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Assessment of Climate Responsiveness of Public Office Buildings Designs in Selected Tertiary Institutions in Niger State towards Energy Efficient Buildings in Nigeria

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Abstract
The building sector had been strongly linked with the global dreaded climate change menace owing to huge energy demand of the sector. Buildings consumed about 40% of the world energy supply and responsible for significant percentages of CO_2 emissions. This scenario has made buildings object of research globally and energy efficiency a major priority. However, climate responsive design has been long identified as effective and economical means of reducing building energy consumption. Thus, most developed nations have explored this medium unlike developing nations including Nigeria. Moreover, offices being high energy consuming buildings, hence reducing their energy use has been a target globally. This study assessed adoption of bio-climatic design strategies office buildings design in tertiary institutions in hot and humid climate of Nigeria. Case study approach was adopted and data were collected via observation checklist from three administrative offices, each from university, polytechnic and college of education in Niger state, Nigeria and results compared with Building Energy Efficiency Guidelines for Nigeria released in 2016. The findings revealed that, critical strategies that impact significantly on energy reduction like orientation, passive measures and Air-tightness of envelope were poorly observed. Therefore, it is recommended that implications of architects' designs on energy demand of buildings should be a major concern. Also, there should be a paradigm shift from the conventional design process to integrated design process (IDP) that encouraged collaborative efforts of other professionals from the beginning of the design process to ensuring planning, design and construction of energy efficient building.

Keywords: *Office buildings, Bio-climatic design, Energy demand, Energy efficiency, Tertiary Institutions.*

INTRODUCTION

The increasing energy demand of buildings and the eventual negative environment impacts has been a major source of worry globally. The building sector having strongly linked with the global warming and the dreaded climate change menace; this is not unconnected to the huge energy demand of the sector. Buildings consumed about 40% of the world energy supply and responsible for significant percentages of CO_2 emissions, this scenario made buildings objects of research globally (Pout, *et al.*, 2002; Huovila, *et.al.* 2007; Asimakopoulus, *et. al.*, 2012). Although, there have been several efforts globally towards energy reduction of this sector. These include several peer-assessment reviews such as the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Barker *et. al.*, 2007); the Energy Technology Perspectives (IEA 2008); the Global Energy Assessment (Ürge-Vorsatz *et. al.*, 2011). Likewise, the establishment of World Green Building Council (WGBC) in the year 2002 and establishment of green building rating tools by most developed nations as well as energy codes and standards for various buildings categories. However, Architectural design decisions at the early design stage had been found to impact significantly on the eventual energy demand of building products (Wouters and Loncour (2005); Zhao and Magoules (2012). In this light, architects as a major player in the built environment need to be conscious of the energy demand of their design decisions at early stage. Moreover, bio-climatic design principles/strategies have been long established as an easy and economical means of ensuring significant energy reduction globally, most especially in tropical climate like Nigeria. Based on this premise, this study investigated the level of adoption/ adherence to these techniques in the design and construction of administrative office buildings in Federal Tertiary Institutions in hot and humid climate of Niger state, Nigeria. Administrative buildings were typical office buildings similar in design, construction and operations to other office buildings outside academic environment. Moreover, office buildings globally have acclaimed to be one of the highest energy consuming human shelters (Ravetz, 2008).

LITERATURE REVIEW

Global Energy Consumption in Buildings

Buildings and its related activities has been strongly responsible for consumption of about half of the global energy supply (Huovila, *et al.* (2007). Despite this, there has been a continuous increase in the global energy use in the recent decades, 3.15% was observed as an average annual energy growth between 2005 and 2011. Meanwhile, in 2011 the global energy consumption rate was 8.92Gtoe/year (International Energy Agency, 2014). This number was predicted to increase to 14 Gtoe/year by 2020. This trend is expected to continue especially in nations with emerging economies like Africa, South America, South-east Asia and Middle East (IEA, 2008). This is so because energy being an indispensable factor that goes a long way to determine the socio-economic growth and life quality all over the entire world (Kousksou *et. al*, 2014; ASHRAE, 1990). Meanwhile, in Europe buildings sector was estimated to be consuming about 40-45% of total energy demand (UNEP, 2007). Specifically in United States of America (USA) building sector consumes about 40% of energy used and responsible for nearly 40% of greenhouse gas emissions. While in China, above 25% of entire energy use is consumed by the building sector, projection has shown that the figure will increase to 35% by year 2020. Furthermore, in United Kingdom, the building industry consumed between 40-50% of all the energy use and greenhouse gases emission, about 27% of the emission from domestic dwellings while public and commercial buildings were responsible for about 22% (Pout *et. al,* 2002; Perez-Lombard *et. al,* 2008; Bouchlaghem, 2012). Equally, in India building sector accounted for 35% of the of the total energy supply in the country (Manu *et. al.,* 2016). Energy scenario in Nigeria was not far from the global reports, building sector equally consumed about 40% of electricity supply (Akinbami, 2010). However, with the gross inadequacy of power supply only about 40% of the population have access to electricity and were majorly urban dwellers (UNDP, 2011).

Review of Building Energy Efficiency Guidelines for Nigeria (BEEGN)

In response to the global call for energy reduction in built environment and to bridge the gap in the National building codes, Nigeria Energy Support Programme (NESP) and the housing unit of Federal Ministry of Power, Works and Housing (FMPWH) in 2016 rolled out a policy document towards ensuring planning, designing and construction of energy efficient buildings. The document was a swift response to the questions of what the state of energy consumption in Nigeria is; what energy efficiency goal can be set for Nigeria and finally how energy efficiency can be effectively implemented in Nigeria. This document named "Building Energy Efficiency Guidelines for Nigeria" (BEEGN) was introduced to guide relevant stakeholders in the building industry in Nigeria. However, it was noteworthy that the guidelines concentrated on the new buildings rather than improving existing ones. Notwithstanding, some of the solutions could also assist towards improving the performances of the existing buildings.

The document acknowledged the fact that building sector accounted for the largest proportion of electricity consumption in Nigeria (BEEGN, 2016). It looked at legislations and policies including Renewable and Energy efficiency policies of 2015 as well as energy mix, sources and carbon footprint from energy production. Also, noteworthy was the difficulties involved in estimating energy use in Nigeria, this was borne out of the fact that large percentage of energy is generated on-site via petrol and diesel generators. Besides, the guidelines stressed the need for integrated design process (IDP) as opposed to the conventional design process. IDP encouraged active participation and collaborative effort of other professionals from the beginning of the design process to ensure planning, design and construction of energy efficient building. Most importantly, the document presented set of guidelines based on bioclimatic design approach to ensuring energy efficient building design that is premised on building physic concept of heat flow in and out of buildings in tropical hot-dry and hot-humid climate of Nigeria.

Bio-climatic strategies for hot and humid climate in Nigeria

Bio-climatic design concept is based on the vivid understanding of the climate parameters of a particular location. This concept is a strong tool that can be harness by architects to achieve energy efficient buildings. Energy efficient buildings ensure physical comfort for occupants with minimum use of resources, most especially energy consumption. This concept in tropical climate like Nigeria required in-depth knowledge of heat flows in and out of buildings. This phenomenon is premised on adaptive thermal comfort theory which explained the impact of outdoor weather conditions on the thermal comfort of indoor environment. This concept has been acclaimed to be the starting point in the sequence of planning, design and construction of energy efficient buildings as illustrated in Figure 1.

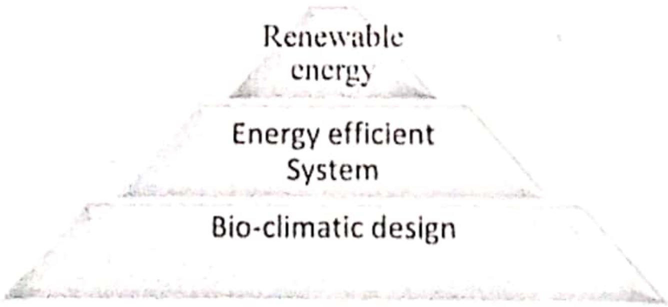

Figure 1: Heirachy of energy efficient buildng design
Source: Arup (2014)

The climate parameters mostly considered in bio-climatic design include air temperature, solar radiation, sun angle, relative humidity, wind speed and direction and precipitation. The orientation of the building in relation to geographical north is the main factor that determined the energy balance of building in hot and humid climate, as it affects the air movement and solar heat gain. The building in this climate is expected to be oriented with the longest side in North/south direction where most windows are expected to be located. Also the building geometry is equally significant to energy use, reducing building outer skin in relation to volume proportionally reduces heat gain, and therefore buildings are expected to be compact with the use of courtyard to aid daylight and ventilation. Furthermore, exterior shading is equally important, overhang and horizontal shading is advised North/South direction while combination of vertical and horizontal shading is encouraged on the East/West direction, this approach should be complemented by planting of trees. The glazing Solar Heat Gain Coefficient is expected to be low while the visual transmittance should be high not less than 60%. Also the envelope materials should have light colours to reflect heat while roof solar reflective index (SRI) higher than 78 is recommended. The opaque wall is also recommended to have a low thermal transmittance value (U-value) to act as good insulator. Notwithstanding, the buildings should further ensure that the envelope is airtight with low thermal mass and evaporative cooling could be incorporated to further reduce heat gain.

METHODOLGY

This study adopted a case study approach. However, having prior understanding of the element of the population that will give the desired results informed the purposive sampling method adopted (Ranjit,1999) to select the main administrative buildings being typical office buildings in Federal Tertiary Institutions that cut across University, Polytechnic and College of Education in Niger state, Nigeria. The photographic documentations of case study buildings B1, B2 and B3 for case study building one, two, and three are presented in Plate I, II and III respectively.

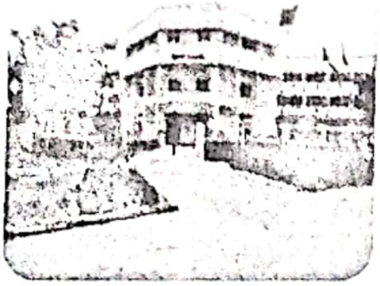

Plate I: Adminstrative building, Federal University of Technology, Minna. (B1)

Plate II: Administrative building, Federal Polytechnic, Bida (B2)

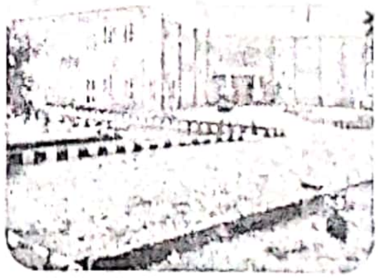

Plate III: Adminstrative building, Federal College of Education, Kontagora (B3)

Source Author's Fieldwork, 2018

RESULTS/DISCUSSION OF FINDINGS

The buildings were assessed based on four variables that may minimise heat penetration and reduce energy demand of building as recommended by BEEGN (2016). The variables were building orientation, building form and geometry, building envelope and passive strategies. The outcome of the field exercise is presented in Table 1. The building orientation in relation to geographical north is the most important consideration in bio-climatic design towards energy reduction of built environment. All the buildings were oriented with their main axis in north/east

(N/E) direction which was in contrary to the recommended position, despite adequate spaces to ensure proper orientation. The buildings had their longest sides where most windows were located on the east/west (E/W) axis in the direction of direct solar penetration. The implication of this is that more energy will be required for indoor comfort. Moreover, the results of building form and geometry revealed that all the buildings complied partially. The buildings forms were open and permeable for air movement which is in accordance with the recommendation of BEEGN. Buildings surface to volume (S/V) ratio determined the compactness of building design, the lower the (S/V), the lower the cooling load demand. The results of (S/V) were 0.19, 0.22, and 0.26 for B1, B2 and B3 respectively. This means that B1 has the lowest figure, which implied that B1 had lesser outer skin exposed to solar penetration in relation to the volume. Consequently, lesser cooling load will be incurred. Also the buildings layouts were narrow, with courtyard concept that incorporated shaded balcony that aids daylight, ventilation and reduce heat penetration. This means that the buildings might use less energy for lighting and ventilation. Notwithstanding, compactness of the building form could be improved upon, by reducing the S/V ratio for further heat gain reduction.

Table 1: Variables examined and outcome of the field exercise.

Variables Examined	B1	B2	B3
1.Building orientation	N/E (main axis)	N/E (main axis)	N/E (main axis)
2.Building form & geometry	S/V=0.19, courtyard concept, shaded balcony	S/V=0.22, courtyard concept, shaded balcony.	S/V=0.26, courtyard concept, shaded balcony.
3.Building envelope			
-Wall	225mm Sandcrete block, U-value=1.6.W/m²K, white colour	225mm Sandcrete block, U-value=1.6.W/m²K, white colour	225mm Sandcrete block, U-value=1.6.W/m²K, white colour
-Glazing	Single clear glass (V.T= 88%, g- value = 0.82)	Single clear glass (V.T= 88%, g- value = 0.82)	Reflective glass (V.T=11%, g-value=0.23)
-Roof	Light green aluminium (SRI=50)	Silver colour aluminium (SRI=79)	Red colour aluminium (SRI= 47)
-Shading	Horizontal/vertical (700mm) in S/W,N/E,S/E.	Recess wall (450mm) in S/E and N/W	No shading
Air-tightness	Air gap in windows & doors	Air gap in windows & doors	Air gap in windows & doors
4.Passive strategies			
-Double skin system	Not adopted	Not adopted	Not adopted
-Evaporative cooling	Not adopted	Not adopted	Not adopted

Source: Author's Fieldwork, 2018.

Note: S/V=surface to volume ratio, U-value= thermal transmittance value, V.T=visual transmittance, g-value= solar factor, SRI=solar reflective index.

Furthermore, the outcome of the envelopes materials shows that all buildings shared commonalities in terms of opaque walling materials, 225x225x450mm plastered on both surfaces with U-value of 1.6 W/m²K which was finished with white colour except B3 with dark orange. Also all the buildings used longspan aluminium as roof covering, the SRI based on the roof colour are 50, 79 and 47 for B1, B2, and B3 respectively. However, according to Akbari (1992) light colours and reflective materials can reduce heat gain by 30% on hottest hours of the day. This means that B1 and B2 minimised heat gain better than B3 in terms of wall surface colour while B2 had better heat reflective capacity. This is so because the higher the SRI, the better the reflective performance. The glazing revealed that B1 and B2 had 6mm single clear glass with V.T and g-value of 88% and 0.82 respectively. While B3 used 6mm reflective glass with poor V.T of 11% but with a better g-value of 0.23. However, higher V.T and low g-value was recommended for hot and humid climate. Therefore, this means that B1 and B2 enjoyed better illumination above 60% recommended while B3 with lowest g-value gives better performance by reducing heat gain through the entire glazing area. External shading against solar radiation analysis revealed that all buildings except B3 had one form of shading technique or the other. B1 had combination of vertical and horizontal in S/W, N/E and S/E with average depth of 700mm. B2 employed recess wall system to shade the windows with average depth of 450mm in S/E and N/W axis while B3 had no shading device at all. Only B1 complied with the recommendation by BEEGN with right shading type in the recommended axis coupled with few trees. This means that B2 and B3 may not perform optimally to screen solar radiation for effective thermal control. Although, B2 will give a better performance with the recess wall and few trees unlike B3 without any shading device and trees. All the buildings were not properly sealed, air gaps were visible on the window and door areas which is an avenue for energy leakage thereby amounting to wastefulness. Finally, all buildings had single wall construction; there was no case of double skin system and evaporative cooling as mitigation to the challenge of heat penetration.

CONCLUSION AND RECOMMENDATION

The study had examined the adoption of Bio-climatic design variables in the design of administrative office buildings in tertiary institutions in Niger state, Nigeria. The study revealed that bio-climatic design was partially adopted. Obviously, orientation of building being the major determinant of energy balance of buildings was not given critical consideration as well as passive strategies. Also thermo-physical properties of envelope components during specification of materials and air-tightness of building joints during construction should be paramount by professionals concerned. The U-value of the opaque walling materials being the major component of the envelope can be further lowered for belter thermal performance by application of appropriate insulation type and thickness on the external surface. In this light, the study recommended that all professionals involved in planning, design and construction of buildings should be energy conscious by embracing bio-climatic design principles towards a sustainable built environment in Niger state and Nigeria at large. To achieve sustainable built environment, there is need for paradigm shift from the conventional design process to integrated design process (IDP) that ensures active participation and contributions of other professionals right from initial design stage to achieve a building product that is energy efficient.

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