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Building Spatial Characteristics and Sustainable Thermal Comfort in a Tropical City

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ABSTRACT: *This paper evaluated sustainable thermal comfort and the impact of building spatial characteristics on thermal comfort within residential buildings in a warm-humid tropical city in Nigeria. A thermal comfort survey was conducted in 528 houses in Ibadan, Nigeria, within twelve neighborhoods selected by stratified random sampling. Respondents filled questionnaire indicating their thermal responses using the ASHRAE thermal comfort scale. Building spatial characteristics were assessed for all the selected buildings. The Mean Comfort Votes varied across the different types of buildings in the study area. The residents' thermal responses and the measured indoor climatic elements were found to respectively co-vary with most of the building spatial characteristics. The results inferred the significance of the impact of building characteristics on thermal response and indoor climatic condition. For comfort level of respondents, the main predictor spatial variables were: Roof material, Type of accommodation, Orientation, Percentage of window to wall area ratio, Colour of curtains, Number of spaces cross-ventilated and Wall material (R Square = 0.365, P≤0.05). It was concluded that building spatial characteristics are additional parameters to be analyzed on a contextual platform using the field study approach for proper understanding of the dynamics of urban residential thermal comfort.*

KEYWORDS: *building spatial characteristics, naturally ventilated building, sustainable, thermal comfort, tropical urban environment.*

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I. INTRODUCTION

Sustainability of the built environment can be enhanced through the attainment of indoor thermal comfort at little or no cost to the building user. This is however a challenge in urban buildings within the tropical climate because of the influence of heat from the climatic elements and the pollutions generated in the urban environment (Hyde 2000). According to Peeters (2008), residential buildings can vary much more in thermal comfort than public and commercial buildings. Roaf et al (2005) suggested an elimination of climatically disastrous building types and radical reduction in carbon dioxide emissions from buildings. The passive design of buildings makes contribution towards sustainability of buildings.

Thermal comfort within residential living spaces cannot be discountenanced when considering building performance. . The residential building must provide a functionally acceptable thermal environment. Markus and Morris (1980) pointed out that buildings act as barriers and as responsive filters concerning the environmental conditions. The homely atmosphere should offer the occupants emotional tranquillity, mental rejuvenation and renewal of strength through comfort provision., According to Fry and Drew (1956) and supported by Peeters (2008), the architecture of residential buildings should collaborate with nature to establish an order in which human beings may live in harmony with their surroundings. If the environment is harmonious to people they will find it easy to be in harmony with one another. This is why thermal comfort is indispensable in the home environment (Szokolay 2008). The home environment, being a place of rest, should present an atmosphere suitable for its purpose. The elements constituting the building and the building characteristics in relation to its design physically define the building and determine its essence and impact. Croome (1991) asserted that buildings modify climate and influence behaviour and culture. The spatial and design characteristics of the building can therefore have remarkable potential in influencing indoor comfort levels.

A major aspect of the indoor environmental quality is the thermal comfort within the building spaces. The cost of providing and maintaining indoor comfort through mechanical means can be overbearing if adequate measures are not in place. Thermal comfort is therefore a key factor to examine when considering the level of sustainability of urban residential buildings especially in the tropical environment. The study aims at identifying building characteristics and applicable measures in the development of passive design that would enhance sustainability of the urban built environment. Building spatial characteristics are examined in this paper as variables of thermal comfort on a contextual platform using the field study approach for proper understanding of the dynamics of urban residential comfort and sustainability.

II. LITERATURE REVIEW

The interaction between architecture and climate became another focus of thermal comfort study as the proponents of bio-climatic design related climatic conditions to building design and indoor comfort. According to Szokolay and Brisbin (2004), architecture is the art and science of building. The term 'bioclimatic architecture' was coined by Victor Olgyay (Design with Climate, 1963). He synthesized elements of human physiology, climatology and building physics, architectural regionalism concept and designing with regard to the environment. Szokolay (1982) asserted that it is axiomatic that climate is (or should be) a major determinant in house design. Beng (1994) observed that climate as a prime factor in built form, is the mainspring for all the sensual qualities that add up to a vital tropical architecture. A building can thus be climate-responsive.

The thermal behaviour of a building, which is a product of the interaction between architecture and climate, has great effect on the energy use and sustainability of the building. According to Szokolay and Brisbin (2004), the building envelope is a selective filter: to exclude unwanted influences like excessive radiation, but to admit the desirable and useful like appropriate daylighting. The design and spatial characteristics of the building will therefore play a role. It should be the designer's aim to ensure the required indoor conditions by applying appropriate building design and spatial characteristics with little or no use of energy, other than from ambient or renewable sources

The analysis of the local climatic conditions is the starting point in formulating building and urban design principles aimed at maximizing comfort and minimizing the use of energy for heating and cooling. Different comfort standards are justified for countries with different climatic conditions and stages of economic development. According to Givoni (1998), studies have indicated that persons living in hot countries prefer higher temperatures than the recommendations by the American and European standards such as ASHRAE comfort nomogram and Fanger's Comfort Equation. There is presently a dynamic interaction between the built and natural environments that need to be balanced (Pearlmutter 2000). There should be a return to the bio-climatic concept of design in architecture.

Haase and Amato (2009) examined the potential for natural ventilation in achieving thermal comfort. In tropical climates the improvement in comfort by natural ventilation ranged between 9% and 41%. For subtropical climate the improvement varied between 3% and 14%. In the temperate climate, the improvements varied between 8% and 56%. The study showed that natural ventilation has a good potential in tropical and temperate climates but not in subtropical climates. According to Mallick (1996), the perception of comfort in the warm-humid climate is influenced by long-term conditioning of high temperature and humidity. The exterior conditions influence clothing, personal habits and expectations of comfort. In the study of occupants of urban housing in Bangladesh, it was found that there was unexpected tolerance to high temperatures and very high humidity for comfort (Mallick 1996). The study also found that the building design in urban areas was marked by increasing popularity of multi-storied apartment blocks, where the choice of wall thickness and exposure to radiation can make significant contribution to indoor comfort. The comfort provisions utilized in the buildings were cool surfaces and ceiling fans. The result further establishes the dynamic relationship between architecture and climate.

The previous studies have indicated the importance of the dynamic interaction between climate and architecture. The role that building physical, spatial and design characteristics play in the modification of climatic factors indoors is recognized in this study. The indoor thermal conditions would be studied on the basis of man, climate and architecture. There are therefore additional parameters to be analyzed on a contextual platform using the field study approach for proper understanding of the dynamics of urban residential space use, adaptive opportunity and sustainable thermal comfort.

Study Area

The location for this study was Ibadan, a Nigerian city in the South-West with latitude $7^0$23'N and longitude $3^0$55'E. The city ranges in elevation from 150m above sea level in the valley area to 275m on the major north-south ridge which crosses the central part of the city (http://www.absoluteastronomy.com/topics/Ibadan). Ibadan falls within the warm-humid tropical climatic zone having a seasonally humid classification because of its inland location. For Ibadan, there are two broad seasonal patterns, namely the dry season (November to April) and the rainy season (May to October). {Ojo 1977}. The climatic context in the study area presents challenges for indoor comfort.

Methodology

A thermal comfort survey was conducted in Ibadan. Ten percent (12) of the 119 neighborhoods identified from the metropolitan map were selected by stratified random sampling comprising 2 low, 3 medium and 7 high residential densities. The total number of houses in each of the neighborhoods was estimated to be an average value of 885 based on data from National Bureau of Statistics (2008). A sample size of five percent of this gave 44 houses in each neighborhood which were selected using systematic random sampling to give a total of 528 houses for the survey. For each selected building, an adult resident filled a questionnaire indicating the thermal response at different periods of the day using the ASHRAE thermal comfort scale. The building spatial characteristics were assessed for all the selected buildings. Indoor and outdoor measurements of relevant climatic elements were done in representative buildings in the neighborhoods.

III. FINDINGS

The frequency analysis of the data gave the following results concerning the residents' thermal responses in the afternoon critical period using the ASHRAE scale of warmth: 1.3% felt cold, 7.6% felt cool, 13.5% felt slightly cool, 15.0% neutral, 23.9% felt slightly warm, 24.7% felt warm and 14% felt hot. This gave a mean comfort vote of +0.827 (warm) for all respondents. Concerning how respondents rated their level of comfort, 10.8% voted for very uncomfortable, 22.2% for uncomfortable, 30.7% for slightly uncomfortable, 7.0% for neutral, 12.1% for slightly comfortable, 14.0% for comfortable and 3.2% for very comfortable. Those respondents that were not comfortable at different levels of discomfort totaled 63.6%. level of satisfaction with their respective indoor thermal conditions. It was found that 11.2% were very dissatisfied, 26.7% were dissatisfied, 21.6% were slightly satisfied, 10.6% were neutral in their vote, 13.8% were slightly satisfied, 11.7% were satisfied and 4.4% were very satisfied. This meant that a total of 59.5% expressed different levels of dissatisfaction with the indoor thermal condition in the afternoon period considered.

The mean comfort votes were calculated on the bases of type of accommodation, typology and neighbourhoods. Variations in values were noticed across the different residential buildings. Different levels of indoor comfort were found for the different house types, typologies, Further analysis was done using mean comfort votes of respondent' thermal comfort assessments categorized into building types. The analysis indicated that the duplex buildings were assessed as the most comfortable building type while the face-to-face storey buildings were assessed as the most uncomfortable building type during the afternoon period (Table 1). Results also implied that contemporary buildings were assessed as the most comfortable typology with traditional buildings taking second position while vernacular buildings were assessed as the least comfortable typology (Table 2).

Table 1: Assessment of the Mean Comfort Votes of Respondents by Building Type.

Building Type	Mean Comfort Vote
Bungalow Face-to-Face	+1.387
Storey Face-to-Face	+1.535
Bungalow Flats	+0.290
Storey Flats	+0.505
Duplex	-0.918

Table 2: Assessment of the Mean comfort votes of respondents by Typology.

Typology	Mean Comfort Vote
Traditional	+0.831
Vernacular	+1.574
Contemporary	+0.061

Relationship between the Indoor Climatic Elements and the Building Spatial Characteristics

Measurements of indoor climatic elements were done during the study. The building spatial characteristics were found to be significantly related to the climatic elements in the afternoon critical period according to the results of the Spearman rho and Kendall tau_b correlation tests. The indoor air temperature, mean radiant temperature and relative humidity were found to co-vary respectively with most of the building spatial characteristics. Specifically the correlating building characteristics were the following: type of accommodation, typology, wall material, roof material, colour of walls, orientation, fenestration type, room window orientation, number and percentage of spaces cross-ventilated, number of semi-outdoor spaces, percentage of window:wall area, percentage of window:floor area and colour of curtain. This result is aligned with the 'climate-architecture' inter-relationship that have been emphasized in the submissions of Olygay (1963), Markus and Morris (1980), Szokolay (1982), Croome (1991), Beng (1994), Givoni (1998), Szokolay and Brisbin (2004), as discussed earlier in the section reviewing the literature.

Relationship between Residents' Thermal Response and Building Spatial Characteristics

The thermal response in the afternoon assessment was found to significantly co-vary with most of the building spatial characteristics according to the result of Chi-square test. The significance of the relationship between residents' thermal response and spatial variables like Type of accommodation, Typology, Plan and Form, Wall material, Colour of walls, Roof material, Orientation, Fenestration type and Number of semi-outdoor spaces, Percentage of Window:wall area, Percentage of Window:floor area, Number and percentage of cross-ventilated spaces and Room window orientation established the significance of the variations found in the results of calculated mean votes of thermal responses across different building types and neighbourhoods as was presented earlier. The implied differences in the indoor comfort levels of the buildings were therefore significant and were rightly perceived to be related to the differences in building characteristics.

Influence of Building Physical and Spatial Characteristics on Indoor Comfort

A regression analysis was done taking thermal response in the afternoon living room assessment as the dependent variable and the building spatial characteristics as the set of predictor variables (Table 3). The result indicated R Square = 0.357 which implied that the set of predictor variables explained 35.7% of the variance of the dependent variable. The ANOVA test indicated F = 14.797 and 0.000 level of significance (l.o.s.) implying very high significance of the result. The value of F obtained from the table (1.61) was lower than the computed F value. This confirmed the linear relationship between the dependent variable and the set of predictor variables. The regression equation derived, selecting variables with considerable levels of significance, is:

$y = 9.044 – 0.172B_1 - 0.190B_4 – 0.138B_7 – 0.125B_8 – 0.341B_9 – 0.172B_{10} – 0.119B_{10'}$
$- 0.267B_{14} + 0.145B_{11} – 0.254B_{16} – 0.216B_{17}$

The main predictor variables (P≤0.05) affecting adaptive thermal responses were: Orientation (0.004 l.o.s), Type of Accommodation (0.019 l.o.s.), Number of semi-outdoor spaces (0.022 l.o.s), Percentage of spaces cross ventilated (0.045 l.o.s), Colour of curtains (0.042 l.o.s), Type of electric lighting fittings (0.041 l.o.s.) and Wall material (0.058l.o.s).

The result of the regression analysis taking comfort level rating at the special afternoon assessment as the dependent variable and the building spatial characteristics as the set of predictor variables (Table 4), indicated R Square = 0.365. This implied that the set of predictor variables explained 36.5% of the variance of the dependent variable. ANOVA test indicated 0.000 level of significance and F value of 15.370. The F value obtained from the table (1.61) was lower than the computed F value. This confirmed that there is a very significant linear relationship between the dependent variable and the set of predictor variables. The equation obtained, selecting only variables with considerable levels of significance, is:

$y = -0.81 + 0.255B_1 + 0.207B_4 + 0.411B_6 + 0.124B_7 + 0.195B_{10} + 0.539B_{11*} + 0.316B_{16}$

The main predictor variables (P≤0.05) affecting the comfort level of respondents were: Roof material (0.000 l.o.s), Type of Accommodation (0.001 l.o.s), Orientation (0.017 l.o.s) Percentage of window:wall area ratio (0.001 l.o.s), Colour of curtains (0.020 l.o.s), Number of spaces cross-ventilated (0.037 l.o.s), Wall materials (0.056 l.o.s).

Table 3 a,b,c: Regression Analysis

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.598[a]	.357	.333	1.25611

ANOVA Table testing the Significance of Regression Coefficients for Thermal Response

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	443.574	19	23.346	14.797	.000[a]
	Residual	798.367	506	1.578		
	Total	1241.941	525			

Regression Coefficients and the Semi-partial Correlations for the Thermal Response

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	9.044	.531		17.018	.000

Type of Accommodation occupied by respondent	-.172	.073	-.131	-2.356	.019
Typology	-.092	.114	-.040	-.810	.418
Plan Form	-.008	.060	-.006	-.141	.888
Wall material	-.190	.100	-.079	-1.902	.058
Colour of walls	.113	.087	.052	1.294	.196
Roof material	-.089	.102	-.042	-.872	.384
Orientation	-.138	.048	-.114	-2.891	.004
Fenestration type	-.125	.074	-.080	-1.679	.094
Number of semi-outdoor spaces	-.341	.148	-.097	-2.304	.022
No of spaces cross-ventilated	-.172	.086	-.096	-2.002	.046
Percentage of spaces cross-ventilated	-.119	.059	-.117	-2.005	.045
% window: wall area	.145	.106	.079	1.374	.170
Room windows' orientation	.009	.035	.011	.257	.798
Protection level of windows	-.097	.087	-.045	-1.120	.263
% window: wall area	-.120	.152	-.061	-.788	.431
% window: floor area	-.267	.159	-.114	-1.683	.093
Texture of curtain material on windows	-.078	.117	-.030	-.665	.506
Colour of curtains on windows	-.254	.125	-.086	-2.037	.042
Type of electric lighting fittings	-.216	.105	-.084	-2.052	.041

a. Dependent Variable: Express how you are feeling now within this living room space with respect to its thermal condition

Table 4a,b,c: Regression Analysis

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.605[a]	.365	.342	1.35836

ANOVA Table testing the Significance of Regression Coefficients for Comfort Level

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	538.832	19	28.360	15.370	.000[a]
	Residual	935.491	507	1.845		
	Total	1474.323	526			

Regression Coefficients and the Semi-partial Correlations for the Comfort Level

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.810	.573		-1.414	.158
	Type of Accommodation occupied by respondent	.255	.079	.179	3.229	.001
	Typology	.110	.123	.044	.896	.371
	Plan Form	-.016	.065	-.010	-.249	.804
	Wall material	.207	.108	.080	1.918	.056
	Colour of walls	.030	.094	.013	.315	.753
	Roof material	.411	.110	.180	3.722	.000
	Orientation	.124	.051	.094	2.402	.017
	Fenestration type	.022	.080	.013	.279	.780
	Number of semi-outdoor spaces	.165	.160	.043	1.032	.302

	No of spaces cross-ventilated	.195	.093	.100	2.096	.037
	Percentage of spaces cross-ventilated	.001	.064	.001	.018	.985
	% window: wall area	-.023	.115	-.011	-.199	.843
	Room windows' orientation	-.042	.038	-.048	-1.116	.265
	Protection level of windows	.055	.094	.023	.582	.561
	% window: wall area	.539	.164	.250	3.280	.001
	% window: floor area	.016	.172	.006	.096	.924
	Texture of curtain material on windows	-.176	.126	-.062	-1.397	.163
	Colour of curtains on windows	.316	.135	.098	2.341	.020
	Type of electric lighting fittings	.134	.114	.048	1.177	.240

a. Dependent Variable: How do you rate your level of comfort now?

IV. CONCLUSION

There were variations in the values of Mean Comfort Votes across the different residential buildings in the study area. The indoor air temperature, mean radiant temperature and relative humidity were found to co-vary respectively with most of the building spatial characteristics. The thermal response of residents correlated with most of the building spatial characteristics. Regression analysis results indicated strong relationship between building characteristics and the thermal comfort experience of residents. The significance of the impact of building characteristics on thermal response and comfort level with indoor thermal condition was inferred by the results.

The main predictor spatial variables of thermal response were: Orientation, Type of Accommodation, Number of semi-outdoor spaces, Percentage of spaces cross-ventilated, Colour of curtains, Type of electric light fittings and Wall material. For comfort level of respondents, the main predictor spatial variables were: Roof material, Type of accommodation, Orientation, Percentage of window to wall area ratio, Colour of curtains, Number of spaces cross-ventilated and Wall material. From the results of this study, it can be inferred that there are additional parameters to be analyzed on a contextual platform using the field study approach for proper understanding of the dynamics of urban residential thermal comfort. There is therefore need for more detailed research into the inferred impact of building spatial characteristics on indoor thermal comfort in the tropical warm-humid climatic context.

REFERENCES

[1]. Beng, T.H. (1994); Tropical architecture and interiors. Page one Books. London. UK.
[2]. Croome, D.J. (1991); The Determinants of architectural form in modern buildings within the Arab world. Building and Environment Vol. 26, No. 4 pp 349 – 362.
[3]. Fry, M. and Drew, J. (1956); Tropical Architecture. BT Batsford Ltd. London.
[4]. Givoni, B. (1998); Climate Considerations in Building and Urban Design. John Wiley and sons, U.K.
[5]. Haase, M. and Amato, A. (2009); An investigation of the potential for natural ventilation and building orientation to achieve thermal comfort in warm and humid climates. Solar Energy, Vol. 83, No.3, March 2009, pp 389-399.
[6]. http://www.absoluteastronomy.com/topics/Ibadan. Ibadan climate. Retrieved on Aug.15,2011.
[7]. Hyde, R. (2000); Climate Responsive Design. E and F.N. Spoon. London UK.
[8]. Mallick F.H. (1996); Thermal comfort and building design in the tropical climates, Energy and Buildings Vol 23, Issue 3, pp 161-167.
[9]. Markus, T.A. and Morris, E.N. (1980); Building, Climate and Energy. Pitman Publishing Ltd. London, UK.
[10]. National Bureau of Statistics (2008); Annual Abstract of Statistics 2008. National Bureau of Statistics, Nigeria.
[11]. Ojo, O. (1977); The Climates of West Africa. Heinemann Educational Books Ltd. London.
[12]. U.K.Olgyay, V. (1963); Design with climate. Princeton University Press, New Jersey, USA.
[13]. Pearlmutter, D. (2000); Architecture and Climate: the Environmental Continuum, Geography Compass, Vol.1 No. 4, pp752-778.
[14]. Peeters, L. (2008); Thermal comfort in residential buildings: comfort values and scales for building energy simulations. Applied Energy, Vol. 86, No.5, pp.772-780.
[15]. Roaf, S., Crichton, D. and Nicol, F. (2005); Adapting Buildings and Cities to Climate Change: A 21st Century Survival Guide. Elsevier.
[16]. Szokolay, S.V. (1982); Climate data and its use in design. In: Proceedings of the 1st PLEA Int. Conference, 13- 15 Sept. Bermuda pp. 18 – 25.
[17]. Szokolay, S.V. (2008); Introduction to Architectural Science: the basis of Sustainable Design, Architectural press, Oxford, U.K.
[18]. Szokolay, S.V. and Brisbin, C. (2004); Introduction to Architectural Science, Elsevier publishers, U.K.

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