Optimizing Building Orientation for Reduced Cooling Load in Northeast Nigeria’s Residential Architecture

M A Alkali*1,*, Liu Jie1, S G Dalibi 2,3, I I Danja1, M.H. Nasir4, Usman Inuwa Labaran5, Abdullahi M. Umar6 and Kabiru Adamu6

1School of Architecture, Southeast University, Nanjing, China.
2Institute of Project Management, Business School, Hohai University, Nanjing, China.
3Department of Quantity Surveying, Abubakar Tafawa Balewa University, Bauchi, Nigeria.
4Department of Geography, Federal University Kashere, Gombe, Nigeria.
5School of Architecture and Construction, Nanjing Tech University, Nanjing, China.
6School of Civil Engineering, Nanjing Tech University, Nanjing, China.

*223175698@seu.edu.cn; *alkalimoukhtar@gmail.com

Abstract. Between 1996 and 2005, the domestic sector was responsible for over half (55% - 61%) of energy consumption in Nigeria. In addition, electrical energy used for cooling makes a significant contribution to national consumption. In the larger context of climate change and its accompanying adverse effects, it is important for architecture to reduce its global carbon footprint. Developing nations lack sufficient building performance standards, and as a consequence, sustainable building methods are neither pursued nor enforced. Thus, in the absence of high-tech green building practices, this paper seeks to evaluate how simpler passive means of design can be used to reduce cooling energy consumption in Northeast Nigeria’s hot dry climate. DesignBuilder is used to produce different building orientation iterations to evaluate their impact on cooling loads and an ideal building orientation is determined for the region. An optimal orientation of 270⁰ is found to be optimal, as it reduces maximum cooling loads from 11150.95 kwh/yr to 9981.1 kwh/yr, a reduction of energy use of 10.5%.

1. Introduction
In Nigeria, there is a general lack of awareness on the direct relationship between building technologies, design, and their impact on human thermal comfort as well as the energy efficiency and use of a building. There is a tendency to disregard the potential for Traditional building materials and concepts in their response to local climate conditions, while giving a preference to modern imported materials and building design. This has led to architectural creations that consume significant amount of energy in order to cool indoor conditions or provide adequate lighting [1]. Globally, advanced building strategies have been made available, that have been utilized for decades to provide habitable comfort levels as well as reduced consumption for different climates, these strategies however are not studied enough to be established as a national green building code for Nigerian building industry to utilize. Therefore, there are relatively few local precedents that can serve as case studies with performance standards that can be achieved.

According to Akande [2], between 1996 and 2005, the domestic sector was responsible for over half (55% - 61%) of energy consumption in Nigeria. Furthermore, the study states that the most significant
contributors to energy use in Nigerian houses are space cooling, lighting and other daily activities like cooking and household appliances. Space cooling is associated with the relationship between indoor climate, outdoor climate and thermal comfort, with many studies revealing that there is a constant need for space cooling in Nigerian households [3], [4], [5]. Olaniyan [5] suggests that building occupants are subject to thermal discomfort caused by high temperatures for most of the year in Nigeria and the most widely used solution is mechanical cooling, which is powered by electrical energy in especially in urban areas. Adunola [4], Akande [2] and Olaniyan [5], note that the buildings which are most likely to run these mechanical cooling systems are contemporary buildings, which are relatively new constructions that have poor indoor thermal performance. As a result, significant amounts of energy are used to cool down building occupants in attempting to improve thermal comfort.

1.1. Research Aim
This study aims to identify the optimal orientation angle for which the longer side of the building should face in Northeast Nigeria’s climate for reduction of annual cooling loads.

1.2. Limitations of the study
This study investigates the impact that building orientation has on cooling loads to identify the optimal orientation the main, longer face of a building should face. Therefore, its results in terms of cooling load improvements are going to be limited to the building orientation parameter alone. In addition, as building performance varies across different climate zones and latitudes, the results obtained in this study are limited to Gombe town and the climate zone the study area belongs to.

1.3. Study Area
The study context is in the state capital, which is Gombe town, located between latitudes 10° to 10° 20′ N and longitudes 11° 01′ E and 11° 19′ E, and shares local boundaries with Akko LGA to the South and West; Yamaltu-Deba to the East and Kwami to the North. It occupies an area of about 45 square kilometers. Its urban agglomeration population is estimated at 460,000 [6].

The climate of Gombe is characterized by a dry season of six months, alternating with six months of rainy season, similar to other parts of the Nigerian Savanna. This precipitation distribution is mainly triggered by the seasonal shift of the Inter-Tropical Convergence Zone. Its mean annual precipitation is 835 mm and the mean annual temperature is about 26°C and temperatures during the hottest period between March and May sometimes exceed 40°C [7].

2. Literature Review
The absence of well-defined and enforceable building standard in Nigeria’s construction industry has been outlined by Geissler [1], who states that the National Building Code provided by the Federal Government as a set of rules, only refers to structural systems, general protection, and fire safety, with no specified requirements concerning building performance in terms of energy efficiency and renewable energy use. Moreover, this code is only mandatory for buildings owned by the Federal Government. The lax regulation of building standards in urban areas and the practical non-existence of any regulation in rural areas presents a challenge and it becomes pertinent to create guidelines whose enforcement can be domesticated in the various states of the federation, for effective regulatory framework, implementation and enforcement at the local level.

The dearth of sustainable building guidelines has resulted in a lack of general public interest in green building, whose strategies are only employed by professionals who are aware and have an interest in pursuing such initiatives. Across three climate regions of Nigeria, the major hindrances to development of high-tech green building solutions was found to be the low level of knowledge amongst built environment professionals [8]. S G Dalibi et al [9] also found that the high-cost perception of green building concepts is a major hindrance to its implementation, alongside the low availability of high-performance green building materials.
The apparent disconnect between employment of high-tech sustainable building and the local construction industry has led researchers to suggest the use of passive methods of design, which may be easier to implement [10], [11], [12], [13]. However, these passive principles are similarly underutilized as stated by Alkali [14] who found that in Northeast Nigeria, the lack of client awareness for the importance of climate responsive design is a major hindrance to the employment of passive climate responsive principles, alongside socio-cultural needs of occupants. Odimegwu [15] reports that in this region, proper orientation which is a passive, climate responsive design element is not given major consideration when designing buildings. According to Akande [12], buildings that are properly oriented take advantage of solar radiation and prevailing wind. Gut [16] suggests that while designing, the longer axis of a building should be laid along the east-west direction for minimum solar heat gain by the building envelope.

Liping [17] found that north and south facing facades can provide much better thermal comfort than west and east facing in Singapore. In this study, thermal comfort index (PMV) improved from 1.29 (East-West) to 0.41 (North-South). Yao [18] similarly suggested a north to south orientation was best in the cities of Chongqing, Changsha and Shanghai, with the worst being an orientation of west to east. A study of the effect of shading and orientation on the indoor temperature of high-rise residential buildings in Malaysia conducted thermal performance simulations using IES-VE revealed that a 16% improvement in the indoor thermal hours per annum could be achieved if an unventilated room is oriented to the north compared to the base case oriented to the south–west [19]. Similarly, a previous investigation of thermal characteristics of Malaysian building envelopes found that buildings lined longitudinally along north and south had 10% less energy consumption than buildings arranged longitudinally along east to west, regardless of building form [20].

3. Methodology

For the purpose of investigating the improvements in cooling loads as a result of varied building orientation, thermal performance simulations were carried out using DesignBuilder, which is a software with established capabilities for energy assessment. It has been uniquely developed to run EnergyPlus simulations on building models and has been used to conduct building thermal performance research with successful and reliable outcomes in previous studies [5], [13], [21], [22], [23], [24]. The study was conducted in May, the hottest month of the year for the region and included three phases.

3.1. Phase 1: Field recording of indoor temperatures

Field measurements were carried out for the month of May, with hourly indoor temperatures for a prevalent low-income residential typology in the study area recorded using a digital dry bulb thermometer placed 1.5m above the floor level in the middle of the room to ensure minimal influence from radiant heat from the building envelope materials. These indoor temperature values were used to validate the simulated temperature recordings of the computer models to ensure representative results.

3.2. Phase 2: Model calibration for base case 180°

The second phase included computer modelling of the residential building on DesignBuilder software, calibrating its relevant data, and simulating its thermal performance to determine the values generated by the base case scenario. Data inputs for latitude, altitude, climate type, region, and Hourly weather datasets were entered into the software interface. As DesignBuilder does not have hourly weather data for the study location, this data is retrieved from the One Building Weather Dataset and imported into DesignBuilder [25].

3.3. Phase 3: Orientation iteration in 15° increments

The final stage consists of modelling various iterations of shading methods as suggested by the relevant literature, with iterations starting from the base case whose longer side faced 180°, to different orientation iterations in 15° increments until an optimal orientation is found. Annual cooling loads as
well as maximum indoor temperatures are extracted and compared to determine the impact different orientation angles have on cooling loads in this region.

3.4. Building typology description
The selected residential typology is a prevalent lower income house seen in towns and cities across the study area. Most new lower to middle-income houses are built in this form, whose style is equated with better aesthetics, durability, performance and luxury [26]. Its style is a resultant of the combination of post-colonial Modern and the Postmodern style. It is a commonly held conception that these contemporary housing designs are less sympathetic to the hot and dry climate compared to the vernacular housing. This housing typology as shown in Figure 1 and Figure 2 below is owned or rented by working class families in towns, providing the bare minimum amenities.

4. Data Presentation and Results

4.1. Validation of field and simulated temperatures
The values generated by DesignBuilder were validated using Pearson’s correlation to determine whether the computer simulated indoor temperatures are representative of the field recorded indoor temperatures. There is a significant positive relationship between field indoor temperatures and simulated indoor temperatures with a correlation coefficient of 0.862. The correlation is significant at the 0.01 level (2-tailed).

4.2. Simulation Results
The studied building base case 180° orientation which denotes east-west placement had an annual cooling load of 11150.95 KWh/yr. With an orientation of 195°, cooling load is reduced to 10965.45 KWh/yr, 210° had an annual cooling load of 10734.03 KWh/yr, 225° had an annual cooling load of 10450.37 KWh/yr, 240° had an annual cooling load of 10174.81 KWh/yr, 255° had an annual cooling load of 10010.13 KWh/yr, and finally 270° was the optimal orientation with a cooling 9981.07 KWh/yr as shown in Figure 3 below. As the angle exceeds 270° (south facing), cooling loads begin to rise again.
with 285° and 300° having cooling loads of 10080.52 KWh/yr and 10275.33 KWh/yr respectively. Hence, 270° provides the optimal cooling load, with a 10.5% reduction.

Similarly, maximum indoor temperatures are reduced as the orientation tends towards the south, with a reduction of 1.4°C at 270° from the base case of 180° as shown in Figure 4 below.

5. Conclusion
This study investigated the potential for optimized building orientation for improving cooling loads in the Northeast Nigerian town of Gombe, through 15° alteration of the building angle. The results found that an angle of 270° is the most preferable as it produces improvements in cooling load of 10.5% as well as reduction in indoor temperatures year-round. This paper suggests the use of proper building orientation during the site planning phase of construction in order to minimize solar gain and maximize cooling load reduction, as that means a reduction in cooling costs as well as a reduction of the building’s carbon footprint as a result of cooling demands. When used in conjunction with other passive design strategies such as proper shading and high-performance building materials, it is possible to further reduce these cooling loads. This study therefore suggests further research on such combinations in the study region to determine their contribution to sustainable living.
References
[1] Geissler S, Österreicher D, Macharm E 2018. Transition towards energy efficiency: Developing the Nigerian building energy efficiency code. *Sustainability* 8 2620
[2] Akande OK, Fabiyi O, Mark IC 2015. Sustainable Approach to Developing Energy Efficient Buildings for Resilient Future of the Built Environment in Nigeria. American Journal of Civil Engineering and Architecture. 3, 4, 144-52
[3] Allu EL and Ebohon OJ 2014. Climate Change and Buildings in Nigeria, Lessons from a Field Survey, *Academic Journal of Science*, 3, 2, 197-206
[4] Adunola AO 2014. Evaluation of urban residential thermal comfort in relation to indoor and outdoor air temperatures in Ibadan, Nigeria. *Building and Environment* 75, 190-205.
[5] Olaniyan SA, Ayinla AK, Odetoye AS 2013. Building envelope vis-a-vis indoor thermal discomfort in tropical design: How vulnerable are the constituent elements? *International Journal of Science, Environment and Technology* 2, 5, 1370-9.
[6] Encyclopedia Britannica,"Gombe," Encyclopædia Britannica, inc. 12 7 2019. [Online]. Available: https://www.britannica.com/place/Gombe-Nigeria. [Accessed 11 05 2020].
[7] Mbaya LA, Ayuba HK, Abdullahi J 2012. An Assessment of Gully Erosion in Gombe Town, Gombe State, Nigeria. *Journal of Geography and Geology*.4, 3, 110.
[8] Allu EL, Ebohon OJ 2015. Assessing the knowledge and awareness level of built environment professionals in Nigeria. *International Journal of Contemporary Applied Sciences*, 2, 5
[9] Dalibi SG, Feng JC, Shuangqin L, Sadiq A, Bello BS, Danja II 2017. Hindrances to Green Building Developments in Nigeria's Built Environment: The Project Professionals' Perspectives. In *IOP Conference Series*.
[10] Danja II, Xinping W, Dalibi SG, Alkali M, Inuwa LU, Safarov A 2020. Greening Vernacular Building Projects in Northern Nigeria. In *IOP Conference Series: Earth and Environmental Science* 495, 1, 012074
[11] Adaji MU, Adekunle TO, Watkins R, Adler G 2019. Indoor comfort and adaptation in low-income and middle-income residential buildings in a Nigerian city during a dry season. *Building and Environment*. 162,106276
[12] Akande OK 2010. Passive design strategies for residential buildings in a hot dry climate in Nigeria. *WIT Transactions on Ecology and the Environment*. 128, 61-71
[13] Ogunrin OS 2019. A parametric analysis of the thermal properties of contemporary materials used for house construction in South-west Nigeria, using thermal modelling and relevant weather data (Doctoral dissertation, University of Liverpool).
[14] Alkali MA, Jie L, Dalibi SG, Danja II 2020. Hindrances to the Utilization of Climate Responsive Architecture Principles for Residential Design in Northeast Nigeria. *International Journal of Scientific & Engineering Research environment* 9,10,
[15] Odimegwu C 2019. A Derivation of Passive Guidelines for Achieving Thermal Comfort in the Design of Residential Buildings in Warm Humid Climate of Abia State, Nigeria. *International Journal of Development Strategies in Humanities, Management and Social Sciences*. 9, 3
[16] Gut P, Ackermanch T. Climate Responsive Building, SKAT, St. Gallen
[17] Liping W, Hien WN 2007. The impacts of ventilation strategies and facade on indoor thermal environment for naturally ventilated residential buildings in Singapore. *Building and Environment*. 42, 12, 4006-15
[18] Yao R, Costanzo V, Li X, Zhang Q, Li B 2018. The effect of passive measures on thermal comfort and energy conservation. A case study of the hot summer and cold winter climate in the Yangtze River region. *Journal of Building Engineering*. 15, 298-310.
[19] Al-Tamimi NA, Fadzil SF 2011. The potential of shading devices for temperature reduction in high-rise residential buildings in the tropics. *Procedia Engineering* 21, 273-82.
[20] Kannan KS 1992. Thermal characteristics of Malaysian buildings envelopes (Doctoral dissertation, Fakulti Kejuruteraan, Universiti Malaya).
[21] Ogunrin SA and Sharples S 2020. "Impact of building envelope construction on thermal comfort: a parametric analysis of modern, low-income housing in south-west Nigeria for current and future climates," 2018. [Online]. Available: http://livrepository.liverpool.ac.uk/3008646/1/Final%20paper%200039_v%20Final%20SS.doc x. [Accessed 11 05 2020].

[22] Mohammadi A, Saghaﬁ MR, Tahbaz M, Nasrollahi F 2018. The study of climate-responsive solutions in traditional dwellings of Bushehr City in Southern Iran. Journal of Building Engineering. 16,169-83.

[23] Sánchez-García D, Bienvenido-Huertas D, Tristanche-Carvajal M, Rubio-Bellido C 2019. Adaptive comfort control implemented model (ACCIM) for energy consumption predictions in dwellings under current and future climate conditions: A case study located in Spain. Energies. 12, 8, 1498

[24] Pérez-Fargallo A, Rubio-Bellido C, Pulido-Arcas JA, Gallego-Maya I, Guevara-García F 2018. Inﬂuence of adaptive comfort models on energy improvement for housing in cold areas. Sustainability. 10, 3, 859

[25] One Building, 2020. [Online]. Available: http://climate.onebuilding.org/WMO_Region_1_Africa/NGA_Nigeria/index.html. [Accessed 2 09 2020].

[26] Muazu AG, 2017. "The Use of Traditional Building Materials in Modern Methods of Construction (A case Study of Northern Nigeria)," International Journal of Engineering Science Technology and Research. 2, 6, 30-40