5%). Most of the respondents were from the (31-45) age group, 24 (55.8%) and 17 (39.5%) from the (18-30) age group. Dutse Alhaji had 43 valid questionnaires returned (80% response), with 33 (76.7%) male and 10 (23.3%) female responses. The age response breakdown was 33 (76.7%) for the (31-45) and 10 (23.3%) from the (18-30) age group.

In the dry season, the warm part of the scale 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 (figure 11). In contrast, in the rainy season, there was a clear shift to the 'cool' part of the scale for respondents in Lugbe with more than 67.0% feeling 'cool' or 'slightly cool', whilst 52.9% of respondents in Dutse Alhaji felt 'cool', 'slightly cool' or 'neutral' (figure 12). The mean thermal sensations for Lugbe and Dutse Alhaji (Table 2) in the dry season were around the 'slightly warm' and 'warm' while in the rainy season between 'cold' and 'neutral'. The overall thermal sensation results across the two case studies show that 80.2% felt either 'warm' or 'hot' during the dry season compared to 29.1% that felt 'slightly warm' or 'warm' during the rainy season

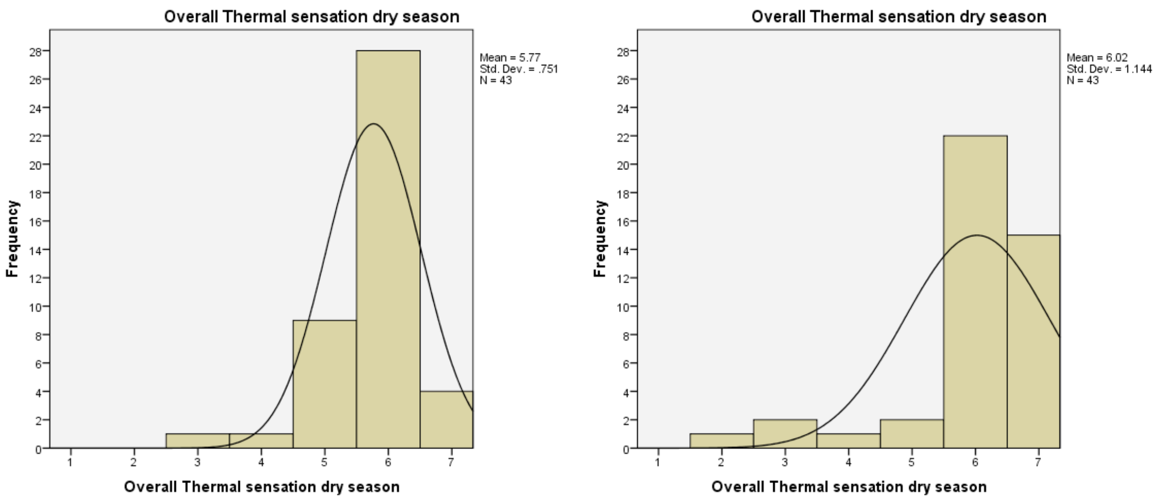

Figure 11: Distribution of overall thermal sensation votes during the dry season in Lugbe (left) and Dutse Alhaji (Right) (Scale: 1 = Cold to 7 = Hot)

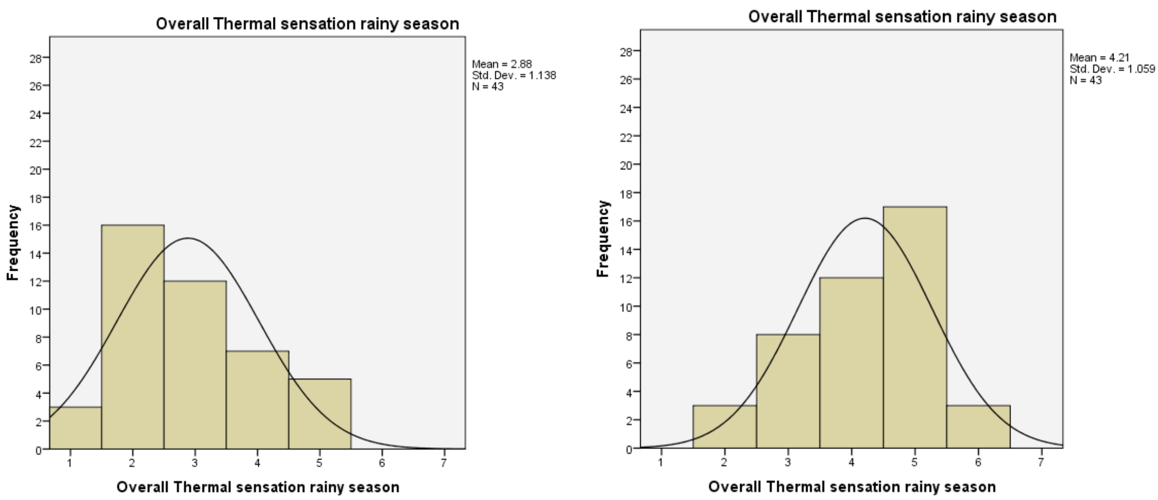

Figure 12: Distribution of overall thermal sensation votes during the rainy season in Lugbe (left) and Dutse Alhaji (right) (Scale: 1= cold to 7= hot)

Table 2: Post occupancy survey mean responses for the overall thermal sensation, thermal satisfaction, overall thermal comfort in the dry and rainy season

Case study	Overall Thermal sensation (Scale: 1= cold to 7= hot)		Thermal satisfaction (Scale: very dissatisfied to 7= very satisfied.)		Overall thermal comfort (Scale: 1 = very comfortable to 7= very comfortable)	
	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season
Lugbe	5.8	2.9	3.9	5.4	3.6	2.5
Dutse Alhaji	6.0	4.2	2.1	3.3	5.3	3.9

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' (Figure 13).

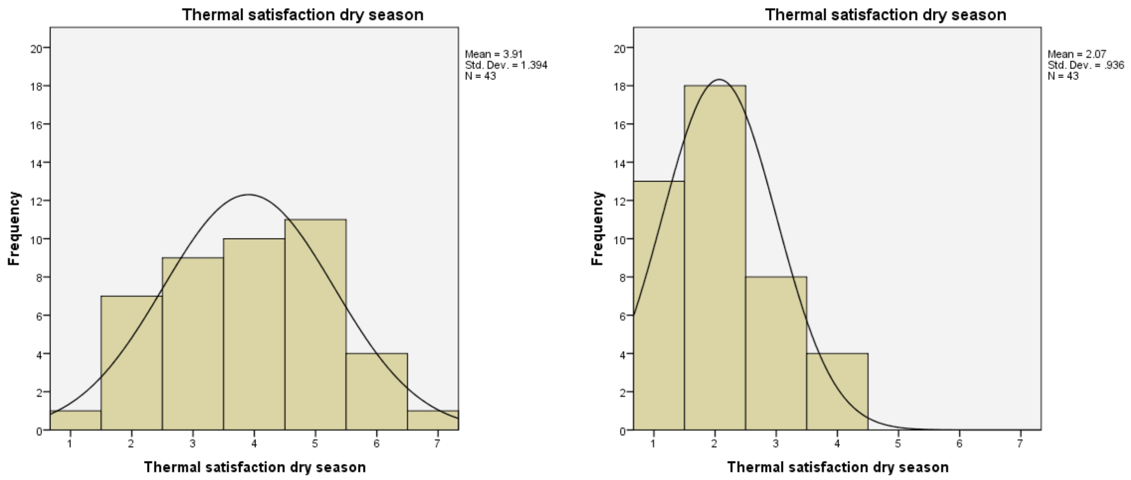

Figure 13: Distribution of thermal satisfaction votes during the rainy season in Lugbe (left) and Dutse Alhaji (right) (Scale: 1= very dissatisfied to 7= very satisfied.)

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 (Figure 14). These results suggest that the thermal environment has been influenced by the air-conditioning in these buildings especially in Lugbe, where 65.1% use air-conditioning in their living rooms and 58.1% in their bedroom while in Dutse Alhaji, 37.2% use air-conditioning in their living room and 30.2% in their bedroom, indicating Lugbe has more air-conditioning users compared to those in Dutse Alhaji.

For the rainy season, the respondents in Lugbe showed a substantial shift in overall thermal comfort vote towards the comfort part of the scale, with 76.7% feeling 'slightly comfortable' or 'comfortable', while 58.1% of respondents in Dutse Alhaji were 'neutral', 'slightly comfortable' or 'comfortable' (Figure 15).

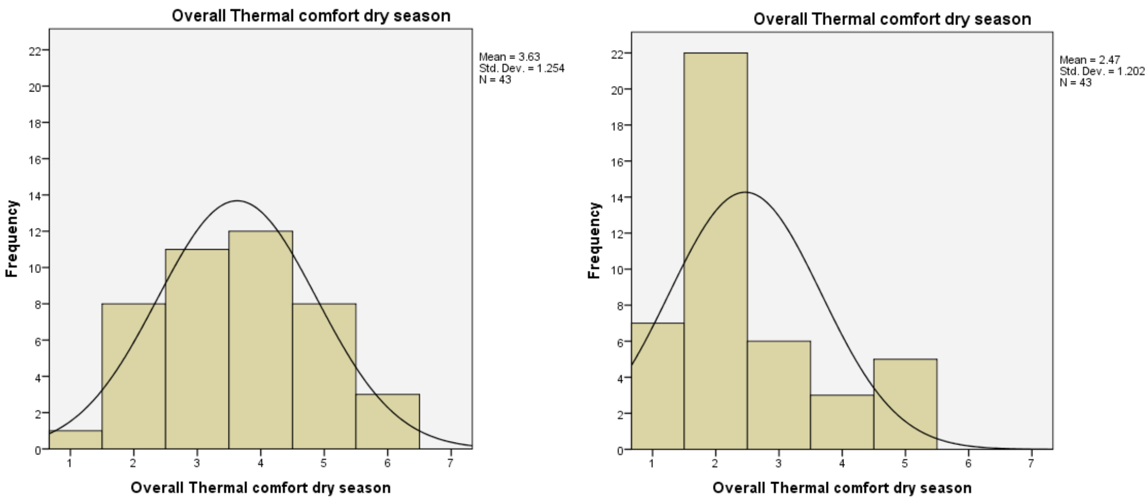

Figure 14: Distribution of overall thermal satisfaction votes during the dry season in Lugbe (left) and Dutse Alhaji (right) (Scale: 1= very uncomfortable to 7= very comfortable)

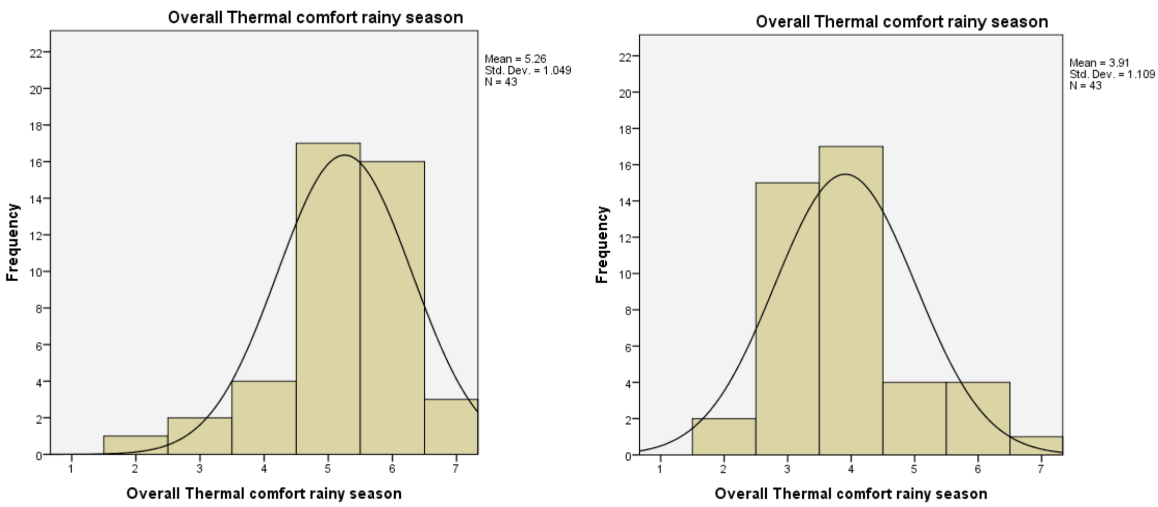

Figure 15: Distribution of overall thermal satisfaction votes during the rainy season in Lugbe (left) and Dutse Alhaji (right) (Scale: 1= very uncomfortable to 7= very comfortable)

6.2 Analysis of Comfort Survey

105 thermal comfort 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 (Figures 16 and 17) 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, 77% 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.

The majority of the residents spent 12 hours inside the house per day and most of the participants from the survey have 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.

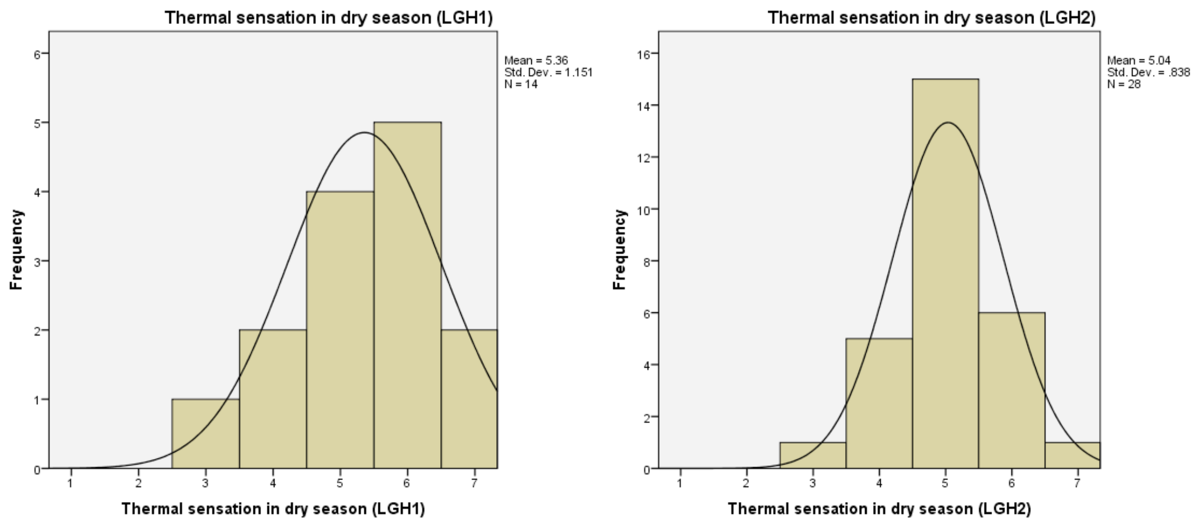

Figure 16: Distribution of overall thermal sensation votes during the dry season in Lugbe with naturally ventilated building (left) and air-conditioned building (right) (Scale: 1= cold to 7= hot)

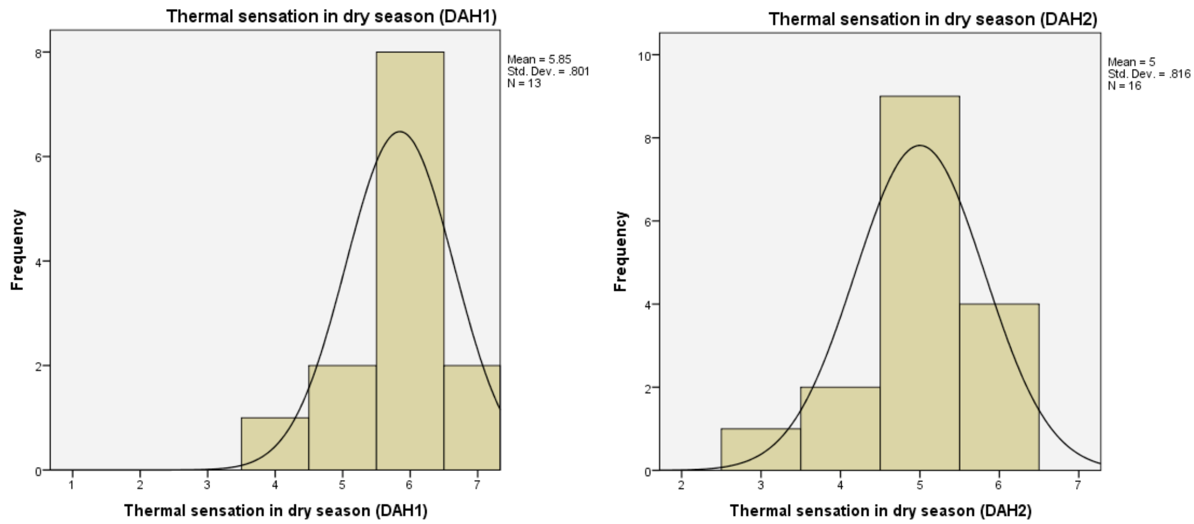

Figure 17: Distribution of overall thermal sensation votes during the dry season in Dutse Alhaji with naturally ventilated building (left) and air-conditioned building (right) (Scale: 1= cold to 7= hot)

There was a shift in the thermal sensation mean votes during the rainy season to the cool and neutral part of the scale (Figures 18 and 19). More than 67% of the time the residents in Lugbe felt either 'slightly cool' or 'neutral' or 'slightly warm' compared to more than 88% of the time in Dutse Alhaji that either felt 'neutral' or 'slightly cool'. The results further suggest that most of the time the residents in the case studies in Dutse Alhaji felt warmer in the rainy season compared to residents in Lugbe.

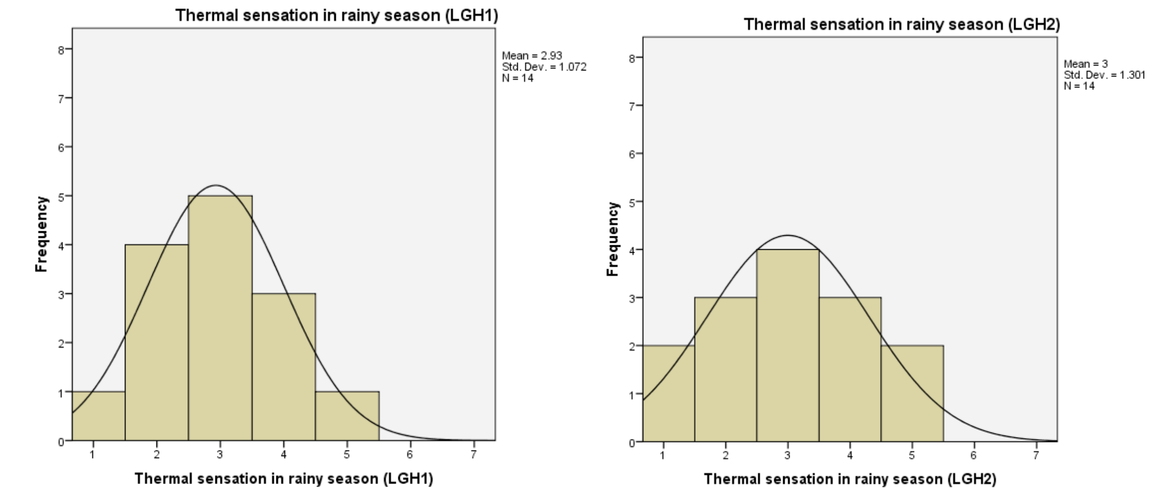

Figure 18: Distribution of overall thermal sensation votes during the rainy season in Lugbe with naturally ventilated building (left) and air-conditioned building (right) (Scale: 1= cold to 7= hot)

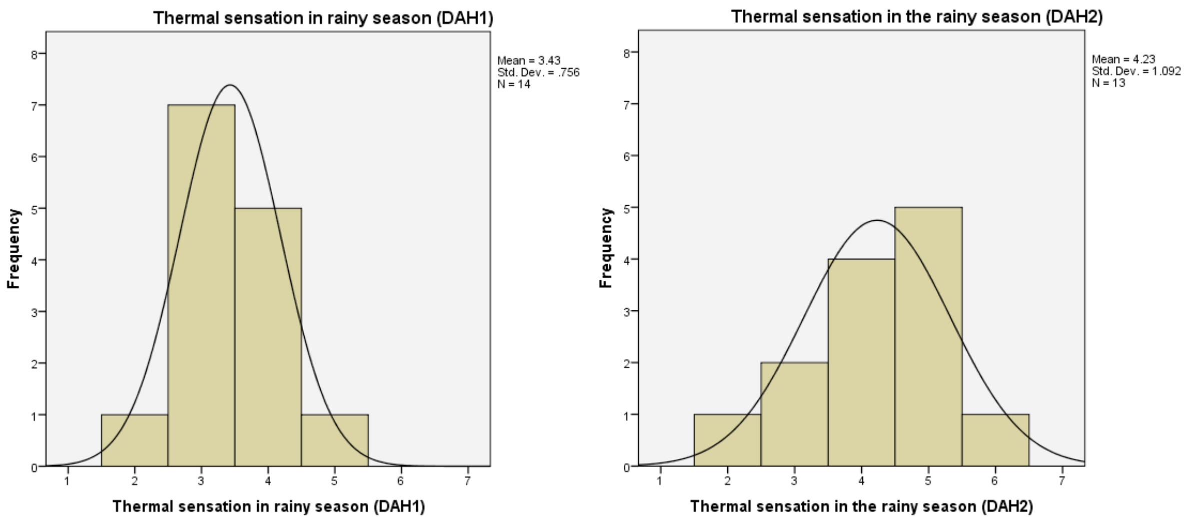

Figure 19: Distribution of overall thermal sensation votes during the rainy season in Lugbe with naturally ventilated building (left) and air-conditioned building (right) (Scale: 1= cold to 7= hot)

Table 3: Comfort survey mean responses for the thermal sensation and thermal satisfactions in the dry and rainy season

Case study	**Thermal sensation** (Scale: 1= cold to 7= hot)		**Thermal preference** (Scale: 1= much cooler to 5= much warmer)	
	Dry season	Rainy season	Dry season	Rainy season
Lugbe LGH1 (NV)	5.4	2.9	2.1	3.1
Lugbe LGH2 (AC)	5.0	3.0	2.3	4.4
Dutse Alhaji DAH1 (NV)	5.9	3.0	1.6	2.5
Dutse Alhaji DAH2 (AC)	5.0	4.0	2.3	3.2

NV: naturally ventilated building, AC: air-conditioned building

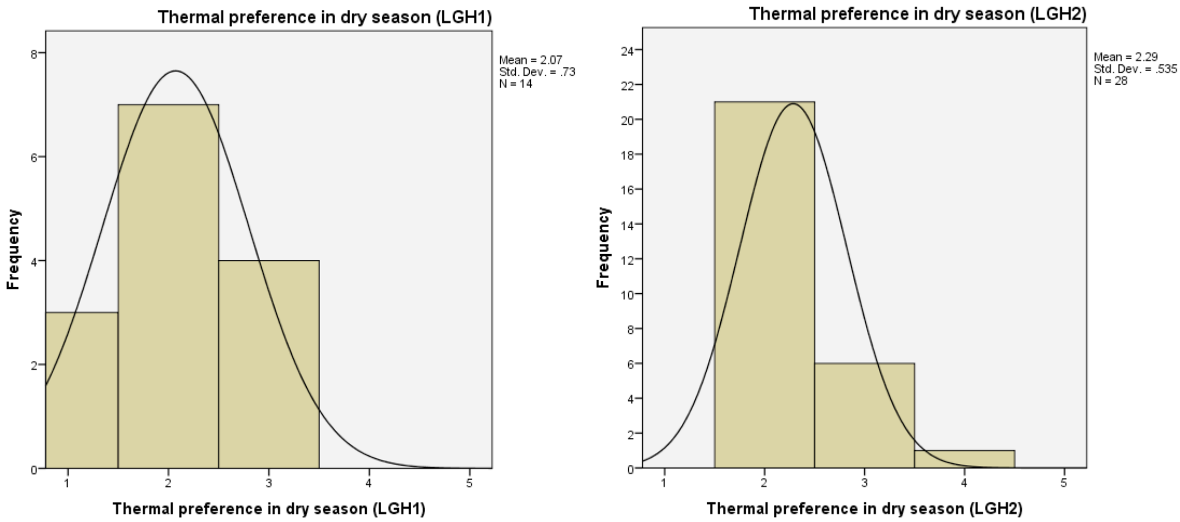

Figure 20: Distribution of overall thermal preference votes during the dry season in Lugbe with naturally ventilated building (left) and air-conditioned building (right) (Scale: 1= much cooler to 5= much warmer)

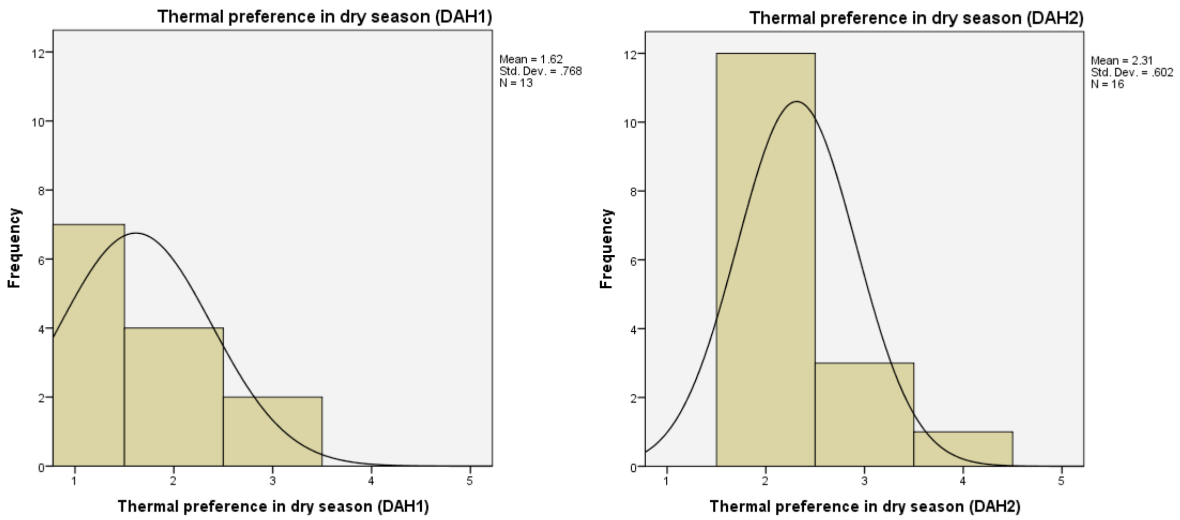

Figure 21: Distribution of overall thermal preference votes during the dry season in Dutse Alhaji with naturally ventilated building (left) and air-conditioned building (right) (Scale: 1= much cooler to 5= much warmer)

The mean distributions of occupants' responses from the dry season surveys shows they would prefer to be cooler (Figure 20-23). Also there was a drift to the 'no change' vote during the rainy season. The survey indicates that most occupants prefer their thermal environment the way it is during the rainy season (Table 3).

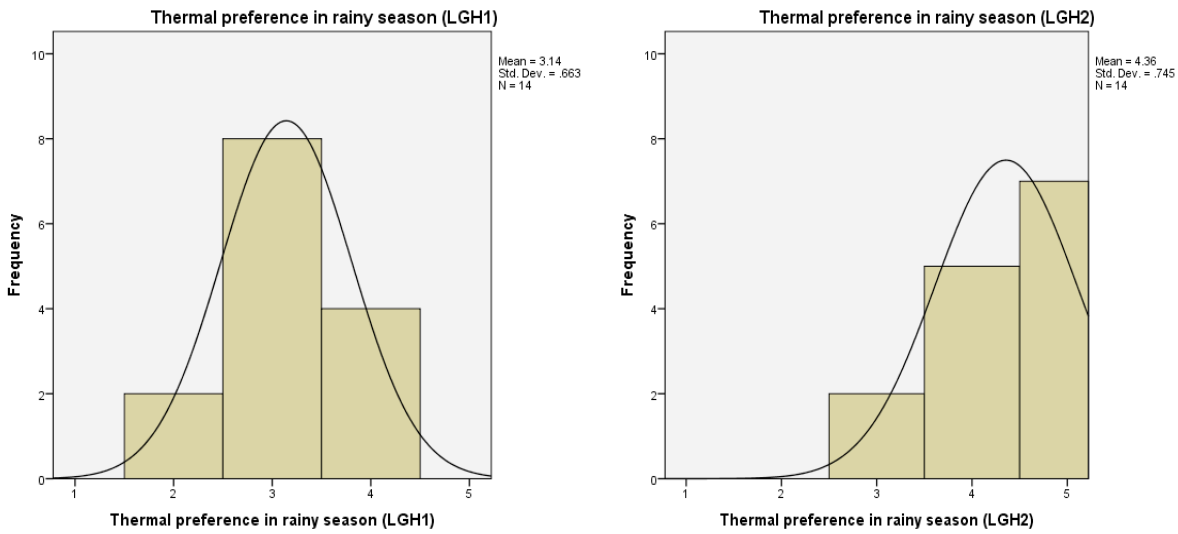

Figure 22: Distribution of overall thermal preference votes during the rainy season in Lugbe with naturally ventilated building (left) and air-conditioned building (right) (Scale: 1= much cooler to 5= much warmer)

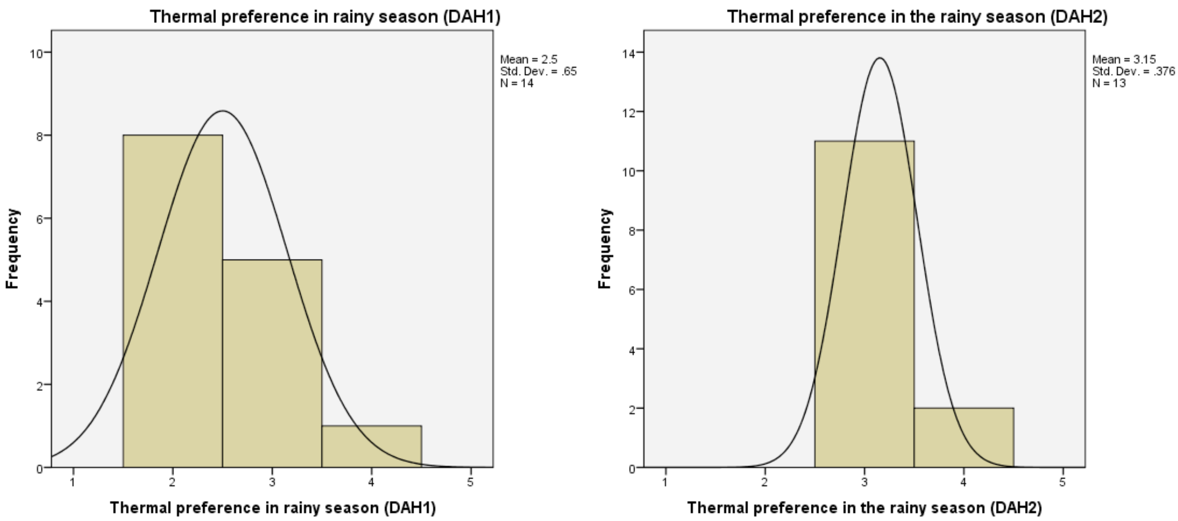

Figure 23: Distribution of overall thermal preference votes during the rainy season in Dutse Alhaji with naturally ventilated building (left) and air-conditioned building (right) (Scale: 1= much cooler to 5= much warmer)

6.3 Analysis of Environmental Survey

The outdoor temperature recorded in Lugbe during the dry season varied from 23.0ºC on 19/3 to a maximum of 41.7ºC on 21/3, with a relative humidity varying from 17.8% on 19/3 to a maximum of 93.1% on 21/3, and an average of 56% (Figure 24); while the outdoor temperature in Dutse Alhaji varied from 23.0ºC on 15/4 to a maximum of 38.0ºC on 15/4, with a relative humidity varying from 35.4% on 14/4 to a maximum of 94% on 15/4 and an average of 35.4% throughout the monitoring period (Figure 25).

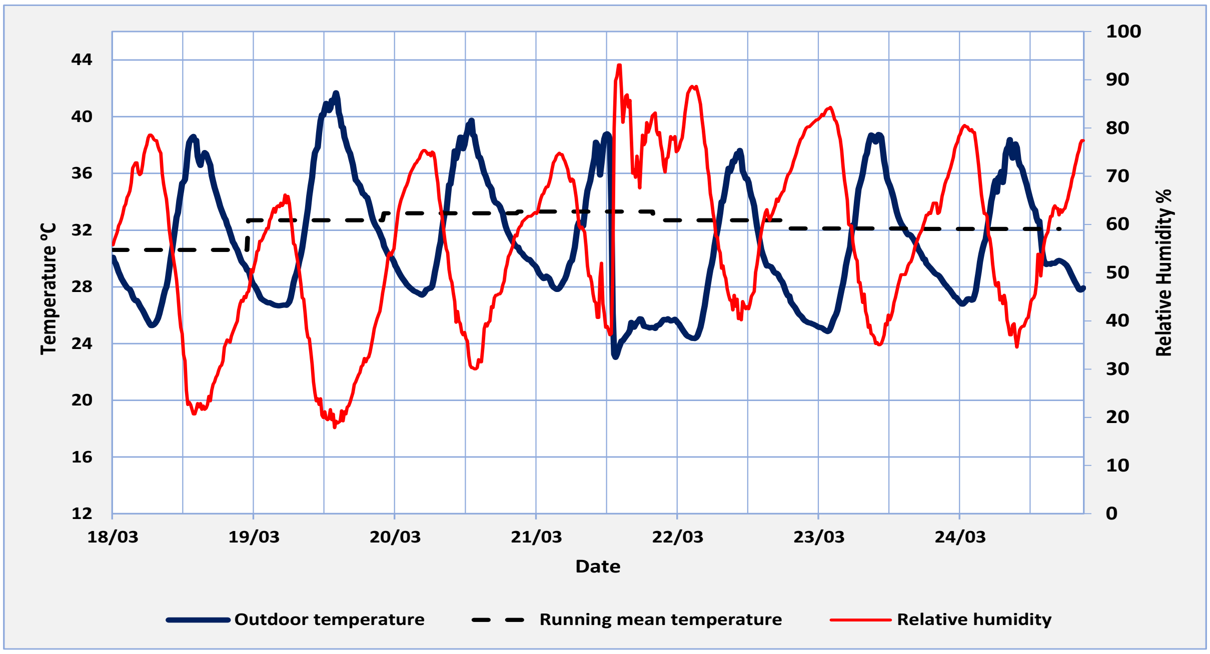

Figure 24: Outdoor temperature, running mean of daily average temperature and relative humidity during the dry season monitoring in Lugbe

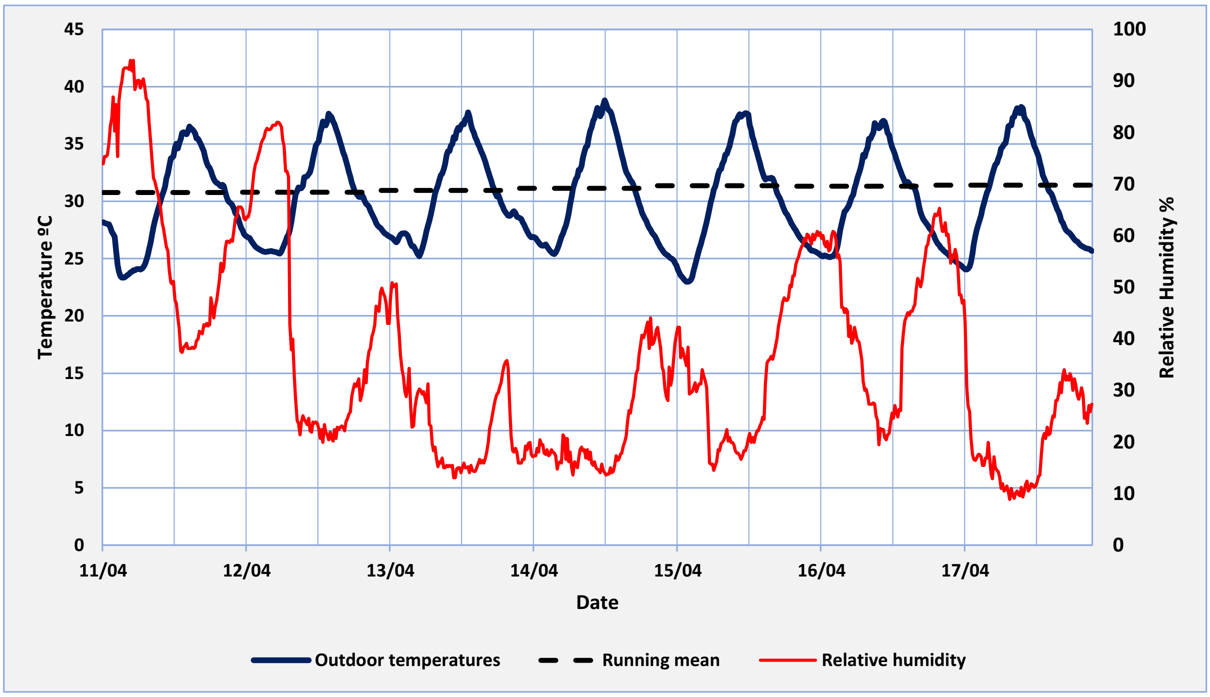

Figure 25: Outdoor temperature, running mean of daily average temperature and relative humidity during the dry season monitoring in Dutse Alhaji

The rainy season recorded an outdoor temperature that varied from 21.0°C on 17/6 to a maximum of 31.0°C on 23/6 in Lugbe, with a relative humidity varying from 55.4% on 23/6 to a maximum of 99.9% on 22/6, and an average of 81.8% (Figure 26); while the outdoor temperature in Dutse Alhaji varied from 20.5°C on 5/7 to a maximum of 32.9°C on 7/7, with a relative humidity varying from 45.9% on 11/7 to a maximum of 98.7% on 5/7 and an average of 75% throughout the monitoring period (Figure 27).

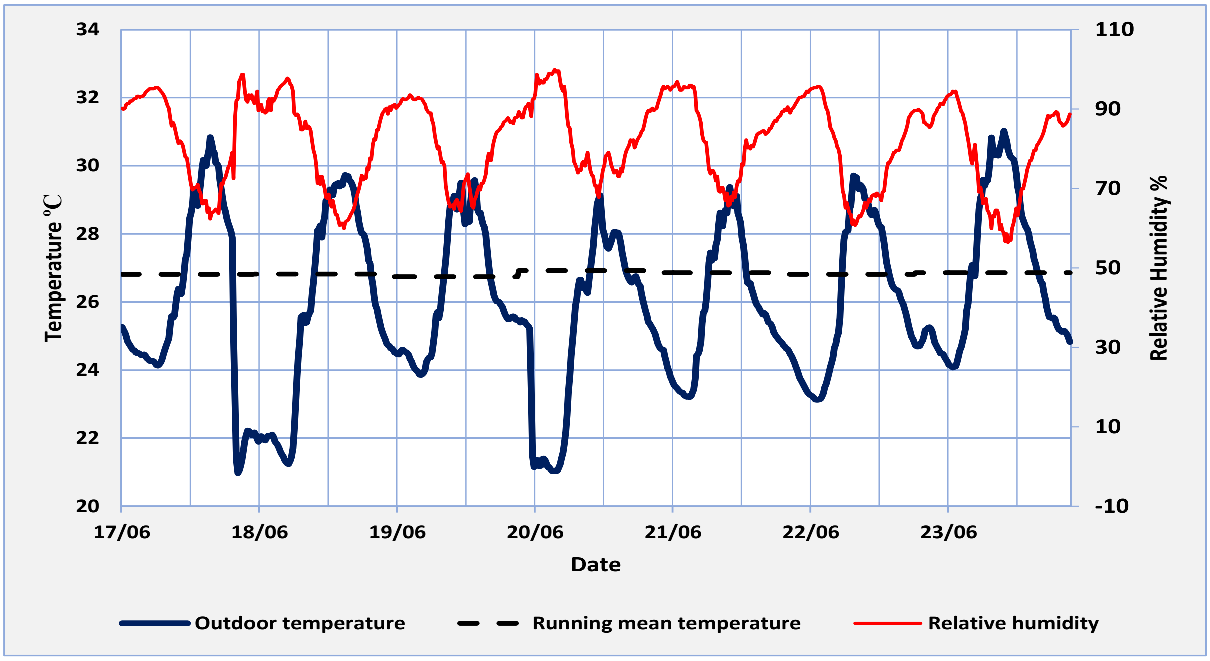

Figure 26: Outdoor temperature, running mean of daily average temperature and relative humidity during the rainy season monitoring in Lugbe

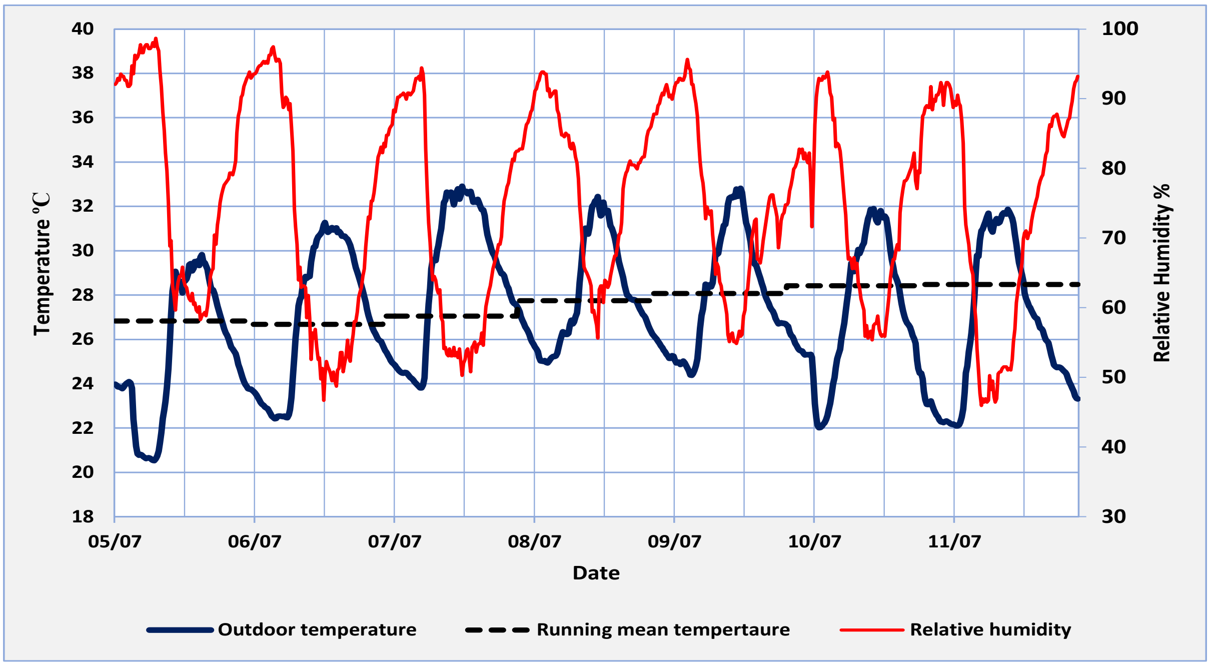

Figure 27: Outdoor temperature, running mean of daily average temperature and relative humidity during the rainy season monitoring in Dutse Alhaji

The measured outdoor temperature had a running mean temperature, $T_{rm,}$ (Figures 24-26) as defined by BSENI 15251 (BSI, 2008), varying from 30.6°C on 18/3 to a maximum of 33.3°C on 21/3 in Lugbe and 30.8°C 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 outdoor monthly temperature of 33.9°C and a maximum outdoor temperature of 41.7°C on 19/3.

The average indoor temperature between 08.00 and 22.00 in the monitored living areas in Lubge was 32.2°C for the living rooms and 32.1°C for the bedrooms. The living rooms 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 spaces in the buildings with a mean temperature of 31.1°C (Figure 28).

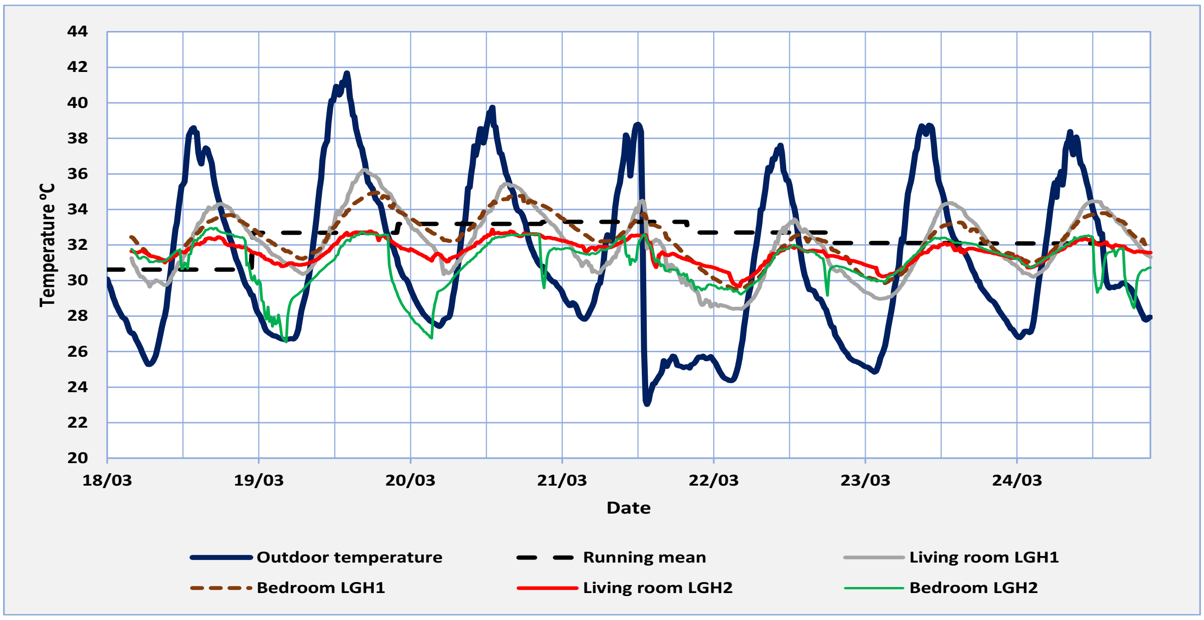

Figure 28: Living rooms and bedrooms monitored in two different buildings in Lugbe during the dry season

In Dutse Alhaji, the average indoor temperature between 08.00 and 22.00 in the monitored living areas in Dutse Alhaji 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 spaces in the buildings with a mean temperature of 32.9°C (Figures 29).

The results indicate the living room is the hottest monitored space in the buildings and occupants in Dutse Alhaji experienced higher temperatures compared to the occupants in Lugbe.

More than 90% of the spaces monitored during the dry season in all case studies recorded temperatures above the (ISO EN7730, 1994) standard for sedentary activities which specified a 23°C and 26°C temperature range. The indoor relative humidity was 21% - 76% for Lugbe and 15% - 66% in Dutse Alhaji, which was outside the (ISO EN7730, 1994) standard range of 30% - 70% for the associated temperatures. However, the maximum relative humidity recorded in Lugbe was within the range.

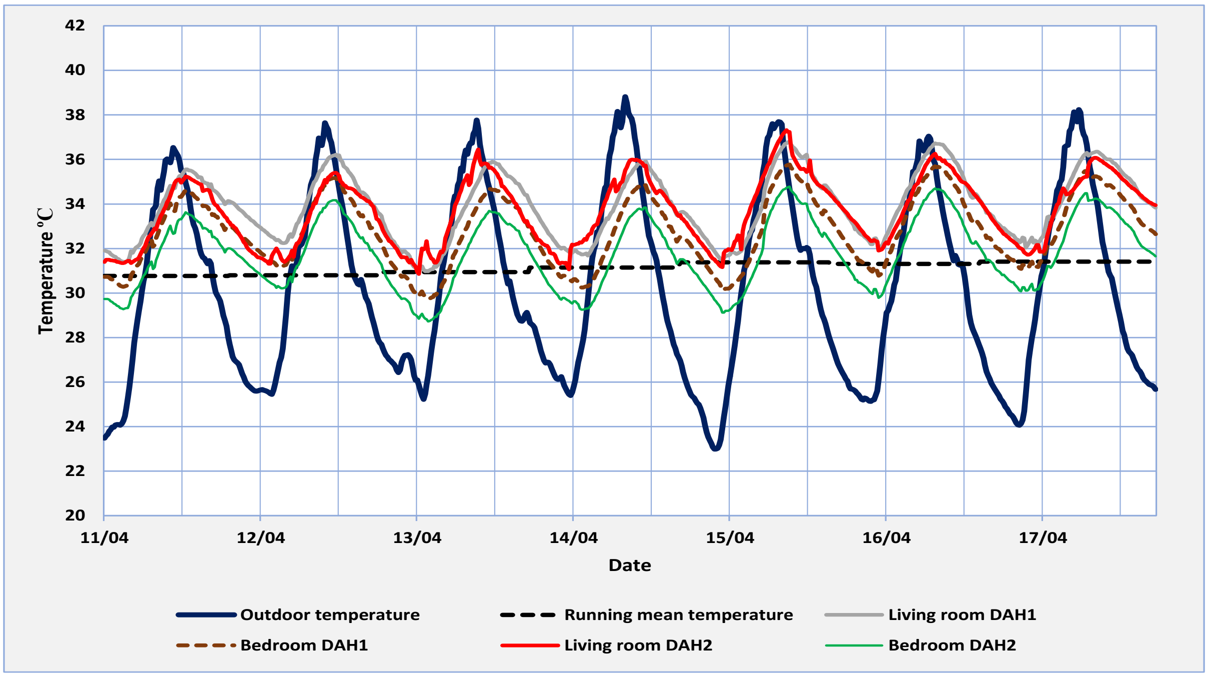

Figure 29: Living rooms and bedrooms monitored in two different buildings in Dutse Alhaji during the dry season

During the rainy season survey, the temperature range of 25°C - 30°C (Figure 30), with a relative humidity range of 29% - 91% was recorded in the living room spaces in Lugbe while a temperature range of 27°C – 35.9°C (Figure 31), with a relative humidity range of 40% - 87% was recorded in the living spaces in Dutse Alhaji.

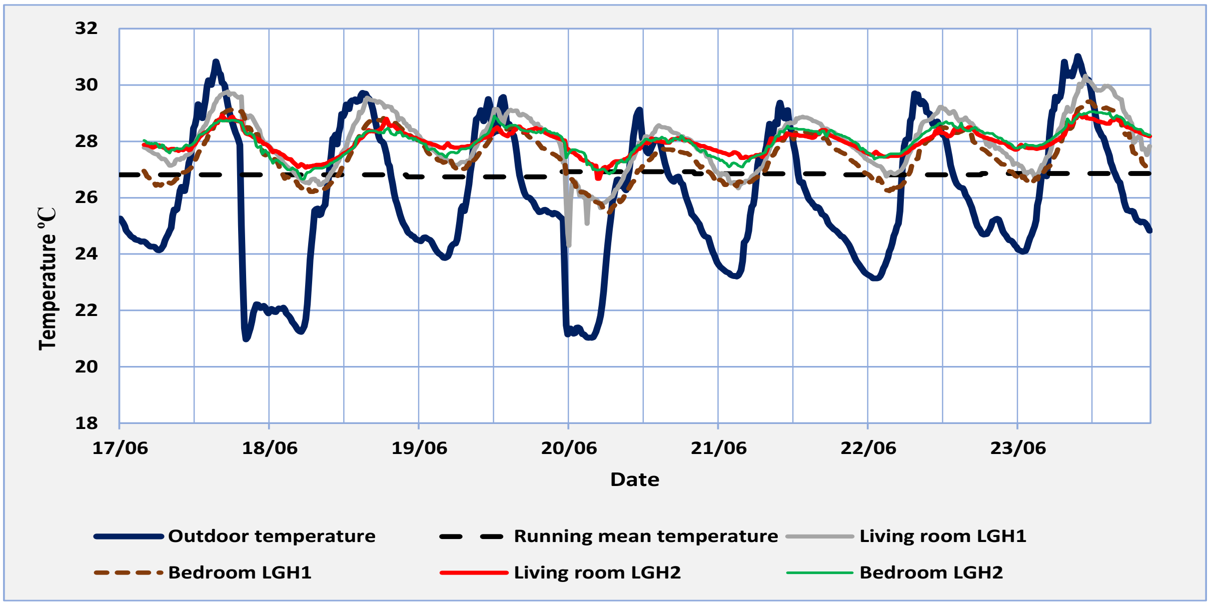

Figure 30: Living rooms and bedrooms monitored in two different buildings in Lugbe during the rainy season

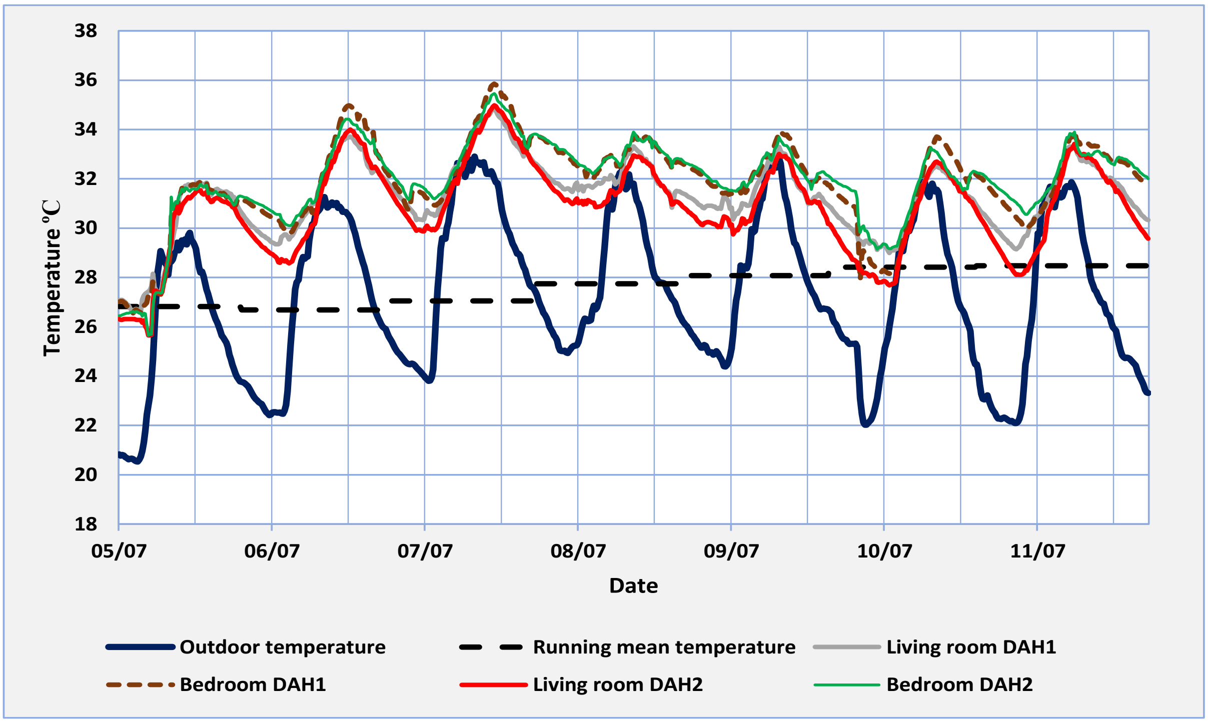

Figure 31: Living rooms and bedrooms monitored in two different buildings in Dutse Alhaji during the rainy season

7 Conclusions

The results from the post occupancy, environmental monitoring and comfort survey from different residential low-income buildings 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 condition. This further suggests that occupants perceived higher indoor temperatures during the dry season.

A different perspective was provided with the comfort survey, as most of the time the monitored occupants in the naturally ventilated buildings felt hotter than the occupants in the air-conditioned buildings. More than 70% of the time the occupants in the monitored case studies felt either 'slightly warm' or 'warm' most of the time when they were indoors.

The maximum outdoor temperature and relative humidity recorded was 41.7°C and 99.9%, with the naturally ventilated buildings recording the highest and lowest temperatures of 36.8°C and 24.3°C in the living rooms in Lugbe and Dutse Alhaji. However, the difference in temperature between the air conditioned and naturally ventilated building was only about 2°C. Most of the occupants do not find their thermal conditions acceptable and more than 80% of the spaces monitored in all case studies recorded temperatures above the (ISO EN7730, 1994) standard for sedentary activities.

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 buildings. Occupants prefer to be much cooler during the dry season, therefore there is high dependence on air-conditioning to improve their thermal condition.

However, air-conditioning is not used as much as it might be because of continual power-cuts, the cost and noise of running generators and personal security issues. This is a good reason for trying to improve the construction of the dwellings so that they are made to be comfortable using more passive means. 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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