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Design Prospects for Thermal Comfort in Institutional Buildings in Hot Dry Climate of Yola, Adamawa State, Nigeria

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Abstract: *The thermal performance of buildings is aimed at providing the most comfortable environment for occupants and thus minimizing demand for cooling and heating. The study examined building elements and climatic factors as a function of ensuring thermal comfort in institutional buildings in selected sites in Yola. Ex-post-facto in conjunction with seven offices and three classrooms of the former Women Development Centre Yola and School of Environmental Sciences Jambutu, Adamawa State Polytechnic Yola respectively were selected based on convenience sampling techniques was employed Architectural characteristics (building form, orientation, building height, floor to ceiling height, floor area, openi,ng sizes and type, position of openings, window/floor ratio, window/wall ratio etc.) of the studied spaces were measured and environmental variables (wind speed, air temperature and relative humidity) were recorded using Testo 405-*v_1 *pocket-sized thermal anemometer with telescopic velocity stick and Kestrel 3000 pocket weather meter. Mean of the environmental variables were compared using ANOVA and P value at interval scale level to establish any significant difference (at 0.05 level of significant) among the studied spaces. The result shows that rectangular form has great potentials than other forms, orientation with longer side facing north-south, opening sizes of wider width are better in thermal comfort and classroom with two placements of trees on two sides (north and south) has the highest value of mean indoor wind speed of 0.19m/s which has a 0.06m/s significant difference and mean ventilation coefficient of 0.55. The maximum mean indoor temperature was 32.83*^{o}*c obtained from classroom with none placement of tree, orientation and position of the openings leads to moderate thermal performance. The research concluded that design factors have affected thermal comfort in the studied spaces. The determination recommend that rectangular form should be adopted, longer side should be oriented north-south, opening size should be between 20% and 35% of wall area and minimum of 30% 0f the floor area, tree to building distance should be within 3-5m, the minimum trunk height should be 1.5m so as to allow free flow and channelling of wind to the indoor spaces and size and type of openings should be given due considerations.*

Keywords: *Design Prospects**,** Thermal Comfort, Institutional Buildings, Hot Dry climate.*

Introduction

Thermal comfort, an important factor for building design, is defined as a level in which heat balance across the body and environment is in a state of equilibrium (Fanger 1970). Thermal comfort fundamentally deals with the temperature that the users of buildings or space occupants reflect as calm to live in (Akande and Adebamowo, 2010). It is very difficult to describe the comfort of individuals living under a roof using degrees. In this context, thermal comfort is also a sensitivity or experience of a person in relation to function of many factors that usually vary from individual to individual within same environment. The International Standard EN ISO 7730 posited that thermal comfort essentially deals with state of observance which prompts fulfilment with the individual thermal environment (Dewidar, *et al.*, 2013).

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 55 standard (2004) defined comfort as the state of mind which expresses contentment with the thermal environment and is evaluated by personal assessment (Fabbri, 2015). Therefore, thermal comfort studies must consider certain variables. These include physical aspect of the environmental, indoor or outdoor factors in which we find the human body affecting exchanges between the human body and environment (Frontczak *et al.,* 2011). Also, psychological and cultural factors that have an effect on the insight of the sensitivity of comfort, or perceptual encryption of the activities between the human body and environment (Fabbri, 2015).

Indoor thermal comfort is achieved when occupants are able to pursue their daily endeavour without any hindrances for which the building is intended. Hence, it is essential for occupants' wellbeing, productivity and efficiency. The first important function of all buildings is to adapt to the prevailing climate and provide an internal and external environment that is comfortable and conducive to the occupants (Akande and Adebamowo, 2010). However, providing comfort for occupants of a building in a dynamic climate is quite challenging but very fundamental. This is as a result of growing ranges of challenges now facing designers to provide buildings that will be fit and comfortable for the 21st century.

Design variables such as form or size and orientation of space-building, in relation to wind directions, size and position of space openings, vegetation and other physical features, are pertinent attributes of good architecture product which greatly affect the thermal performance of indoor spaces, especially in institutional building. Thermal discomfort experience in a built environment is a thing of concern since wellbeing of man depends on the quality of his indoor environment especially in institutional building. This discomfort experience in an occupied space lowers the emotional and physical health of occupants. Students and their instructors spend long periods of time in class rooms and good indoor environmental conditions (e.g temperature, relative humidity and wind speed) in general and student's performance is well established.

Nigeria building and road research institute, 2012 located Yola in a hot dry climate zone. In recent years, most institutional buildings have become what is termed the "glass box" exposing all or most part of its facades to the high day time temperatures. The effects contribute to thermal discomfort within the indoor spaces (Simons, Koranteng, Adinyira and Ayarkwa, 2014).

Numerous field experiments have been performed in hot climates, but most of these have been in humid locations A study by Babagana and Dungus (2015) dwelt entirely on outdoor elements in Maiduguri and their effects in ensuring comfort and environmentally-friendly neighbourhoods. They indicated the improper use and siting of building setbacks, orientation angle, openings, street width, landscaping, use of heat-emitting appliances, floor area ratio and type of finishing. Baker and Standeven (1994) studied thermal comfort in residential buildings during the summer in Athens, Greece. Their result indicated the importance of adaptive opportunity for building occupants to accept temperatures warmer than 24°C. As important as these studies are, their findings have not yet emerged into comprehensive and widely accepted guideline for tropical naturally ventilated buildings (Adebamowo, 2007 cited in Akande and Adebamowo, 2010). In reality, occupants are comfortable in wider range of conditions. This is because people are able to adapt to the environment that they are used to and also because several other factors could also contribute to the adaptation of their indoor environment. This study therefore concentrates in the indoor and outdoor factors of public office buildings where occupants spend most of their productive hours.

One important building functions is to maintain indoor thermal comfort conditions of the space and protect the occupants from undesirable heating or cooling most time this is not achieved, it is expected that buildings in the study zone be designed to maximize thermal comfort, in view of the this, in this regard it became pertinent to identify strategies that could be used to improve thermal comfort in institutional buildings. The study intends to answer the following questions

1. *To what extent does building thermal performance vary with building form in the study area?*
2. *To what extent does building thermal performance vary with building orientation in the study area?*
3. *To what extent does thermal performance vary with building opening size in the study area?*
4. *To what extent is the effect of Vegetation on thermal performance of building indoor spaces in the study area?*

Climate of the study area

Climate of an area helps in understanding thermal behaviour of buildings. Hence apprehending the climate of Yola, Adamawa State, Nigeria, it is of paramount importance. Yola is located on the north eastern part of Nigeria. It is between latitude 7^0 and 11^0 North of the equator and between longitude 11^0 and 14^0 of the Greenwich meridian. The climate is characterized by high temperatures. The surface air, at the beginning of the dry season in November, is very hot. The season starts with a marked and abrupt drop in the moisture content of the surface air followed by a change in the direction of the surface winds. The relative humidity drops abruptly from 82% to 92% between June and October (average at 10:00am.) to about 25% to 36% between December and March. Daily minimum temperatures normally drop more rapidly than the maximum; the diurnal temperature varies from an average daily maximum of 35.5^{o}C to a daily minimum of 17^{o}C. The sky is mostly clear in November and this permits longer hours of sunshine. The average duration of sun- shine in November varies from 10.6 to 9.2 hours. Harmattan period is experienced between December and February. The season is characterized by very strong, dehydrating and dust-laden winds. Trees shed their leaves during this period; grasses die-out entirely and are burnt off. Visibility is generally reduced. The extremely dust-laden atmosphere shuts out insulations and leads to low temperatures. The thickness of this haze and dust layer of the harmattan exceeds a height of 1500 meters. Dense harmattan dust rarely lasts continuously for more than four or five days even during the peak of the harmattan season. The prevalent winds consist of the north-east and south-east trade winds during the dry and wet seasons respectively, Wind speeds range from 1.33m/s in April/May to even below 0.49m/s between August and September.

The study area has three climatic seasons namely, the hot-dry season which occurs between February to April, the Cold-dry season occurs between November to January and the rainy season occurs between May and October.

Material and Method

For this study, the institutional buildings in Yola., seven offices and three classrooms of the former Women Development Centre Yola and School of Environmental Sciences Jambutu, Adamawa State Polytechnic Yola were selected based on convenience sampling techniques. A case study combined with ex-post-facto was employed. Architectural characteristics (building form, orientation, building height, floor-to-ceiling height, floor area, opening sizes, and type, position of openings, window/floor ratio, window/wall ratio, among others) of the studied spaces were measured and environmental variables (wind speed, air temperature, and relative humidity) were recorded using Testo 405-v_1 pocket-sized thermal anemometer with telescopic velocity stick and Kestrel 3000 pocket weather meter. The mean of the environmental variables was compared using ANOVA and p-value at interval scale level to establish any significant difference (at 0.05 level of significant) among the studied spaces.

Case Studies

Case Study 1

Women Development Centre, Yola.

Plate 1: An aerial view of Women Development Centre, Yola. (Source: Google earth (2022).

Description of the Study Area 1

The first case study site was women development centre building which is a low-rise concrete structure of floor levels. The building is occupied by the staff and students. The building is one of the institutional buildings in Yola. It is bonded closely by Government Girls secondary school (G.G.S.S) Yola fence to the east, High court Yola fence to the west and Justice Buba Ardo way, an access road, to the North.

Women development centre, Yola is one of the institutional buildings in Yola town which is built purposely to empower women with various skills through training so as to be self-reliant.

The centre has among other functional spaces, offices for the trainers, administrative offices, exhibition gallery and conference hall. The building form is combination of rectangular and hexagonal shape. The forms are orientated differently some are based on four cardinals (north, south, east and west) while others are on sub-cardinals (north-east, south-east, south-west and north-west). The openings (windows) are sliding type which has only 45 percent allowance of air, as shown in figure 1.

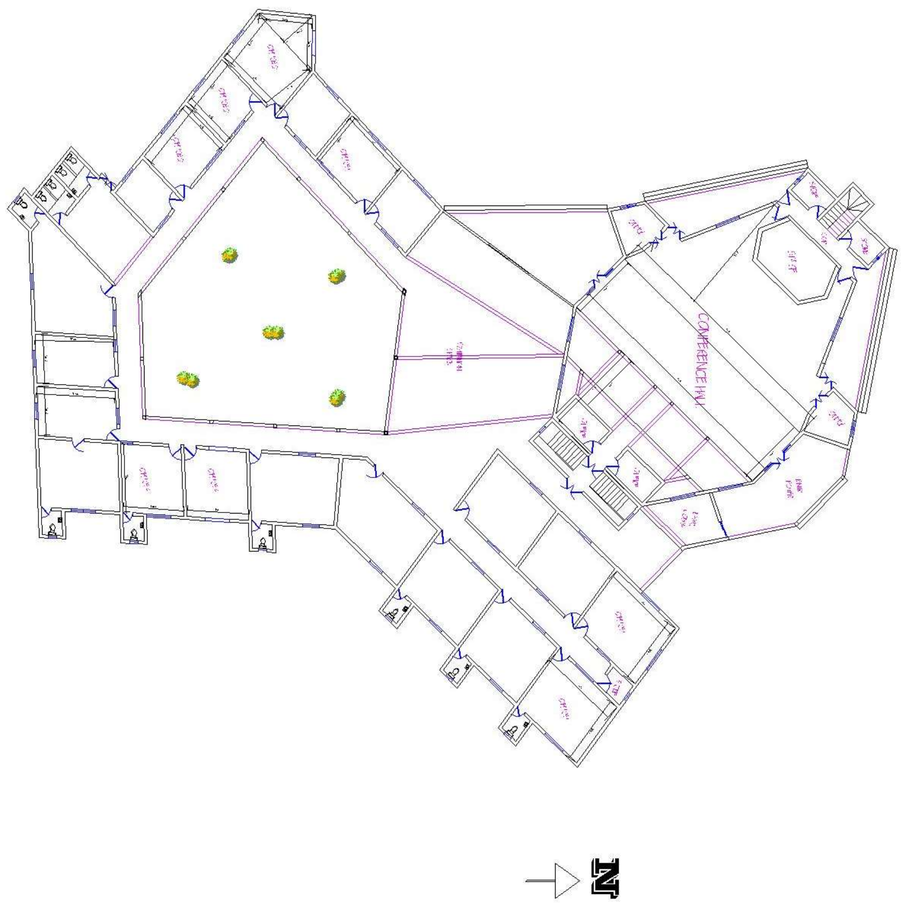

Figure 1: Floor plan of Women Development Centre, Yola and the observed spaces.
(Source: Author’s field work 2022).

Case Study 2

Classrooms of School of Environmental Sciences, Jambutu, Adamawa State Polytechnic, Yola.

Plate 2: Aerial view of Classrooms of School of Environmental Sciences, Jambutu, Adamawa State Polytechnic, Yola. (Source: Google earth 2022).

Description of the Study Area 2

The second study site was class rooms of School of Environmental Sciences Jambutu is a low-rise hollow block building. It is bounded by a library to the east about 13m away, block of design studio to the west about 9.2m away, a block of design studio and technical office to the north about 8m away and an open space to the south. The building is usually occupied by students and staff. The building plan is rectangular shape. The studied building is two blocks with interval of about 9.2m between them and each block has two class rooms and an office in between.

The subjected class rooms for this study were named class room 1, 2, and 3. Where class room 1 has no tree on both sides. Class room 2 has one tree 12.5m away from the external wall. It also has a trunk height of 3.00m with small foliage size on the southern side and classroom 3 has a tree on both sides 3.0m away to the north and 12.5m away to the south with trunk heights of 2.60m and 3.00m respectively and small foliage size as well.

All the three class rooms are on the ground floor level with dimension of about 11.0m by 6.2m and ceiling height of about 3.1m each, the longest sides are oriented in north and south, their windows are also oriented in north and south, as seen in figures 2.

The three class rooms have seven windows each 1.2m by 1.2m, four on the northern side and three on the southern side which swings to the corridor for each class room. All the windows are Louvre type which is ninety five percent operable, with burglary bars 8mm diameter to the outside designed to cross each other.

The walls are 225mm sandscrete blocks finished with cement-sand plaster, all the three class rooms were sealed with hardboard. The floor has sand screed finishing. The roof of the building is gable with height of about 2.6m and a slope which is less than 30^o with long span aluminium roofing sheet (figure 2).

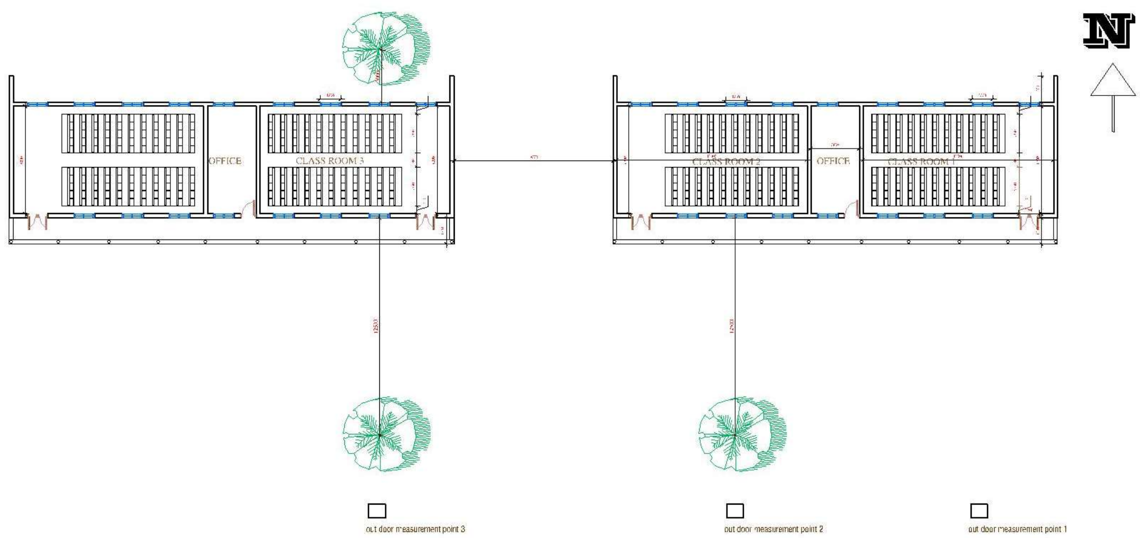

Figure 2: Floor plan of the observed class rooms (Source: Author's field work 2022).

Results

Research Question 1:

To what extent does building thermal performance vary with building form in the study area?

Table 1 shows that offices named form 1, 2 and 3 has rectangle, square and heptagonal form in plan respectively. The building orientations are in northeast-southwest with corridor on southwest for all the three spaces (form1, 2 and 3). Orientations of the windows in the two studied spaces (form1 and 2) are same as orientation of the building except for office named form 3 which has its windows oriented on the southwest-northwest. Size of the doors were 0.9m by 2.1m, while the windows are sliding type which is about fifty percent of the opening size for all the three studied spaces as shown in the table below.

There was 2 number of 1.8m by 1.2m size of windows in all the three studied spaces (form1, 2 and 3), the position of the windows for form 1 and 2 was on the north east and south west and none on the adjacent, while that of form 3 are on the south west and north west sides all at work plane. Wind direction in all the three studied spaces (form1, 2 and 3) was south westerly monsoon wind.

The mean outdoor wind speeds are 0.48m/s at (0.35 S.D), 0.48m/s at (0.35 S.D), 0.48m/s at (0.35 S.D) for form 1, 2 and 3 respectively. The mean indoor wind speeds are 0.28m/s at (0.19

S.D), 0.08m/s at (0.05 S.D), 0.07m/s at (0.05 S.D) for three studied spaces respectively. In addition, the ventilation coefficients are 0.79m/s at (0.65 S.D), 0.26m/s at (0.28 S.D), 0.21m/s at (0.17 S.D) also for the three studied spaces respectively.

While the mean outdoor temperatures are 38.35°c at (0.60 S.D), 38.35°c at (0.60 S.D) and 38.35°c at (0.60 S.D) for form 1, 2 and 3 respectively. Also the mean indoor temperatures are found to be 31.71°C at (0.31S.D), 32.13°C at (0.25 S.D) and 32.83°C at (0.69 S.D) for form 1, 2 and 3 respectively. The temperature differences are 6.64°C at (0.60 S.D), 6.23°C at (0.66 S.D) and 5.53°C at (0.92 S.D) for the three studied spaces (form 1, 2 and 3) respectively.

The percentages for outdoor relative humidity are 61.00, 61.00 and 61.00 for the three studied spaces respectively. Finally, the percentages for indoor relative humidity are 64.70, 63.30 and 63.20 for form 1, 2 and 3 respectively as shown in table 1.

Table 1: Effect of building form on thermal performance of building indoor spaces in the studied spaces.

S/N	Measured attributes/variables	Form 1	Form 2	Form 3
1	Building form	Rectangle	Square	Heptagon
2	Orientation of building	NE-SW with corridor on SW.		
3	Orientation of the Window.	NE-SW (one on NE and another on SW)		SW-NW
4	Size of door	0.9m by 2.1m	0.9m by 2.1m	0.9m by 2.1m
5	Window type	All are sliding type, which is about fifty percent of the opening size operable.		
6	Size of the Window	2no. of 1.8m by 1.2m	2no. of 1.8m by 1.2m	2no. of 1.8m by 1.2m
7	Position of the Window	Windows are on the NE and SW sides, none on the adjacent, located at work-plane.		Windows are on the SW and NW sides
8	Wind direction	South Westerly monsoon wind		
9	Mean outdoor wind speed(m/s) and S.D	0.48 (0.35)	0.48 (0.35)	0.48 (0.35)
10	Mean indoor wind speed(m/s) and S.D	0.28 (0.19)	0.08 (0.05)	0.07 (0.05)
11	Ventilation coefficient and S.D	0.79 (0.65)	0.26 (0.28)	0.21 (0.17)
12	Mean outdoor temperature (°C) and S.D	38.35 (0.60)	38.35 (0.60)	38.35 (0.60)

13	Mean indoor temperature (°C) and S.D	31.71 (0.31)	32.13 (0.25)	32.83 (0.69)
14	Temperature difference (°C) and S.D	6.64 (0.60)	6.23 (0.66)	5.53 (0.92)
15	Outdoor relative humidity (%)	61.00	61.00	61.00
16	Indoor relative humidity (%)	64.70	63.30	63.20

N= North, S= South, E= East, W= West, NE= North East, NW= North West, SE= South East, SW= South West, No. /no. = Number, S.D= Standard Deviation, (Source**:** Author's field work 2022).

Research Question 2:

To what extent does building thermal performance vary with building orientation in the study area?

Table 2 shows that the offices named orientation 1 and 2 has rectangular form in plan. The orientation of the building is in southeast- northwest with corridor on northwest for the office named orientation 1 and slight north-northwest with corridor on south east for office named orientation 2. Orientations of the windows in the two studied spaces (orientation 1 and 2) are slightly north-northwest and northwest-southeast respectively. Size of the doors were 0.9m by 2.1m while the windows are sliding type which is about fifty percent of the opening size for all the two studied spaces as shown in the table below.

There were 2 numbers of 1.8m by 1.2m size of windows in all the two studied spaces (orientation 1 and 2), the position of the windows are same as the orientation of the window. Wind direction in all the two studied spaces (orientation 1, and 2) was south westerly monsoon wind.

The mean outdoor wind speeds are 0.47m/s at (0.39 S.D), 0.47m/s at (0.39 S.D) for orientation 1, and 2 respectively. The mean indoor wind speeds are 0.09m/s at (0.06 S.D), 0.07m/s at (0.05 S.D) for the two studied spaces respectively. In addition, the ventilation coefficients are 0.26m/s at (0.14 S.D), 0.22m/s at (0.21 S.D) also for the two studied spaces (orientation 1 and 2) respectively.

While the mean outdoor temperatures are 38.13°C at (0.65 S.D), 38.13°C at (0.65 S.D) for offices named orientation 1 and 2 respectively. Also the mean indoor temperatures are found to be 30.17°C at (0.35S.D), 30.83°C at (0.0.19 S.D) for the studied spaces (orientation 1 and 2) respectively. The temperature differences are 7.96°c at (0.58 S.D), 7.30°c at (0.69 S.D) for the two studied spaces respectively.

The percentages for outdoor relative humidity are 59.40 and 59.40 for the two studied spaces (orientation 1and 2) respectively. Finally, the percentages for indoor relative humidity are 66.10 and 65.30 for the two studied spaces respectively as shown in table 2.

Table 2: Effect of orientation on thermal performance of building indoor spaces in the studied spaces.

S/N	Measured attributes/variables	Orientation 1	Orientation 2
1	Building form	Rectangular Shape in Plan	
2	Orientation of building	SE-NW with corridor on NW.	Slight N-NW with corridor on SE.
3	Orientation of the Window.	Slightly N-NW	NW-SE
4	Size of door	0.9m by 2.1m	0.9m by 2.1m
5	Window type	All are sliding type, which is about fifty percent of the opening size operable.	
6	Size of the Window	2no. of 1.8m by 1.2m	2no. of 1.8m by 1.2m
7	Position of the Window	One on the slight N and the other on NW side.	On the NW-SE side.
8	Wind direction	South Westerly monsoon wind	
9	Mean outdoor wind speed(m/s) and S.D	0.47 (0.39)	0.47 (0.39)
10	Mean indoor wind speed(m/s) and S.D	0.09 (0.06)	0.07 (0.05)
11	Ventilation coefficient and S.D	0.26 (0.14)	0.22 (0.21)
12	Mean outdoor temperature (^oC) and S.D	38.13 (0.65)	38.13 (0.65)
13	Mean indoor temperature (^oC) and S.D	30.17 (0.35)	30.83 (0.19)
14	Temperature difference (^oC) and S.D	7.96 (0.58)	7.30 (0.69)
15	Outdoor relative humidity (%)	59.40	59.40
16	Indoor relative humidity (%)	66.10	65.30

N= North, S= South, E= East, W= West, NE= North East, NW= North West, SE= South East, SW= South West, S.D= Standard Deviation, (Source: Author's field work 2022)

Research Question 3:

To what extent does thermal performance vary with building opening size in the study area?

Table 3 shows that the two offices named opening size 1 and 2 has rectangular form in plan. The orientations of the building are in east-west with corridor on the west side for the offices named opening size 1 and 2. Size of the doors were 0.9m by 2.1m for all the two studied spaces (opening size 1 and 2), while the windows are sliding type which is about fifty percent of the opening size for all the two studied spaces as shown in the table below.

The size of windows for the two studied spaces varies thus, opening size 1 has 1.2m by 1.2m and 0.9m by 1.2m while the office named opening size 2 has 2 number of 1.8m by 1.2m. The windows are positioned on the shorter side of the wall and none on the adjacent side they were all located at work plane for the studied spaces (opening size 1 and 2). Orientation of the windows was same as the orientation of the building which is on the east-west direction for both the two studied spaces. Wind direction in all the two studied spaces (opening size 1, and 2) was south westerly monsoon wind.

The mean outdoor wind speeds are 0.35m/s at (0.30 S.D), 0.35m/s at (0.30 S.D) for opening size 1 and 2 respectively. The mean indoor wind speeds are 0.07m/s at (0.04 S.D), 0.09m/s at (0.04 S.D) for the two studied spaces respectively. In addition, the ventilation coefficients are 0.36m/s at (0.45 S.D), 0.44m/s at (0.35 S.D) also for the two studied spaces (opening size 1 and 2) respectively.

While the mean outdoor temperatures are 39.12^{o}C at (0.52 S.D), 39.12^{o}C at (0.52 S.D) for offices named opening size 1 and 2 respectively. Also the mean indoor temperatures are found to be 33.78^{o}C at (0.44S.D), 32.01^{o}C at (0.08 S.D) for the studied spaces (opening size 1 and 2) respectively. The temperature differences are 5.34^{o}c at (0.42 S.D), 7.11^{o}c at (0.57 S.D) for the two studied spaces respectively.

The percentages for outdoor relative humidity are 62.90 and 62.90 for the two studied spaces (opening size 1 and 2) respectively. Finally, the percentages for indoor relative humidity are 63.20 and 65.80 for the two studied spaces respectively as shown in table 3.

Table 3: Effect of opening (sizes and location) on thermal performance of building indoor spaces in the studied spaces.

S/N	Measured attributes/variables	Opening. Size 1	Opening. Size 2
1	Building form	Rectangular Shape in Plan	
2	Orientation of building	E-W with corridor on the W. side.	
3	Size of door	0.9m by 2.1m	0.9m by 2.1m
4	Window type	All are sliding type, which is about fifty percent of the opening size operable.	
5	Size of the Window	1.2m by 1.2m and 0.9m by 1.2m	2no. of 1.8m by 1.2m
6	Position of the Window	All are on the shorter sides of the wall, none on the adjacent, located at work-plane.	
7	Orientation of the Window	E-W(one on the E and another on the W)	
8	Wind direction	South Westerly monsoon wind	
9	Mean outdoor wind speed(m/s) and S.D	0.35 (0.30)	0.35 (0.30)
10	Mean indoor wind speed(m/s) and S.D	0.07 (0.04)	0.09 (0.04)
11	Ventilation coefficient and S.D	0.36 (0.45)	0.44 (0.35)
12	Mean outdoor temperature (^oC) and S.D	39.12 (0.52)	39.12 (0.52)
13	Mean indoor temperature (^oC) and S.D	33.78 (0.44)	32.01 (0.08)
14	Temperature difference (^oC) and S.D	5.34 (0.42)	7.11 (0.57)
15	Outdoor relative humidity (%)	62.90	62.90
16	Indoor relative humidity (%)	63.20	65.80

N= North, S= South, E= East, W= West, NE= North East, NW= North West, SE= South East, SW= South West, S.D= Standard Deviation, (Source: Author's field work 2022).

Research Question 4:

To what extent is the effect of Vegetation on thermal performance of building indoor spaces in the study area?

Table 4 shows that the number of trees as none for classrooms 1while class rooms 2 and 3 has 1 and 2 trees respectively. Also, tree to building distance as none for classrooms 1while class rooms 2 and 3 has 12.50m with 12.50m and 3.0m respectively. While their locations are none for class rooms 1 while class rooms 2 and 3 has north, with north and south respectively. Furthermore, the trunk heights are none for class rooms 1 while class rooms 2 and 3 have 3.00m, with 2.60m and 3.00m for the two class rooms respectively. Wind direction in all the studied spaces was south westerly monsoon wind.

The mean outdoor wind speeds are 0.41m/s at (0.33 S.D), 0.51m/s at (0.35 S.D) and 0.41m/s at (0.20 S.D) for classrooms 1, 2, 3 respectively. The mean indoor wind speeds are 0.13m/s at (0.6 S.D), 0.13m/s at (0.10 S.D) and 0.19m/s at (0.18 S.D) for class rooms 1, 2 and 3 respectively. In addition, the ventilation coefficients are 0.44 at (0.38 S.D), 0.37 at (0.38 S.D) and 0.55 at (0.51 S.D) for the class rooms 1, 2, 3 respectively.

While the mean outdoor temperatures are 37.45^{o}C at (0.74 S.D), 38.35^{o}C at (1.00 S.D) and 38.03^{o}C (1.46 S.D) for class rooms 1, 2, 3 respectively. Also the mean indoor temperatures are found to be 32.83^{o}C at (0.76 S.D), 32.68^{o}C at (0.62 S.D) and 32.13^{o}C at (1.00 S.D) for class rooms 1, 2, 3 respectively. The temperature differences are (0.86 S.D), 5.66^{o}c at (1.16 S.D), 5.90^{o}c at (0.95 S.D) for class rooms 1, 2, 3 respectively.

The percentages for outdoor relative humidity are 29.40, 30.50 and 32.90 for class rooms 1, 2 and 3 respectively. Finally, the percentages for indoor relative humidity are 32.80, 33.40, and 35.60 for class rooms 1, 2, 3 respectively (see table 4).

Table 4: Effect of Vegetation on thermal performance of building indoor spaces.

S/N	Measured attributes/variables	Class room 1	Class room 2	Class room 3
1	Number of trees	None	1	2
2	Tree to building distance (m)	None	12.50	12.50 and 3.00
3	Location of tree	None	North	North and south
4	Trunk height (m)	None	3.00	2.60 and 3.00
5	Wind direction	South Westerly monsoon wind		
6	Mean outdoor wind speed(m/s) and S.D	0.41 (0.33)	0.51 (0.35)	0.41 (0.20)
7	Mean indoor wind speed(m/s) and S.D	0.13 (0.06)	0.13 (0.10)	0.19 (0.18)
8	Ventilation coefficient and S.D	0.44 (0.38)	0.37 (0.38)	0.55 (0.51)
9	Mean outdoor temperature (^{o}C) and S.D	37.45 (0.74)	38.35 (1.00)	38.03 (1.46)
10	Mean indoor temperature (^{o}C) and S.D	32.83 (0.76)	32.68 (0.62)	32.13 (1.00)

11	Temperature difference (°C) and S.D	4.62 (0.86)	5.66 (1.16)	5.90 (0.95)
12	Outdoor relative humidity (%)	29.40	30.50	32.90
13	Indoor relative humidity (%)	32.80	33.40	35.60

S.D = Standard Deviation (Source: Author's field work 2022)

Discussions

The result revealed that the studied spaces have three (3) different building forms in plan which includes; rectangle, square and pentagon. However, the spaces with rectangular form (form 1) have more potentials for better thermal comfort despite having same other factors (orientation and opening size). Consequently the rectangular form appears to have higher mean indoor wind speed (0.28 m/s at 0.19 S.D), a lower mean indoor temperature (31.71°C at 0.31 S.D) and a higher mean temperature difference (6.64°C at 0.60 S.D) as a result the rectangular form has a significant difference among the three studied forms. Hence such form should be encouraged because they present more potential to enjoy air movement than square form especially in classroom design. This is corroborated by Idowu and Okonkwo (2012) conclusion that rectangular form appears to have more potential to gain air movement than square form and should have a length-to-width ratio of 1.7:1.

The findings also state that orientation of building especially to wind direction has great effect on thermal performance of building indoor spaces, it revealed that there is a significant difference among the two studied spaces despite having same other design factors (building form, opening size). The studied space with longer side oriented slightly north-south (orient. 1) has the highest mean indoor wind speed (0.09m/s at 0.06 S.D), lower mean indoor temperature (30.17°C at 0.35 S.D) and higher mean temperature difference (7.96°C at 0.58 S.D) among the two spaces compared. Hence such orientation greatly minimizes solar radiation. It conforms with Komolafe (1988) (cited in Idowu and Okonkwo, 2012) position that longer side of building should be oriented along north- south to minimize solar radiation.

The result in summary also revealed that opening size and their location also has great effect on thermal performance of building indoor spaces. Thus, among the two studied spaces, one of the space (opening size 2) which has a higher mean indoor wind speed (0.09 m/s at 0.04 S.D), lower mean indoor temperature (32.01°C at 0.08 S.D) and higher temperature difference (7.11°C at 0.57 S.D) is relatively better than the other spaces compared (opening size 1) in thermal comfort despite having same other design factors (building form, orientation). This was achieved as a result of the space (opening size 2) having bigger opening sizes than the other (opening size 1). Komolafe (1988) (cited in Idowu and Okonkwo, 2012) revealed that opening should be on the north and south wall at body height on wind ward side and size of openings should be between 20% and 35% of wall to optimize indoor ventilation. In the same vein Idowu and Okonkwo (2012) revealed that openings should be of equal size on opposite side to optimize the effect of outlet-inlet ratio on ventilation and that size of openings should be 30% of the floor area.

The result in summary revealed that classroom 3 has the highest mean indoor wind speed of 0.19m/s at (0.18 S.D) which shows a significant difference of 0.06m/s among other classrooms with and without vegetation, mean ventilation coefficient was 0.55 at (0.51 S.D). A lower mean indoor temperature of 32.13°C at (1.00 S.D) and a high mean temperature difference of 5.90°C at (0.95 S.D) were also obtained. The classroom also has an indoor relative humidity of 35.60 %. Thus, classroom 3 is relative better in thermal comfort as compared to other classrooms and it is as a result of the classroom having two number of trees located at northern and southern orientation with tree-to-building distance of 3.00m and 12.50m respectively, while the other classrooms has less and even no number of tree placement. Kamal (2012) posit that trees can be used with advantage to shade roof, wall and windows, shading and evapotranspiration from trees can reduce surrounding temperatures as much as 5°C, of which this research agreed with. Misni (2012) also revealed that trees should be within 3-5m away from the building so as to provide shade for the roof and wall, of which one of the trees located on the northern side of classroom 3 is within the range as a result greatly improve the classroom's thermal performance, therefore this study shows relationship with their findings.

Lastly, classroom 3 is relatively better in thermal performance which is attributed also to the fact that the trunk height of trees around it (which are 2.6m and 3.0m north and south respectively) provide shade to the roof and wall surface there by channelling wind and allowing it to flow through, to the building surface. As a result, the classroom in particular has the maximum mean indoor wind speed of 0.19m/s with 0.06m/s significant difference if compared to the mean indoor wind speeds of the other classrooms and a highest mean ventilation coefficient of 0.55, thereby making the indoor temperature to be the lowest (at 32.13°C) among the three class rooms, with a highest mean temperature difference of 5.90°C, complimenting the findings of Kamal (2012). Misni (2012) clearly portrayed that the height of shade tree should be proportionate to the height of the building and the minimum trunk height to channel wind and allow it to flow through the garden to the building surface was 1.5m, of which the tree trunk heights are not below the minimum, this makes this study to have relationship with their study as well.

Conclusion

In conclusion, this study which seek to ascertain the extent to which design factors affect thermal performance of building indoor spaces aimed at enhancing thermal comfort in institutional buildings revealed among other things that building form, orientation, type, size and position of openings and inadequate strategic placement of vegetation has negatively affected the indoor thermal performance of the studied spaces. Thus, rectangular building forms present more potential to enjoy air movement than square form and even other forms, this is because they produce varying magnitude of low-pressure region. proper orientation, opening sizes and their location also enhance the thermal performance of the indoor spaces. Conclusively design factors have been seen to have great effect on the studied spaces, thereby making some of the spaces to be poor in thermal performance of building indoor spaces.

Recommendations

It could be recommended that designers should first get the climatic /environmental data and a good knowledge of the site before commencing any design.

Recommendations for future designers in hot dry climate region include;

- Rectangular building form should be encouraged because they present more potential to enjoy air movement than square form especially in class room design and length-to-width ratio should be at least 1.7:1.
- Orientation of building should be north-south to minimize solar radiation.
- Openings should be on the north and south wall at body height on wind-ward side and of equal size on opposite wall to optimize the effect of outlet-inlet ratio on ventilation.
- Ventilation induced techniques should be incorporated into design to generate ventilation by stack-effect and wind.
- Size of openings should be between 20% and 35% of wall area and minimum of 30% of the floor area.
- Combination of evergreen tropical native trees, shrubs and ground cover provide a balanced and harmonious building design which provide extensive shade to gardens and building and are therefore the best means of reducing the amount of heating in the building envelope and ambient air.
- The height of shade trees should be proportionate to the height of the building. They should provide shade to the roof, walls and garden surfaces. Trees should also be within 3-5m away from the building to provide shade for the roof. The minimum trunk height to channel wind and allow it to flow through the garden to the building surfaces was 1.5m.
- Orientation of building and internal configuration is important. The best design is a north-south orientation for openings to receive only indirect solar radiation. Openings on the east and west sides should be minimized to reduce the effect of direct solar radiation. Use of shade should be focused on the east and west of the building. However, plant-made shade reduced solar radiation regardless of position.
- All plant types should be in a fertile and lush condition. Plants with a medium amount of small to medium sized foliage (leave) produce maximum shade and evapotranspiration cooling and channelled the preventing wind properly. All plants should be planted in groups to survive well in bad weather conditions and make maintenance easier.
- The positioning and arrangement of vegetation around building should be compatible with prevailing wind directions to promote and channel wind to the appropriate places through and around the building.
- The combination of shading by vegetation and compatible moderate wind flow can produce fresh, cool and comfortable environment.
- Multi-storey buildings should be encouraged to reduce overcrowding of buildings at ground level and to achieve more wind at higher levels.
- Walls, floors and roof should be heavy so as to encourage time lag.

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REFERENCES

Akande, O. K. & Adebamowo, M. A. (2010). Indoor Thermal Comfort for Residential Buildings in Hot-dry Climate of Nigeria. *Proceedings of Conference: Adapting to Change: New Thinking on Comfort Cumberland Lodge, Windsor, UK, 9-11* April 2010. London: Network for Comfort and Energy Use in Buildings, Retrieved from http://nceub.org.uk 11/07/2015.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (2004). Standard 55-2004 & Standard 55-1992. *Thermal Environmental Conditions for Human Occupancy*. *ASHRAE*, Atlanta.

Babagana, A. & Dungus, B. (2015). Towards the Achievement of Environmental-Friendly Development of Residents in Maiduguri Neighbourhoods. *International Journal of Technical and Educational Research.* Vol. 2 No.2 pp1-12

Baker, N. & Standeven, M. (1994). Comfort Criteria for Passively Cooled Buildings. *A PASCOOL task". Renewable Energy, V.5, pp.977-984*.

Batagarawa, A. (2013). *Assessing the Thermal Performance of Phase Change Materials in Composite Hot Humid/hot Dry Climates*: An Examination of Office Buildings in Abuja Nigeria. Ph.D thesis. New Castle University.

Dewidar, K. M., Mahmoud, A. H. & Moussa, R. R. (2013). *Enhancing the Human Thermal Comfort inside Educational Buildings in Hot-arid Regions.* Arab Academy for Science, Technology & Maritime Transport. Alexandria Egypt.
Emissions of Buildings in Southeast Asia by Help of Thermal Simulation.

Fanger, P. O. (1970). *Thermal Comfort-analysis and Applications in Environmental Engineering*. Danish Technical Press. Copenhagen.

Fanger, P. O. (2001). Human Requirements in Future Air-conditioned Environments. *Int J Refrig 24(2), 148-153*

Frontczak, M. & Wargocki, P. (2011) Literature Survey on how different Factors Influence Human Comfort in Indoor Environments. *Build Environ* 46:922–937

Haase, M. & Amato, A. (2006). Passive and Low Energy Architecture. *The 23rd Conference On Passive and Low Energy Architecture*. Geneva. Switzerland.

Hiroaka, H. (2002). Simulating the Microclimate produced by a Single Tree. Ecole d' Architecture de Nantes (CERMA). *Proceedings of International Workshop on Architecture and Urban Ambient Environment, Nantes, 6-8*.

Hoof, J. V., Mazej, M. & Hensen, J. L. M. (2010). Thermal Comfort Research and Practice. *Frontiersin Bioscience, 15(2), 765-788*.

Idowu, O. M. & Okonkwo, M. M. (2012). Natural Ventilation Design. *Journal of the Association of Architectural Educators in Nigeria (AARCHES) Monographic series*. Published by AARCHES. ISSN: 1595-9805.

ISO 7730 (2005). Determination of the PMV and PPD indices and specification of the Conditions for thermal comfort. *Moderate thermal environments 2nd ed*. Gevena, Switzerland: International Organisation for Standardisation.

Kamal, M. A. (2012). An Overview of Passive Cooling Techniques in Buildings: *Design Concepts and Architectural Interventions Acta Technica Napocensis: Civil Engineering & Architecture Vol. 55, No. 1.* http://constructii.utcluj.ro/ActaCivil Eng.

Khalifa, A. J. N. & Abbas, E. F. (2009). A Comparative Performance Study of Some Thermal Storage Materials used for Solar Space Heating. *Energy and Buildings, 41(4), pp. 407-415.*

Komolafe, L. K. & Agarwal, K. N. (1987). Climate Zones and Thermal Standards for Low-cost Houses in Nigeria. *Proceedings of International Conference on Low-Cost Housing for Developing Countries.* Rookee India. Pp505-516

Misni, A. (2012). *Effect of Surrounding Vegetation, Building Construction and Thermal Performance of Housing in a Tropical Environment*. Doctor of Philosophy (PHD) thesis. Victoria University of wellington. New Zealand.

Nigeria Building and road Research Institutes (NBRRI, 1983).

Obi, N. I. (2014). The influence of Vegetation on Microclimate in Hot-humid Tropical Environment: A Case of Enugu Urban. *International Journal of Energy and Environmental Research Vol.2, No.2,* pp.28-38. European Centre for Research Training and Development UK (www.eajournals.org).

Ochoa, C. E. & Capeluto, I.G. (2008). Strategic Decision-making for Intelligent Buildings: Comparative Impact of Passive Design Strategies and Active Features in a Hot Climate. *Building and Environment, 43(11),* pp. 1829-1839.

Ogunsote, O. O. (1991). *Introduction to Building Climatology: A Basic Course for Architecture Students. Zaria*: Ahmadu Bello university Press.

Pidwirny, M. (2008). Introduction to the Atmosphere, Climate Classification and Climatic Regions of the World. *Physical Geography, Fundamentals ebook* Retrieved 28, September 2016, from http://www. physicalgeography.net/fundamentals/7v.html

Rilling, D. & Al-Shalabi, A. (2008). On Optimized Energy Consumption and Reduced CO_2

Saxena, M. (2001). Microclimate Modification Calculating the Effects of Trees on Air Temperature, website. www.sbse.org/awards/docs.

Simons, B., Koranteng, C., Adinyira, E. & Ayarkwa, J. (2014). An Assessment of Thermal Comfort in Multi Storey Office Buildings in Ghana. *Journal of Building Construction and Planning Research, **2**, 30-38*. http://dx.doi.org/10.4236/jbcpr.2014.21003.

Szokolay, S. V. (2004). *Introduction to Architectural Science*: *The Basis of Sustainable Design.* Oxford Architectural Press.

Uji, Z. A. (2009). *Tools and Instruments of Research in Design and allied disciplines.* Jos: Ichejum press.

Vinet, J. (2002). Modelling the Impact of Urban Vegetation to Analyse Urban Microclimate and Outdoor Thermal Comfort. *Proceedings International urban Ambient Environment Workshop on Architectural Nantes, 6-8.*

Zahoor, A. (1997). *Effects of Trees in Ameliorating Air Temperature in Urban Setting in Pakistan*. Dissertation Unpublished, University of Idaho.

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