Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Remodelling façade design for improving daylighting and the thermal environment in Abuja's low-income housing

Mahmood Abdulkareem[a], Sura Al-Maiyah[b,*], Malcolm Cook[c]

[a] Portsmouth School of Architecture, University of Portsmouth, Portsmouth PO1 2DJ, United Kingdom
[b] School of the Built Environment, University of Salford, Salford M5 4WT, United Kingdom
[c] School of Architecture, Building & Civil Engineering, Loughborough University, Leicestershire LE11 3TU, United Kingdom

ARTICLE INFO

Keywords:
Thermal comfort
Visual comfort
Overheating
Passive solutions
Low-income housing
Nigeria

ABSTRACT

The housing typologies that were developed as part of Abuja's master plan over 30 years ago are still in use today as prototypes for low-income housing developments. The value of the local climate received only cursory consideration in the early developments; as the process was mainly focused on the delivery of units needed to accommodate those involved in the construction of the city. More detailed records of the climate have become available since the mid-1990s. Yet, despite the availability of such data and the global interest in eco-friendly architecture, energy use per household has increased in Abuja over the last two decades. Nigeria is already struggling to meet its current energy demands; therefore, it is important to examine whether improvements made to future housing design can assist in reducing their energy use.

This paper evaluates the performance of four of Abuja's common housing types and examines the impact of changing their fenestration design on occupants' comfort, using validated simulation. Assessing the performance of the buildings in their existing state revealed clear overheating problems and excessive natural lighting. However, the investigation indicated a 4–6% reduction in the frequency of thermal discomfort and a 4–29% reduction in visual discomfort by adjusting the orientation of the facades. Integrating external shading components can also reduce thermal and visual discomfort by up to 4% and 29%, respectively.

1. Introduction

Nigeria has the largest population in Africa with over 186 million people, of which 47.8% live in urban areas. The country has been experiencing a relatively high population growth and rate of urbanisation estimated in 2014 at 2.7% and 4.7% respectively [1]. Due to such rapid rates of urban population growth, concerns over the deficiency in the housing quality across the region and the lack in housing availability to accommodate the urban residents have been repeatedly reported in previous studies [2–4]. Nigeria's current housing deficit was recently projected at over 17 million units [5]. Along with the ongoing housing shortage, there is also limited access to electricity in the country, primarily a consequence of a rapid increase in population without a corresponding increase in the production of electricity [6]. 55% of the existing households, equivalent to over 90 million people, lack access to grid supply of electricity and the supply to those connected to the grid is unreliable [7]. As a result, the use of back-up power generators to mitigate poor grid-based supply has become increasingly common in Nigeria over recent decades. A survey of over 1000 households located in Lagos [8] revealed that between 60–92% of the examined sample use private back-up generators frequently.

Like many other countries in Sub-Saharan Africa the housing sector in Nigeria has been a main contributor to the total energy use in buildings [9]. Over 57% of the electrical energy consumed in Nigeria is used in housing [10], mainly in cooling and lighting. An investigation of electricity use in residential units in Gusau (North of Nigeria) [11] revealed that on average 78% of the annual electrical energy consumed in the units was dedicated to running air conditioning systems and 1% for artificial lighting. However, in a study on energy consumption pattern of dwellings in Kaduna and Kano, (also North of Nigeria) the authors reported that on average 62.7% of the annual electrical energy consumed was used for lighting while 23.6% was used to run air conditioning systems [12]. These findings suggest that the ability to minimise the use of mechanical cooling and artificial lighting in providing the level of comfort desired by the occupants in Nigeria's housing is key for reducing the overall energy use in the region.

Notwithstanding the above, the contemporary architectural practice that emerged in the 1970s has contributed to inefficient energy use in the housing sector (through the reliance on mechanical solutions) and is still prevalent today. Over the years, this has led to increasing demand

* Correspondence to: University of Salford, Room 5.40, New Adelphi Building, Salford M5 4WT, United Kingdom.
E-mail address: S.A.M.Al-Maiyah@salford.ac.uk (S. Al-Maiyah).

http://dx.doi.org/10.1016/j.rser.2017.10.010
Received 18 November 2016; Received in revised form 23 June 2017; Accepted 3 October 2017

for active energy through various devices for both cooling and lighting [13]. With such dependency on artificial solutions and the rapid increase in population, some believe that the energy consumption in Nigeria might become impossible to sustain in the future [14].

Several technical studies have been undertaken to examine energy use and occupants' sensation of comfort in Nigeria's housing across different cities. For example, Adaji et al. [15] have recently investigated urban residents' perception of thermal comfort in four low-income residential buildings in Abuja using occupant comfort survey and environmental monitoring. Similarly, Adunola and Ajibola [16] examined the relationship between the quality of the residential indoor thermal environment and the pattern of use of spaces among residents of over 500 dwellings situated in different areas in Ibadan metropolis. In a follow up study published in 2014, Adunola [17] further reported the results of the thermal comfort survey of the same sample. The main objective of this (later) phase of evaluation was to examine the indoor thermal experience of the residents in relation to the outside air temperature across the various neighbourhoods. Likewise, Akande and Adebamowo [18] reported the findings of a comfort field study of residential properties in Bauchi in northern Nigeria. Akinwolemiwa and Gwilliam [19], on the other hand, have explored low energy and passive cooling opportunities to improve thermal comfort in low-income residences in Lagos through the use of financially affordable living walls (vertical green systems). As informative as these studies are, providing an insight into the thermal behaviour of Nigeria's housing, surprisingly only a few (studies) examined the environmental performance of the residential architecture of Abuja, where one of the most extensive public housing development programmes in the country's history has been implemented [20,21]. In addition, most publications on comfort and the housing sector in Nigeria tend to focus on the thermal aspect of the housing units, while little attention is given to the visual aspect of the design. Of the few published daylight-related studies in Nigeria's urban context and climatic zone is a study by Atolagbe [22]. The paper examined residents' satisfaction with natural light availability in different house types across three residential zones in Ogbomoso using questionnaire survey.

As improving the thermal performance of residential dwellings could positively contribute to the thermal residential environment, providing an acceptable level of daylight indoors is equally essential for improving occupants' visual comfort. Effective utilisation of passive design measures has long been proven to help greatly in improving residential occupants' comfort while reducing energy bills cost [23–26]. Yet, despite its tropical location and the abundance of solar radiation all year round little is known about the effectiveness of applying passive principles to residential buildings design in Nigeria's climate zone [27]. Hence, this paper assesses the performance (of four) of Abuja's common low-income housing types and examines the impact changing their fenestration components have on thermal comfort and daylighting. The paper aims at exploring whether the integration of passive design principles that were not considered in the early generation of housing schemes built in the city can assist in improving their occupants' sensation of comfort. The sample selected as a basis for the evaluation is among the early housing typologies developed by the government as part of mass housing schemes. The purpose of the investigation is to propose recommendations to improve occupants' comfort in future public housing schemes for the low-income group through the integration of low-energy passive design methods.

2. Abuja's housing sector: an opportunity for improvement

The architectural landscape in many cities throughout Nigeria has changed since the 1970s, largely dominated by mass housing production schemes implemented by the public sector [21,28]. The oil boom in the mid-70 s boosted the country's economy and in turn the government, for the first time, participated actively in the provision of housing for all income groups. This led to the housing sector becoming more

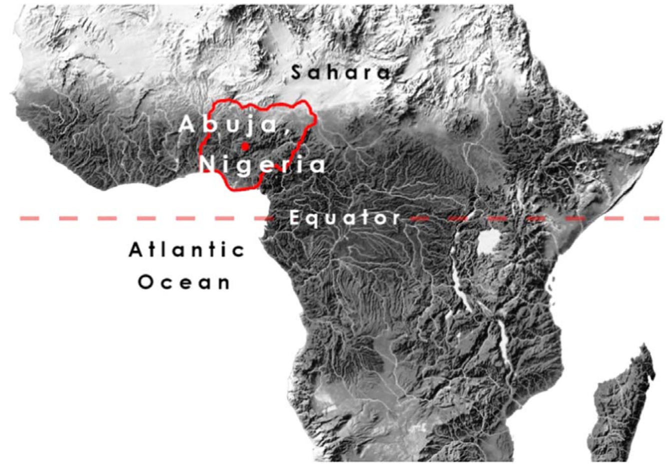

Fig. 1. Location of Abuja, Nigeria.

involved in turn-key projects built on the premise that energy was cheap and as a result form became more important than performance in the building design [28].

Abuja, the capital city of Nigeria, was also conceived in the mid-1970s, when the government introduced the most extensive public housing development programme in Nigeria's history. At the early stage of development, the designers involved in the process were mainly focused on providing the required quantity of dwellings to accommodate those involved in the construction of the city [29]. This is clearly reflected in the master-plan stating that "*the architectural and engineering aspects of housing are perhaps the least complicated or problematic aspects of housing*" [30]. With this mind-set, thousands of residential buildings in Abuja were originally designed and eventually constructed without proper regard for the climatic context of the region [31] (Fig. 1).

Since the mid-1990s more records of the climatic conditions have become available as the city has become one of the largest urban areas in Nigeria. However, despite the availability of such records and the global interest in climate conscious architecture, the prototypes for low-income housing in the schemes that were developed as part of Abuja's master plan over 30 years ago are still in use today as a blueprint for housing developments [28]. Thus, the homogeneous nature of public housing design has partially negated the possibility of improvements towards more energy efficient dwellings. Nevertheless, only about half the area allocated for residential building construction in the city is fully developed (Fig. 2). With the government seeking to complete the remaining phases of development, there is a real opportunity to influence the architectural practice in the city by examining the performance of this early generation of housing which is still in use today, providing guidelines for future development.

2.1. Location and climate of Abuja

Located in the central region of Nigeria (at latitude 9°06′N and longitude 7°49′E), Abuja has a tropical Savannah climate where two pronounced seasons prevail, namely the dry season and the rainy season. The dry season starts in November and ends in April, while the rainy season occurs from May to October.

The dry season is characterised by very little cloud cover and intense solar radiation (5.9–6.3 $kWh/m^2/day$), as a result daytime temperatures can be as high as 37 °C. During the rainy season the combination of solar radiation (4.2–5.6 $kWh/m^2/day$) and the humidity of the air mass forms dense clouds and leads to the occurrence of torrential rain, which has a cooling effect. Nevertheless, daytime temperatures can still rise above 29 °C [32,33]. The findings reported in this paper focused on the dry season because of the relatively high temperatures that occur during this time of year in Abuja and the negative effect it