AN INVESTIGATION INTO THERMAL COMFORT IN RESIDENTIAL BUILDINGS IN THE HOT HUMID CLIMATE OF SUB-SAHARAN AFRICA: A FIELD STUDY IN ABUJA-NIGERIA

Michael Adaji	Kent School of Architecture, University of Kent	Mua2@kent.ac.uk
Dr Richard Watkins	Kent School of Architecture, University of Kent	R.Watkins@kent.ac.uk
Prof. Gerald Adler	Kent School of Architecture, University of Kent	G.Adler@kent.ac.uk

Fig 1: Mpape, A typical low-income residential area in Abuja, Nigeria

Research summary

A field study was conducted to understand the real and preferred conditions of thermal comfort in low-income residential buildings in Abuja, Nigeria. Knowing the temperatures people are experiencing in their houses and the limits which residents can tolerate is a first step to proffer passive solutions to reduce discomfort. During the study, 40 people responded to a post occupancy questionnaire and two households were issued a comfort survey questionnaire. Physical measurements were taken simultaneously during the comfort survey in both an air-conditioned and naturally ventilated residential building. The ASHRAE and air flow sensation scale were chosen as voting scales. The results from this study show that during the monitoring period the average and maximum temperatures in an air conditioned residential building were 31°C and 34°C; and 33°C and 36°C for natural ventilated buildings in Abuja. This compares with the external average and maximum air temperatures of 31°C and 39°C

Keywords: thermal comfort, low-income, residential building, post occupancy survey, comfort survey.

1. Introduction

In Nigeria, the Federal Government's 2009 vision 2020 report in Oyedepo, (2014) showed that 55.3% of electricity generated was consumed by the residential building sector; 24.4% by the commercial and public sector while 20.0% went for the industrial sector. However, there's a lack of continuous and reliable power from the grid supply to run the fans and air conditioners, and the use of these mechanical systems requires lots of energy and energy costs money. For this reason, air conditioning cannot usually be operated continuously.

Nigeria is a country with numerous resources but cannot provide constant power to the domestic sector because of pervasive mismanagement and corruption. Designers and house builders may also be seen as contributing to the problem. They construct buildings with little or no regard to the local climate and thermal comfort considerations. Most of the building materials used, especially sandcrete concrete blocks, don't insulate or reflect sunlight; there's no effective shield or insulation between the outdoor environment and the building interior. As a consequence, a high level of solar gain enters the building through its opaque fabric. Given the hot climate of Nigeria, this causes thermal discomfort to the occupants.

Sustainable low energy approaches should be encouraged to reduce the cooling load and energy consumption since most occupants are now relying on air conditioning systems as the best way to improve thermal comfort, increasing bills along the way.

Although research into the field of thermal comfort and passive cooling in various climates around the world has been undertaken, there is little or no comprehensive research on thermal comfort and passive cooling in residential buildings in Abuja. There have been thermal comfort studies carried out in Nigeria by (Ogbonna and Harris, 2007); (Akande and Adebamowo, 2010); (Ojebode and Gidado, 2011); (Adunola, 2012); (Sangowawa and Adebamowo, 2012); (Adebamowo et al., 2013); (Adebamowo and Adeyemi, 2013), but these carried out limited rather than twenty-four hour studies of residential buildings in Nigeria. The current and on-going research of this paper is aimed at filling this gap by carrying out more comprehensive thermal comfort investigations in residential buildings in Abuja; to try to understand the real and preferred conditions of thermal comfort in low-income residential buildings. In particular, the monitoring shows what maximum, minimum and average air temperatures and humidity people are experiencing in their houses and the limits at which residents can tolerate discomfort. The research also aims to proffer passive solutions and strategies that suit the hot-humid climate of the city which would be culturally accepted, affordable – especially for those in low-income households – and reduce energy use and be easy to install and integrate into the dwelling design.

Fig 2: Building construction in Nigeria

2. Research objectives

2.1 Aim

To improve the indoor thermal conditions and reduce the energy load by using passive cooling strategies in low-income residential buildings in Abuja, a city in the hot-humid climate of sub-Saharan Africa.

2.2 Objectives

(i) Undertake indoor monitoring of selected residential buildings in different locations in Abuja, to understand the thermal conditions in real life situations.

(ii) To study the behaviour of buildings in their current form.

(iii) To analyse the possibility of the appropriate applications of passive cooling techniques that could be used to enhance thermal performance in the hot humid climate of Abuja.

(iv) Try and identify possible barriers to implementing passive cooling strategies on residential housing and proffer possible solutions

Fig 3: A t typical medium-high income residential area in Abuja, Nigeria

3. Research Method

The methodology for the study included environmental monitoring, post-occupancy and comfort surveys. This study was aimed at obtaining a comprehensive understanding of occupants' thermal comfort sensation within buildings and occupant's energy demands and use.

3.1 Environmental Monitoring

Abuja has two main seasons: the dry (Hot) season and the rainy season. The field survey was conducted during the dry season from 21/4/15 to 28/4/15. Air temperature and relative humidity were recorded using HOBO T/RH sensors installed on the internal walls at a height of 1.1m above floor level. Two bungalows were monitored in Abuja, with two spaces representing the living area and bedroom area monitored in each case study. One of the dwellings monitored had air conditioning and was roofed using aluminium while the other was naturally ventilated and had iron roofing.

The outdoor environmental conditions measured were air temperature and relative humidity using Tinytag T/RH sensors inside a radiation shield while the total solar radiation on the horizontal was measured using a Kipp and Zonen pyranometer.

For this research to incorporate the evaluative methods, based on an adaptive approach, the ANSI/ASHRAE standard 55-2010 involving the ASHRAE sensation scale of (-3 to +3) for thermal comfort was adopted.

3.2 Post-occupancy surveys

Post-occupancy surveys help understand and compare the nature and frequency of occupants' complaints that cannot be obtained 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 building 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 looked at how residents made themselves comfortable (control votes) and clothing type. 52 questionnaires were distributed and 40 were returned completed. The time of the post occupancy survey visits was between 6.30 am to 18.00 pm.

3.3 Comfort surveys

Thermal comfort questionnaires were issued to the occupants' of the dwellings monitored and 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' response 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.

3.4 The respondents

The field study tries to obtain votes and information from Abuja residents covering a wide age range of people (18 - 60) living in either air conditioned or naturally ventilated buildings. Most were employed and had post-secondary education. The majority of respondents lived in rented apartments and had an alternative source of electricity from the national grid.

Fig 4: Installation of HOBO Temp/Rh indoor loggers

Fig 5: Installation of Tiny Tag external data loggers

4. Results and design potential.

The early results from this study show the temperatures in an air conditioned and a naturally ventilated dwelling, and the simultaneous outdoor air temperatures in Abuja. See Figures 6 and 7. For the indoor air temperatures of the living room of the Air conditioned building, Tmax°C was 34.8°C, Tmin°C was 27.8°C and Tavg was 31.0°C. For the Indoor air temperatures of the bedroom of the air conditioned building, Tmax°C was 33.1°C, Tmin°C was 29.2°C and Tavg. was 31.4°C. For the Indoor air temperatures of the living room of the naturally ventilated building Tmax°C was 37.3°C, Tmin°C was 30.9°C and Tavg. was 33.7°C. Lastly, for the Indoor air temperatures of the bedroom of the naturally ventilated building, Tmax°C was 35.8°C, Tmin°C was 29.8°C and Tavg. was 32.8°C. Also, the indoor Tavg. at night i.e. 6pm - 6am, are 33.9°C for air conditioned building and 36.0°C for naturally ventilated building respectively

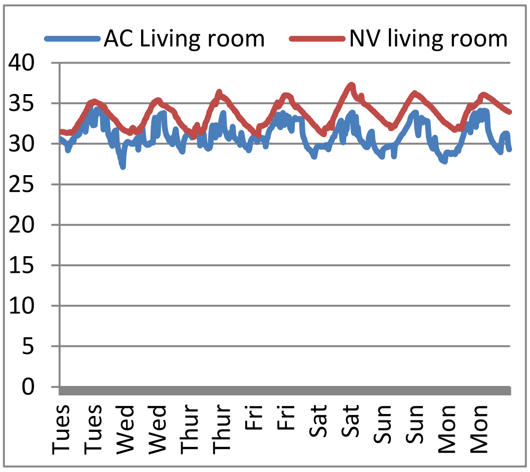

Fig 6: Half-hourly indoor temperatures in the living room of the air-conditioned and naturally ventilated buildings.

Furthermore, the maximum outdoor temperature recorded was 39.2°C; the minimum recorded was 24.9°C with an average value of 31.0°C. During the monitoring, the highest internal temperature recorded was 37.3°C in the living room of the naturally ventilated building, while the lowest internal temperature was 27.1°C, recorded in the living room of the air conditioned building.

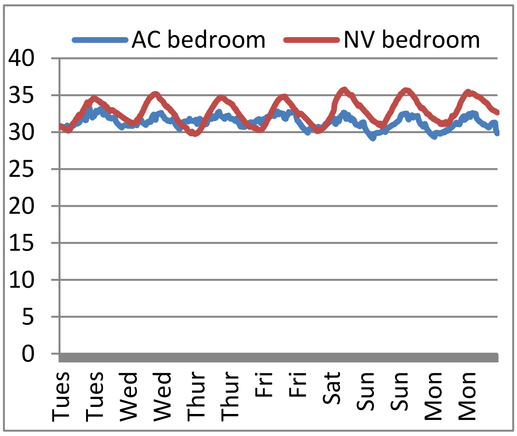

Fig 7: Half-hourly indoor temperatures in the bedroom of the air-conditioned and naturally ventilated buildings.

5. Future implementation

The two dwellings monitored had boreholes as the main source of water supply. This may offer the potential for ground cooling and evaporative cooling. Although humidity is high in the rainy season, it is in the dry season when extreme temperatures and discomfort are experienced. Evaporative cooling could be powered using photovoltaic panels which would support pumping water though pipes and operating a fan to help cool the water.

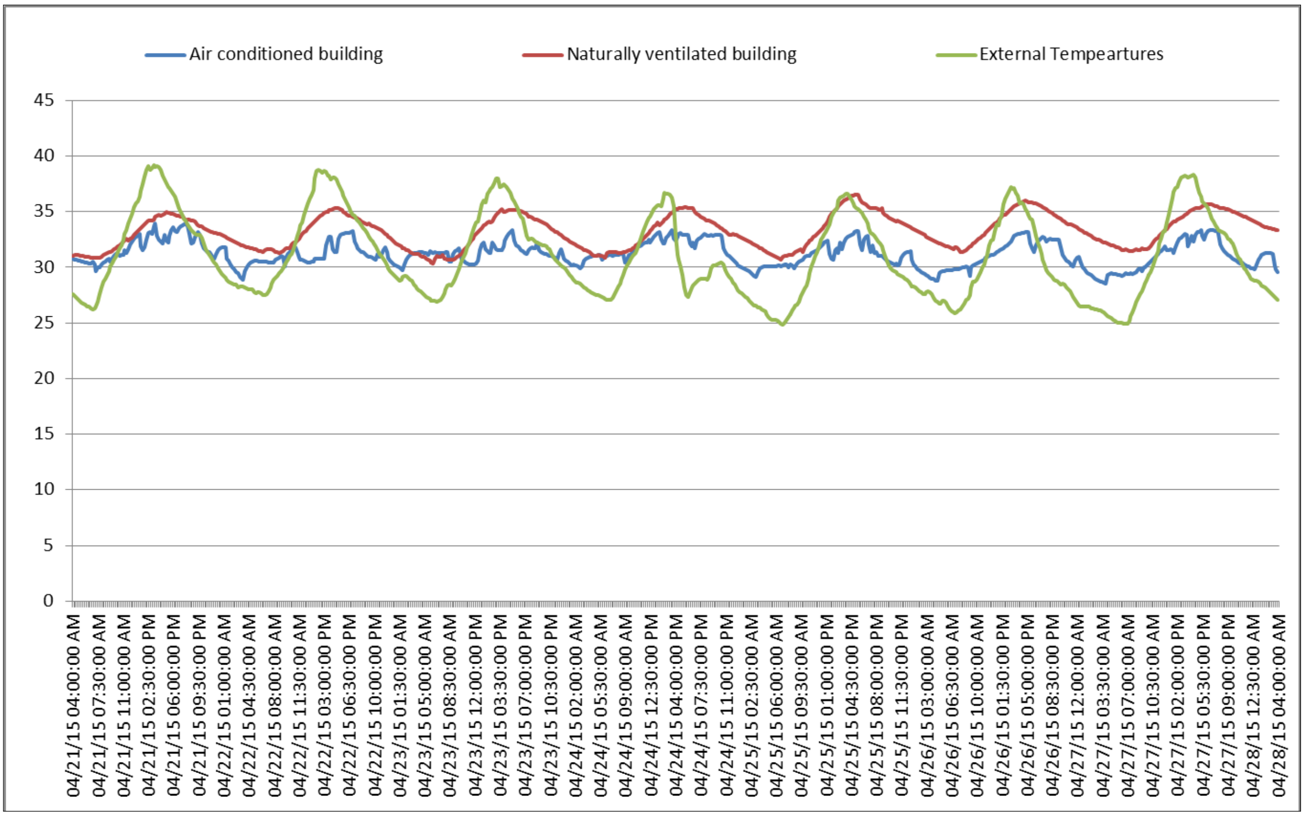

Fig 8: The external temperature, Half-hourly indoor temperature in an air conditioned building and a naturally ventilated building for a week

6. Conclusions

The paper presented the initial results from indoor monitoring, in a naturally ventilated building and an air conditioned building in Abuja, Nigeria. The detailed monitoring is on-going and will eventually cover a sample of ten air conditioned and naturally ventilated dwellings in both the rainy and dry seasons. Early Findings from the current field study can be stated as follows:

1. The study showed a 3.0°C difference between the average temperatures of the air-conditioned and naturally ventilated buildings. The naturally ventilated building was warmer than the air-conditioned building.
2. The study also showed a 2.1°C difference between the average temperatures of the air-conditioned and naturally ventilated buildings at night.
3. Most residents in Abuja are either self-employed, privately employed or public servants.
4. The small difference between the night-time temperatures in the AC and Naturally Ventilated dwellings is perhaps surprising, and will be investigated further in the other case studies – but this may well reflect the high cost of running generators, avoiding their noise at night-time, and security issues at night.

7. Acknowledgments

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