Relating forms and materials of traditional and contemporary building types to indoor and outdoor air temperatures for sustainable development in Okigwe, Nigeria

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Abstract. This paper relates forms and materials of traditional and contemporary building types to indoor and outdoor air temperatures in Okigwe, Nigeria, with a view to developing design criteria for minimum consumption of energy for maximum comfort. Data on indoor air temperature were collected from nine purposively sampled buildings monitored simultaneously on hourly basis for a year (1 Nov 2015 - 31 Oct 2016), using Tinytag Explorer Data Loggers. The mean annual indoor air temperature value of traditional building types was 28.2^0C, contemporary building types 28.7^0C and mean annual outdoor air temperature value was 29.0^0C.The mean daily values of indoor air temperature of both building types were significantly different ($z = 1.74$, $p = 0.04$). Contrastingly, there were no significant differences between the outdoor and indoor temperature values of traditional building types [$t(20) = 1.25$, $p = 0.22$], and contemporary building types [$t(20) = 0.53$, $p = 0.60$]. The forms and materials of traditional building types ensure reduction in energy and consumption pattern and provide acceptable indoor thermal environment. The adaptation of its forms and materials will aid in the conceptualisation of design criteria for sustainable development strategies in Nigeria and other developing nations.

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1. Introduction

The urban milieu is stressed by the rate at which humankind exploit its resources. Buildings as part of the urban environment enable humans perform greater part of their activities within them; they also contribute to the generation of greenhouse gases, thereby making attempts at understanding their thermal characteristics a major plank in the discursive field of sustainability. Although much have been done on the need for shift in energy demand, building design and internal temperature control to reduce the rapid global warming and climate change which have been adduced to be devastating and exhaustive, very little efforts are yet to be made in knowing the thermal climate and its integration into conceptions of sustainability and urban development in Nigeria and other developing nations [1, 2, 3]. More so, according to [2], developing nations are at advantage in that much of their urbanisation has not taken place and as such it's planning and management can be construed in ways amenable to the dictates of the risks associated with climate changes.

The challenges connected with unsustainable consumption patterns have continued to undercut society's sustainability goals. Issues of air quality due to carbon and greenhouse gas emissions remain predominant and bothersome. The evolution of industrialisation and transfer of technology in the guise of global enterprise coupled with growing costs of energy, scarcer and more expensive, and more extreme changes in the global climate, have confronted the environmental designers and stakeholders to design buildings and articulate policies that are not only going to provide thermally acceptable but secure, accessible, healthy and productive while reducing its effects on the environment [4, 5].

The rate at which the human race reshape the environment has raised concern to the global community, hence, the World Commission on Environment and Development in 1987 agreed that development should be sustainable by meeting the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development was further devolved to incorporate economic, social and environmental key dimensions. According to [5] economic sustainability is a method of production that satisfies present consumption rates without affecting future needs. Social sustainability has to do with the ideas of equity, empowerment, accessibility, participation, sharing and cultural identity [6]. Whereas environmental sustainability conforms to consumption of natural resources by humans at a rate where they are able to replenish themselves, and maintaining ecological integrity of all earth's environmental systems.

Forms and materials of composition of traditional and contemporary building types differ in the approaches toward providing suitable and sustainable strategies in ensuring users' satisfaction, reduction of energy consumption and provision of acceptable indoor thermal environment. The forms and materials for buildings constitute the interface between the external and internal environments and as such control energy efficiency, indoor environment and functional performance of buildings. They are described as 'climate moderators' and first lines of defence against impact of external climate on indoor environment [7]. In the attempt to attain desired thermal comfort levels, different forms and materials are manipulated and they reflect the relationship between climate, architecture and people [5].

Different climates, cultures and traditions akin to different regions all over the world are not endowed with same building materials and techniques either in type or quantity [8]. Consequently, forms and types of shelter vary [9]. Each culture, tradition and regions developed her architecture based on the availability of these materials and her ability to handle them within the ambit of their knowledge prowess. With the independence of Nigeria from her British colonialists in 1960, mud (known as *aja ulo* in Igbo Language, one of the major tribes in Nigeria), timber (*osisi*), bamboo (*achara*), palm midribs (*ogugu*), thatch (*akilika*), and rope (*udo*) were the component materials used in the forms and materials composition of traditional building types. Similarly, sandcrete walls, cement, metal roofing sheets, asbestos ceiling sheets and other materials such as steel, glass, plastics, and plywood gave rise to the systems of composition adopted in contemporary building types. Also, the development of new materials, technology and increase in the number of indigenous architects and practices aided in the blossoming of contemporary architecture. However, use of electro-mechanical devices for comfort in the contemporary building types which are variance with the passive design strategies associated with traditional building types adversely led to mismanagement of energy resources [10]

Numerous studies have identified air temperature, relative humidity, mean radiant temperature, air velocity, metabolic rate and clothing insulation as the factors that define thermal comfort and also established indices for their measurements, however, air temperature has been singled out as the main design parameter since it determines the sensation of occupants within spaces [11, 12, 13]. The design challenge in warm-humid climate like Okigwe, Nigeria, revolves around mitigation of adverse effects of elevated temperatures and humidity. Despite global worries mitigating and adapting buildings for sustainable development, there is dearth of literatures on the thermal performance of forms and materials and methods of composition of different types of buildings in Nigeria. The few existing studies

concentrated on thermal performance of residential buildings and its occupants' responses to thermal environment without investigating the effects of outdoor on indoor environmental variable of air temperature on forms and materials of traditional and contemporary building types [14].

Therefore, the thrust of this paper, is to relate forms and materials of traditional and contemporary building types to indoor and outdoor air temperatures for sustainable development in Okigwe, Nigeria, with a view of providing design criteria for minimum consumption of energy for maximum comfort. The hypotheses formulated for the study test the significant differences between indoor air temperature values of traditional and contemporary building types, and compared each of the types to the outdoor temperature of the study area – Okigwe, Nigeria.

2. Research Methodology

2.1 Study area

Okigwe, a semi-urban city in the warm-humid climate of Nigeria lies between Latitudes 5^0 30' and 5^0 57' North of the Equator and Longitudes 7^0 04' and 7^0 26' East of the Greenwich Meridian. It is one of the 27 Local Government Areas (L.G.A.) and has a land area of about 1,824 km^2. It is bounded in the north and east by Abia and Anambra States; Ideato North and Onuimo L.G.As of Imo State share the western boundary whereas, Ehime Mbano and Ihite-Uboma L.G.As are on the southern fringe of Okigwe. The tropical rainforest climate designated by the Koppen climate classification as 'AF' characterizes the south-eastern part of Nigeria including Okigwe. It experiences dry and rainy (wet) seasons. The mean annual temperature is 26.4^0C with 27.6^0C, 25.0^0C and 2.6^0C as maximum, minimum and range respectively. The annual precipitation is over 2000mm.

The relative humidity is high in the mornings and during rainy seasons. It ranges from 80% to 100% while in the afternoons and during the dry seasons, it hovers between 60% and 80%. This semi-urban city experiences the conventional type of rainfall due to its proximity to the equatorial belt. Rainfall is heaviest during the months of June and July. It is situated approximately 62 km north-east of Owerri, Imo State capital; 87 km south of Enugu, the regional headquarters of south-east Nigeria. It is also about 549 km east of Lagos – commercial nerve centre of Nigeria and about 525 km, south-east of Abuja – the Federal Capital Territory (F.C.T) of Nigeria. Generally, the people are predominantly farmers.

2.2 Research design

To gain an in-depth understanding of the phenomenon of indoor and outdoor air temperature, the case study research design approach was adopted with multiple case study variant used to collect data from nine purposively sampled case buildings. The sampled buildings possess forms and materials reminiscent of traditional and contemporary building types and practices. Two of the buildings belonged to the traditional types, whereas the other seven were of the contemporary types.

Buildings whose walls and roofs fabrics were made of mud and thatches constitute traditional building types whereas contemporary building types comprise those with sandcrete block and corrugated iron and aluminium roofing sheets. Walls and roofs as elements of buildings possess inherent qualities that modify the internal environment of buildings [3].

2.3 Data collection

Indoor environmental variable of air temperature for the nine sampled buildings was monitored simultaneously on hourly basis from 1 November 2015 to 31st October 2016 using Tinytag Explorer Data Loggers. They were mounted at 1200mm above the finished floor level. The secondary data comprise outdoor temperature values obtained from the nearest Meteorological Station at the Imo (Sam Mbakwe) International Cargo Airport, Owerri, Nigeria.

3. Results

Data on indoor and outdoor environmental variable of air temperature were obtained from traditional and contemporary building types. Also, secondary data were got for outdoor temperature in the study area.

3.1 Indoor air temperature values in traditional building types

As in Table 1, the mean annual indoor air temperature value obtained for traditional building types was 28.2^0C. The maximum and minimum values of 30.6^0C and 26.3^0C were recorded in February 2016 and August 2016 respectively. As stated earlier, there are two major seasons in the study area: rainy (wet) and dry seasons. Rainy season starts from April to October whereas; dry season is from November to March. A difference of 1.1^0C exists between the mean rainy season indoor air temperature value of 27.7^0C and 28.8^0C for the dry season. The standard deviation was 1.4^0C and range 4.3^0C.

3.2 Indoor air temperature values in contemporary building types

As indicated in Table 1, the mean annual indoor air temperature value obtained for contemporary building types was 28.7^0C. The maximum and minimum values of 30.9^0C and 26.8^0C were similarly recorded in February 2016 and August 2016 respectively. The mean indoor air temperature value of 28.1^0C was obtained for rainy season and 29.4^0C for the dry season; with a difference of 1.3^0C. The standard deviation was 1.36^0C and range 4.1^0C.

3.3 Outdoor air temperature values in Okigwe, Nigeria

Further Table 1 showed that the mean annual outdoor air temperature value obtained for the Nigeria was 29.0^{0}C. The maximum and minimum values of 30.7^{0}C and 28.4^{0}C were recorded in January 2016 and September 2016 respectively. The mean indoor air temperature value of 28.2^{0}C was obtained for rainy season and 30.2^{0}C for the dry season; with a difference of 2.0^{0}C. The standard deviation was 1.97^{0}C and range 2.3^{0}C.

study area from the nearest Meteorological Station at the Imo (Sam Mbakwe) International Cargo Airport, Owerri,

3.4 Relationship between indoor and outdoor air temperature values of traditional and contemporary building types in Okigwe, Nigeria

Table 1 and Figure 1 depict the relationship between indoor and outdoor environmental variable of air temperature with respect to traditional and contemporary building types in Okigwe, Nigeria.

Table1: Statistical results for indoor and outdoor air temperature values of traditional and contemporary building types in Okigwe, Nigeria from Nov 2015 – Oct 2016.

Period	TBT	CBT	O/DOOR
November 2015	28.5	29.0	29.0
December 2015	27.1	27.9	28.5
January 2016	28.1	28.8	31.9
February 2016	30.6	30.9	29.8
March 2016	29.7	30.2	31.6
April 2016	29.4	29.9	30.0
May 2016	28.8	29.4	31.1
June 2016	27.6	28.1	27.6
July 2016	26.6	27.1	27.0
August 2016	26.3	26.8	27.7
September 2016	26.8	27.2	26.2
October 2016	28.5	28.5	27.6
Annual Min	*26.3*	*26.8*	*26.2*
Annual Max	*30.6*	*30.9*	*31.9*
Annual Mean	*28.2*	*28.7*	*29.0*
Standard Deviation	*1.40*	*1.36*	*1.97*

TBT = Traditional building type, CBT = Contemporary building type and O/DOOR = Outdoor
Source: Fieldwork 2016

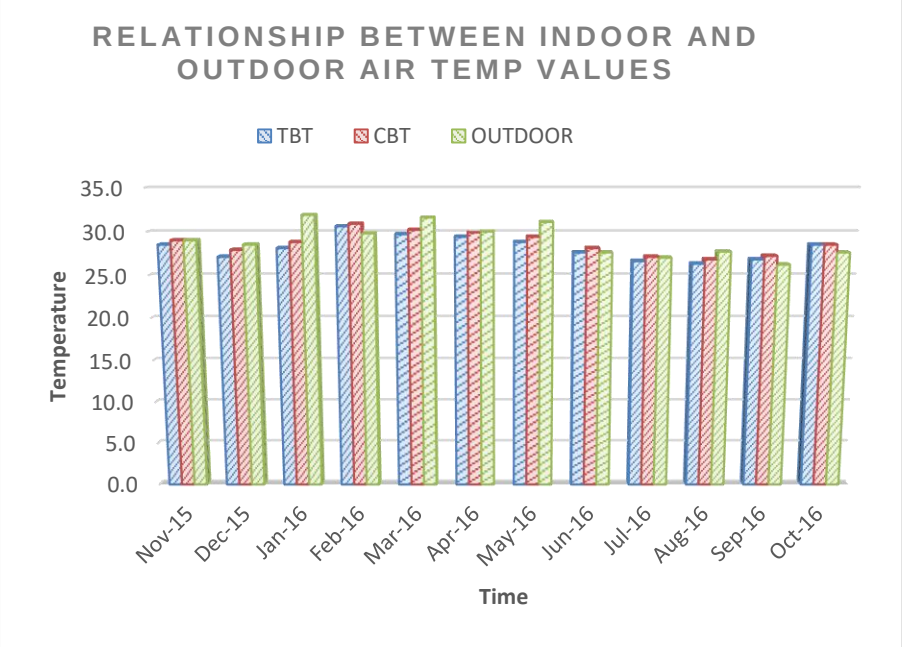

Figure 1: Variations between indoor and outdoor monthly mean air temperature of traditional and contemporary building types

4. Findings and Discussion

Data were exported to MS Excel computer program for analyses. A z-test was conducted to test whether there was a significant difference between the mean daily values on indoor air temperature of traditional and contemporary building types. The findings revealed that a significant difference existed between both building types ($z = 1.74$, $p = 0.04$). Another test was carried out to ascertain if there was a significant difference between outdoor and indoor air temperature values of traditional building types using t-test statistical analytical tool. The result showed that there was no significant difference between indoor and outdoor air temperature values of traditional building types [$t(20) = 1.25$, $p = 0.22$]. Similarly, there was no significant difference between indoor and outdoor air temperature values of contemporary building types [$t(20) = 0.53$, $p = 0.60$].

However, the mean annual indoor air temperature value obtained from traditional building types (28.2^0C) was lower than the value for contemporary building types (28.7^0C) by 0.5^0C. Furthermore, it was found that the mean annual indoor air temperature values of both building types were lower than that of the outdoor temperature (29.0^0C) by 0.8^0C and 0.3^0C respectively. Comparing the seasonal results, traditional building types equally had lower indoor air temperature values both in the dry and rainy seasons than contemporary building types. They also had lower values than contemporary when related to outdoor values.

Invariably, the forms and materials adopted in the composition of traditional building types were instrumental to the lower values of indoor air temperature obtained throughout the year. It would be recalled that traditional building types were made from locally sourced materials such as mud (*known as aja ulo in Igbo Language, one of the major tribes in Nigeria*), timber (*osisi*), bamboo (*achara*), palm midribs (*ogugu*), thatch (*akilika*), and rope (*udo*). Contemporary building types had much of the influence of new materials, and technology from steel, glass, plastics, and plywood. They relied heavily on the use of electro-mechanical devices for comfort whereas, passive design strategies played much greater roles in the composition of traditional building types.

The significance of these results obtained from the statistical analysis confirmed that differences exist in the thermal qualities of traditional and contemporary building types in Okigwe, Nigeria. Thus aligning with opinions expressed by [15], and [16]. Therefore, the architect and other environmental designers and stakeholders are tasked to produce building designs and policies that would lead to reduced adverse environmental effects in the conception of sustainable development in Nigeria, for thermally comfortable, healthy, secure and productive living spaces.

5. Conclusion

The paper has through the indoor and outdoor air temperature values shown the differences in the thermal qualities of traditional and contemporary building types. The forms and materials enabled traditional building types to modify the external environment better than contemporary building types. In other words, the building practices and types handed over to us by our forebears provide suitable and better sustainable strategies. They ensured reduction of energy consumption and provision of acceptable indoor thermal environment. The adaptation of its forms, materials and techniques will aid in the conceptualisation of design criteria for sustainable development strategies in Nigeria and other developing nations.

References

[1] F. Nicol, M. A. Humphreys and S. Roaf, Adaptive thermal comfort: Principles and practice, Oxon: Routledge, 2012.

[2] D. Satterthwaite, S. Huq, H. Reid, M. Pelling and P. R. Lankao, "Adapting to climate change in urban areas: The possibilities and constraints in low- and middle-income nations," in *Adapting cities to climate change:Understanding and addressing the development challenges*, London, Earthscan, 2010, pp. 3-34.

[3] M. Evans, Housing, climate and comfort, New York: Halsted Press, 1980.

[4] N. W. Alnaser, R. Flanagan and W. E. Alnaser, "Model for calculating the sustainable building index (SBI) in the Kingdom of Bahrain," *Journal of Energy and Buildings,* vol. 40, pp. 2037-2043, 2008.

[5] B. Salgin, O. F. Bayram, A. Akgun and K. Agyekum, "Sustainable features of vernacular architecture: Housing of Eastern Black Sea region as a case study," *Arts,* vol. 6, no. 11, pp. 1-14, 2017.

[6] A. M. Kahn, "Concepts,Definitions and Key Issues in Sustainable Development: The outlook for the future," in *International Sustainable Development Research Conference*, Manchester, UK, 1995.

[7] I. Lee and R. Tiong, "Examining the role of

building envelopes towards achieving sustainable buildings," in *International Conference on Whole Life Urban Sustainability and its Assessment*, 2007.

[8] M. U. Okafor, U. S. Marcel-Okafor, R. K. Nwokocha and A. O. Olotuah, "Effect of fabric composition on thermal performance of pre-colonial, colonial and contemporary residential buildiny types at Okigwe, Nigeria," in *Environmental Design and Management International Conference*, Ile-Ife, Nigeria, 2017.

[9] N. M. Obinegbo, "Basic Historical Development in Architecture," in *Fundamentals in Architecture*, Enugu, Nigeria, Cheston LTD, 2011.

[10] R. de Dear and G. S. Brager, "Towards an adaptive model of thermal comfort and prefernce," *ASHRAE Transactions* , vol. 104, no. 1, pp. 145-167, 1998.

[11] C. Koranteng, C. Essel and S. Amos-abanyie, "The effect of different wall materials at different orientations on indoor thermal comfort in residential buildings in Kumasi, Ghana," *Research Journal of Engineering and Technology,* vol. 1, no. 1, pp. 9-18, 2015.

[12] W. Cui, G. Cao, J. H. Park, Q. Ouyang and Y. Zhu, "Influence of indoor air temperature on human thermal comfort, motivation and performance," *Building and Environment,* vol. 68, pp. 114-122, 2013.

[13] N. Djongyang, R. Tchinda and N. Donatien, "Thermal comfort: A review paper," *Renewable and Sustainable Energy Review,* vol. 14, pp. 2626-2640, 2010.

[14] A. B. Wahab, "Effect of physical characteristics and thermal performance of secondary school built with bricks on adaptive behaviour of its occupants," *Civil andEnvironmental Research,* vol. 7, no. 1, pp. 55-63, 2015.

[15] P. E. Hermawan and E. Setyowanti, "The difference of thermal performance between houses with wooden walls and exposed brick walls in tropical coasts.," *Procedia Environmental Sciences,* pp. 168-174, 2015.

[16] K. M. Nematchuoa, R. Tchinda and J. A. Orosa, "Effect of wall construction materials over indoor air quality in humid and hot climate," *Journal of Building Engineering,* pp. 16-23, 2015.