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Examining the Dry Season Results of Indoor Thermal Comfort of Residential Building with Courtyard in some Urban Centers in Abia State, Nigeria

Ochi, E.,

Department of Architecture, Abia State University, Nigeria

ABSTRACT

The paper examined the dry season results of indoor thermal comfort of residential buildings with courtyards in some urban centres in Abia, namely, Aba, Umuahia and Ohafia. It was observed that indoor thermal comfort in the residential buildings were less in the afternoon and evening but nights and mornings were stable. Specifically, afternoon result for the three urban centres; were highest; slightly warm, (24.37%) warm (25.31%) and hot, (36.64%). It was recommended that courtyards should be properly placed to ventilate the indoors of the residential buildings.

Keywords: Indoor comfort Temperature residential building courtyard.

INTRODUCTION

Improved economy and increased urban population, especially in the study areas has required more buildings (communal residential, institutional and industrial) to be built to accommodate the corresponding increasing human activity (Ochi, 2019). This condition increased the built-up landscape, thereby exacerbating the urban microclimate incidentally requiring more mechanized method or achieving conducive indoor thermal comfort. Alozie, Nwobi and Eze, (2017), Fatima, (2015) and Alozie, 2024 identified mechanical methods such as air conditioners contrasting with non-mechanized methods like, courtyards wind lowers, high widows and ventilation tunnels as best ways to achieve indoor thermal comfort. Unfortunately, courtyards are in most cases not provided in residential buildings in the area, nor other passive cooling systems, making it absolutely imperative for most buildings to rely on mechanical methods like air-conditions to achieve conducive indoor thermal comfort. Day and night temperatures in the urban centres are likely to be higher, ranging from 27°C to 30°C (Alozie 2014 and Alozie, 2020). This means that both day and night will be lost especially in the dry seasons. Fatima, (2015) and Alozie, et al, (2017) equally in observed that relative humidity will be around 75% to 95% and will never be less than 60 in the right. Therefore residential and non residential buildings will be subject to significant cooling necessities due to the high intensity of heat passing from building external envelope necessitating the need to rely on mechanical cooling systems to gain indoor thermal comfort which will incidentally increase energy consumption (Ochi 2019). Although indoor temperatures decreases, while humidity rises in percentage, especially in rainy seasons, it may not be for morning, afternoon, evening and night results. This provides reasonable gap to and capture the predicted mean reactions of occupants in these separate periods in the day. These feelings will be articulated, using structured questionnaire

The Concept of Thermal Comfort

The Historical Perspective

Xie, Zhua and Xianilang (2005) described thermal comfort as an important index defined as the condition of mind which expresses satisfaction with the thermal environment. In the early twentieth

century, people have entered into researching on comfortable-sense, air-conditioning engineers and investigators of indoor air quality wish to forecast people's comfortable sense quantificationally. Within these years, a large number of indexes of thermal comfort were brought forward, Xie, *et al* (2005) further observed that the first index of thermal comfort was put forward by Leonard Hill in 1914 and was based on thermal loss. Dutton also developed a synthetic thermostat which can keep room temperature stable, while air temperature, radiation and air speed varies, (Xiaoping and Kiangahav, 2000).

Afterward in 1919, ASHARE in Pittsburg developed the "Effective Temperature index, (ET). It was defined as an environmental index which combines two or more parameters to determine thermal comfort such as; air temperature, mean radiant temperature, humidity or air velocity into a single variable (ASHARE, 2004). The Effective Temperature index equal to the temperature of resting saturated air which produces same feeling in numerical value, ET has been adopted by many official and professional groups, especially in criteria for thermal environment. Xie *et al* (2005) observed that ASHARE reshaped the index till 1967, but ET emphasizes the influence of humidity excessively in low temperature and contrarily in high temperature. Nevertheless, ASHARE later adopted the New Effective Temperature which was brought forward by Gagge in 1971, instead of "Effective Temperature. Oti, (2019) combined the New Effective Temperature Index and modified version of it as adopted by ASHARE, (2013) to assess the indoor thermal comfort of residential buildings in southeastern Nigeria.

Fanger's Equation

i. Comfortable condition

Fanger, (1972) aligned the physical parameters which can ensure human comfortable state to the human body and not the environment. Xie *et al* (2005) highlighted that P.O Fanger made three comfortable conditions the first condition is that human body must be in thermal balance, thus the heat loss to the environment will equal to the heat produced in human body. The second condition is that skin temperature should be corresponding to thermal comfort, the third is that human body should possess the best sweat; sweat is the function of metabolism. Whereafter, Fanger (1972) summed up many literatures and got all the expression for each variable in thermal balance equation. Thus, Fanger derived comfort equation by combining thermal balance equation with other two comfortable conditions, any set of variables which can meet comfort equation must satisfy the three comfortable conditions, thus the equation is the necessary condition but no sufficient condition, Xie, *et al*, (2005), Xiaping and Ziangzhav (2000) and Alozie, *et al* (2015) observed that comfort equation is apt in assessing thermal comfort, especially by applying the Predicted Mean Vote (Pmv) indexing.

ii. Predicted Mean Vote (Pmv)

While a set of environmental variable meets the comfort equation, Fanger, (1972) went ahead to develop a comfort equation index which can predict any fixed environmental variable. The index is called, Predicted Mean Vote (PMV). Fanger then developed a seven grade index, which is presented in Table 4.

To extend the applied range of the formula, Fanger suggested that the thermal sense of a certain activity is the function of human heat load (heat load is the difference between bodily heat production and actual environmental heat loss). The equation for Pmv has not been provided by experimental data of diversified clothes and activities. This is because; when people are sitting and wearing light clothes it can give a better result, but the data of high metabolism is unsatisfactory (Xie, *et al*, 2005). Yet, Alozie, *et al*, (2015). successfully applied the method in assessing the indoor thermal comfort of residential buildings in Umuahia Urban. In addition Adunola and Ajibola, (2016) applied the formula (PMV) to determine the significant factors that affect thermal comfort within residential neighbourhoods of Ibadan metropolis and preferences of adult resident use of spaces.

Heat Balance concept

Heat balance models also referred to as "static' or 'constancy; models were the basis of the early pioneering works of Gagge, (1995) and Fanger, (1970). These models have been adopted into current thermal comfort standards that prescribe acceptable conditions for thermal comforts. Heat balance concept view the person, as a passive recipient of thermal stimuli and are premised on the assumption that the effects of a given environment are mediated exclusively by the physics of heat and mass

exchanges between body and surrounding environment (Xie et al, 2005).

Factors Affecting Thermal Comfort

These factors are classified into four, which represent the most influential factors; Physiology, Psychology, Climate and Building designs, it is believed that each factor contributes in some ways to occupant's TC perception and amongst them there are interdependent and dynamic influences (Fig. 1).

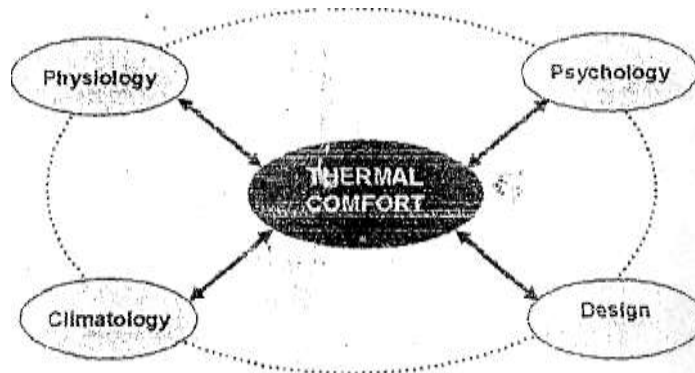


Fig. 1 Interdependent factors of thermal comfort

Physiology and psychology are the two human factors which interact dynamically in responding; toward environment perception based on thermal sensation. Climatology covers wide range of natural setting of climate (macro environment impacts) which cannot be easily modified. People, as a part of the natural ecosystem always need to adapt to climate condition where they live. Climate can influence the planning of towns, buildings, and settlement designs and can evoke strategies to promote the efficiency of TC for both outdoors and indoors (Taleghani, 2013). Lastly, building's design might have significant influence on TC of the occupants. Building is expected to provide good protection from harsh outside condition and create comfortable interior spaces (micro-environment). In turn, the built environment affects local and regional climate change, which can influence comfort and health (Bridson, 2012). Table 1 shows in brief how the four inter-dependent factors affect TC perception in NV buildings.

Table 1: Factors Affecting Thermal Comfort

	Factor	Description	Impacts on Thermal Comfort
Human Factors	Physiology	<ul style="list-style-type: none"> • Metabolic rate • Age • Gender • Weight 	<ul style="list-style-type: none"> • Body thermoregulatory • Acclimatization • Clothing adjustment • Activity (metabolic) adjustment
	Psychology	<ul style="list-style-type: none"> • Behaviour • Control • Expectation • Perception 	<ul style="list-style-type: none"> • Behavioural adjustment • Background and experience • Acceptability, preference • Perseverance

Macro Environment	Climatology	<ul style="list-style-type: none"> • Geographical • location • Climate 	<ul style="list-style-type: none"> • Prevailing wind (Monsoon wind) • Diurnal humidity - • Outdoor temperature • Solar radiation (sky condition) • Precipitation
Micro Environment	Design	<ul style="list-style-type: none"> • Building form • Openings • Orientation • Vegetation 	<ul style="list-style-type: none"> • Building (heat transfer) • Porosity and shading • Room dimension • Window wall ratio • Building layout

The detail discussion of the impacts from four factors had been widely presented in a large body of literature from different field of study such as architecture, psychology, physiology, and geography. The summary of some interesting studies is highlighted in the following discussion.

Mechanism of Body Thermoregulation

It has been reported that the physiological approach, in which the optimum condition is equated with the minimum load on the body's thermoregulatory system, gives results that closely correspond to laboratory (thermal chamber) studies in which semantic scales for comfort are used (Taleghani, 2012). A precise explanation of the principles of thermoregulation system operating is beyond the capability of any schemes of thermoregulation system, if the subject of temperature; control mechanism in an organism and the conditions of life is unknown (Kanaan, 2010). The power of thermoregulation reactions is not large. A naked man is not able to keep the temperature homeostasis even during an extreme stress of thermoregulation if the air temperature decreases to +2° C.

The Study Area

Abia State is firmly located in the geographic region of South eastern Nigeria. Georeferencing coordinates shows that the area lies within Lat 4°4⁰¹, to 6°14N and long 7°10¹ to 8°E. This encompasses a land area of about 4902.24sqkm. The area is firmly situated in the warm wet climatic zone, with annual average rainfall of 2200mm. Daily temperature is in the average of about 26°C. January and February are the hottest months, with July to October as the coldest months. Forest cover is from significant to less significant, especially in the areas that have been intensely cultivated or scraped for industrial. commercial, institutional transportation and institutional uses. Abia State is underlain by these geologic formations rising from the coastal plains in the south to the Uturu-Lokpaukwu Cuesta. Others include; Bende shales, Ameke Basin, False bedded sandstone and the Cross River plains, located at the margins with Ebonyi State.

There are four major urban centres in Abia State, namely, Aba, Umuahia, Ohafia and Arochukwu. In this study, we choose the urban centres with reckoned high order social, economic and industrial activities and higher population sizes, with significant population densities. The urban centres are as follows, Abia, Umuahia and Ohafia.

METHODOLOGY

This research was based on survey design approach, since its reliance on subjective analysis. This is imperative to enable the application of the predicted mean vote. The Predicted Mean Vote (PMV) application facilitate the measurement of feedings or reactions instead of indoor temperature and humidity, to measure indoor thermal comfort.

Table 2: Selection of Sample Population

Senatorial zone Zone	Urban centre	Residential Building	Respondents	
			Occupants	Architects & Town planner
Abia North	Ohia	25	100	5
Abia Central	Umuahia	75	300	15
Abia South	Aba	225	900	45
Total		325	1300	65

We selected, one urban centre from each of the senatorial zones in Abia state, namely, Abia North (Ohafia), Abia Central (Umuahia) and Abia South (Aba) this is presented in table 2 above. Allocation of respondents to the urban centres was based on the ratio of 10%, 30% and 60% for both the buildings, occupants and architects. The reason for this selection is based on the level of economic activities for which Umunakwe, (2015) classified, Aba, Umuahia as first and second levels of urban centres, Stratification of the state enabled us to allocate the various classes of respondents. Thus, each urban centre selected received a ratio of the total classification of the sample population, which is as a result of the population sizes and level or human activities in the respective urban centres, This is shown in Table 3

Table 3: Population size of selected urban centres in Abia State

Urban centre	2006 Pop. Six (1)	2010 Projected (2)	2019 Projected (3)	2020 Projected (3)
Aba	897,560	1,058,375	1,418,537	1,463,929
Umuahia	220,660	262, 654	348,730	359,889
Ohafia	88,250	96,245	123,824	127,786

1. NPC, 2006 census
2. Umunakwe, 2015
3. Projections at 3.02%

Paucity of data for residential buildings in the area, constrained us to rely on the assessment of Umunakwe, (2015). In each residential building chosen, at least four (4) residents were randomly selected. While in the selection of the residential buildings at least 10 major streets were identified and at least one street selected from either the north, south, east or west of the urban centre. In Aba urban, the selected streets were evenly chosen from Aba north and south local government areas. This was necessary, to evenly cover the entire Aba urban which comprises of two local government areas. The residential buildings selected from each of the urban centres were Equally divided between the residences with courtyards and residences without courtyard, and selection made after counting three buildings of their kinds without replacement. An example this classification for one urban centre selected for investigation is presented in Table 4.

Table 4: Allocation of Sample size to classes of residential buildings in Umuahia urban

Classes of Residential Buildings	With Courtyard	Without Courtyard
Storey building (1-4bedroom flats)	7	17
Storey building (1 Tenement)	7	15
Bungalow (1-4 bedroom)	10	10
Bungalow tenement	7	7
Duplexes (all types)	9	8
Total	38	37

Table 4 shows the allocation of sample frame to the various classes of residential buildings in Umuahia urban, which is one of the selected urban centres. Selected residential buildings were chosen from buildings with courtyards and buildings without courtyard. This is to enable us generate comparable data of indoor thermal comfort indices.

Methods of Data Analysis

For the purpose of analysis essentially assessed indoor thermal temperatures of buildings with courtyards during the dry season using ASHARE (American Society of Heating, Refrigerating and Air-conditioning Engineers) standard 55, (2013),

ASHARE (2013) stipulates measures or yardstick for indoor thermal comfort through the Predicted Mean Vote (PMV) and Temperature Humidity Sensors. The Thermal Comfort as stipulated by ASHARE, adopts the Temperature Humidity Index (THI) which stipulates the following, for Temperature, tropical and hot climates

- 15°C to 24°C comfortable
- 24.5°C to +27°C less comfortable
- Above 27°C not comfortable

Although, PMV was first introduced for temperate regions, it has also been applied for tropical regions, Joost, Mitja and Henson (2010) observed that PMV has been applied for forty years in all building forms, all over the world.

Other standards for measuring thermal comfort include, the New Effective Temperature Index (NETI). Xie et al. (2005) classified the index into:

15°C, 20°C, 25°C and 30°C.

There is also the Hent Index Formula, defined as:

- <30°C No discomfort
- 30 - 40°C Some Discomfort
- 40 - 45°C Great Discomfort
- >45°C Dangerous
- >54°C Heat stroke imminent

Nevertheless, this work adopted the PMV (Predicted Mean Vote) technique in measuring indoor thermal comfort. This is because, the Health and Safety Executive of USA observed that thermal comfort describes a person's state of mind in terms of whether they feel too hot or to cold. Thus measurement of thermal comfort can be based on subjective evaluation. Fanger, (1970) described the relationship as comfort equation expressed as an index called PMV. It is based on seven grades index, starting from +3 (heat) to -3(cold).

In this study also, cognizance were taken of types of residential buildings, like; storey buildings and bungalows. However, the work did not include; commercial, industrial, recreational, institutional and religious buildings.

RESULTS AND DISCUSSION

Table 5: Indoor thermal comfort conditions in the morning during the dry season.

Urban centre	Cold	Cool	Slightly cool	Comfort	Slightly warm	Warm	Hot	Total
Aba	15	38	48	68	110	104	53	436
Umuahia	7	9	18	28	33	30	23	148
Ohafia	2	4	7	9	13	9	8	52
Total	24	51	73	105	156	143	84	636
Percentage	3.77	8.02	11.48	16.51	24.53	22.48	13.21	100
Fanger's Equation index	-3	-2	-1	0	+1	+2	+2	

As should be expected the result presented in table 5, is significant department from same period in the day for rainy season, as exposal by Ochi, (2014). Comfort indices were higher for the following, slightly warm +1(24.53%); warm, +2(22.48%) and hot, +3(13.21%) and were lower for cold, -3(3.77%); cool, -2(8.02%) and slightly cool, -1(11.48%). Responses for hot (+3) option was significant; it means that in dry season the indoors of residential buildings in the area are relative hot and unconductive.

Table 6: Nature of Building indoors in the afternoon during the Dry season for buildings with courtyards

Urban centre	Cold	Cool	Slightly cool	Comfort	Slightly warm	Warm	Hot	Total
Aba	2	3	11	26	119	122	153	436
Umuahia	2	5	8	15	28	60	30	148
Ohafia	1	2	4	8	8	9	20	52
Total	5	10	23	49	155	161	233	636
Percentage	0.79	1.57	3.62	7.70	24.37	25.31	36.64	100
Fanger's Equation index	-3	-2	-1	0	+1	+2	+3	

The results presented in Table 6 are an indication of the season wherein the investigation was carried out. Significantly, the indoor nature of the buildings, though with courtyards were not comfortable, 0(7.70%) in the afternoon. It rather ranged from slightly warm, +1(24.37%) warm, +2(25.31%) to hot, +3(36.64%). We also note that the influence of the courtyard may have been responsible for 1.57% and 3.62% recorded as cool and slightly cool. Nevertheless, it is significantly different from the result obtained for the same period in the rainy season.

Table 7: Thermal comfort of building in doors recorded in the evening in the dry season of building with courtyards

Urban centre	Cold	Cool	Slightly	Comfort	Slightly	Warm	Hot	Total
Aba	-	5	10	38	113	120	150	436
Umuahia	1	4	11	28	30	26	48	148
Ohafia	2	2	4	9	8	10	16	52
Total	3	12	25	75	151	156	214	636
Percentage	0.47	1.89	3.93	11.79	23.74	24.53	33.65	100
Fanger's	-3	-2	-1	0	+1	+2	+3	

The result in Table 7 showed that thermal comfort did not improve much for those residential buildings with courtyards in the evenings. Although, it differed slightly from the afternoon results, it is still very low on comfort index, 0(11.79%). Nevertheless, we still emphasize that the presence of courtyard significantly strengthened the cooling of the building interiors, no matter how little, hence 1.89% and 3.93% were recorded for cool, (-1) and slightly cool, (-1). The actions of global warming can be observed in this result, since evenings are almost as hot as the afternoons.

In the other hand in Table 28, and during the mornings, slightly warm (+1) and warm (+2) recorded the highest responses of 24.53% and 22.48% respectively. In the afternoon and for all the urban centres investigated, Hot (+3), Warm (+2) and Slightly Warm (+1) recorded the highest responses of 36.64%, 25.31% and 24.3% respectively. The situation was not different in the evening, this is because, Hot (+3) option recorded the highest result of 33.65%, Warm (+2) recorded 24.53% response, while slightly warm recorded 23.74%.

REFERENCES

1. Ochi, E. (2019) influence of courtyards on indoor thermal comfort of residential buildings in some urban corrupts in Abia Stat, Nigeria an unpublished PhD these submitted to the department of Faculty of Enrv. Studs Abia State University, Uturu.
2. Alozie Nwobi and Eze, (2017) Review and application of passive cooling methods needed in imploring thermal comfort of building in torpid environment journey of the environment of (2): 8666.
3. Alozie L.C (2014) Sustainable Environment Assessment of indoor thermal contrite of resident build up in Abia State Nigeria unpublished proved chary submitted to the type of a Abia State University Uturu, Nigeria.
4. Alozie, I.C (2020) Assessment of indoor thermal comfort of a courtyard Building in Umtata Urban Environment of Abia State, Nigeria. Work Applied several Journal 38 (3:218-222).