Thermal comfort problems in teaching-learning lecture theatres in the tropics: need to establish design criteria

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Abstract: - The study was to establish thermal comfort problems and the need to establish design criteria for thermal comfort in teaching-lecture theatres in the tropics. The formulation of design criteria depends on various factors such as seating capacity, coverage area of door and window openings on the external walls required for ventilation, the combination of the temperature, relative humidity and wind velocity required for thermal comfort, materials for the construction of the building walls and roofs. The study selected three lecture theatres used for teaching large classes for students in various disciplines offering common courses at the Niger Delta University, Wilberforce Island, Nigeria located in the tropical humid climate The results of the analysis with the various indicators: hall size, humid, arid and cold indicators as well as parameters for thermal performance revealed that the lecture theatres do not meet the thermal performance requirements. Prominent among them were the seating capacity of the space, high temperature and relative humidity, low wind velocity recorded, the orientation, spacing for breeze penetration, size and position of openings. The findings were discussed and recommendations proffered were that the construction of lecture theatres should conform to design criteria to assure thermal comfort.

Key-words:-Thermal comfort, Teaching-learning, Ventilation, Humid Climate, Comfort limit

1 Introduction

People perform various activities within building enclosures. One can only perform these activities better when the environmental conditions are favourable. Inside a building, people are affected either positively or negatively because of the physiological reactions and psychological responses to the thermal environment [1]. In the same vein, the activity of lecture theatres is primarily to accommodate the teacher and the students for the purpose of the teaching and learning. They are also room spaces that accommodate a large number of students especially when students from various disciplines offer courses common to them. Therefore, such room spaces are also expected to provide a relative amount of thermal comfort for the students to benefit from the lectures being delivered.

There are various definitions of thermal comfort. ASHRAE defined thermal comfort as the state of mind, which expresses satisfaction with the thermal environment [2]. Thermal comfort can also be described as a condition under which a person can maintain a normal balance between production and loss of heat at normal body temperature without sweating [3]. It is a state a person will judge the environment to be neither too warm nor too cold or thermally neutral, and in this condition, the strain on the body's thermoregulatory mechanism is minimal. That is, thermal comfort as a state a person will judge the environment to be neither too warn nor too cold; a neutral point defined by the absence of any feeling of discomfort [4]. Thermal comfort is also defined as the absence of irritations and discomfort due to heat or cold, or in a positive sense, as a state involving pleasantness [5]. Further, Dagostino defined thermal comfort as being able to carry on any desired activity without being either chilly or too hot [6]. In addition, thermal comfort is a state in which a person will judge the environment to be neither too warm nor too cold; a neutral point defined by the absence of any feeling of discomfort [7]. However, there are no absolute standards of thermal comfort as people have adjusted to live in various ranges of climates from the tropics to cold regions of the world. Various factors can bring about thermal comfort problems in lecture theatres for teaching-learning. Some of them considered in this study are: overcrowding, inadequate door and window openings on the external walls, climatic factors and non-use of design criteria for thermal comfort when procuring the lecture theatres in schools. Crowding occurs in a lecture theatre when space for teaching-learning is accommodating far more students than the required capacity. Crowding refers to the way we feel when there are too many people or not having enough space [8]. In a crowded room space without adequate ventilation, people give off carbon-monoxide, water vapour, dead skin cells, and unpleasant odours and this brings about thermal discomfort [9]. The observable thermal discomfort stresses in a crowded space are restlessness, inattentiveness and sometimes respiratory irritation such as coughing and sneezing [9]. In this regard, overcrowding can cause arousal conditions that can stimulate skin conductance leading to palmer sweat [8].

Another source of thermal comfort problems is inadequate and inappropriate location of external openings. Window and door openings in the external walls of building provide ventilation into the room space. However, this can only occur when the openings are adequate and are appropriately located along the external walls. Ventilation is a determinant of thermal comfort, and more generally, of satisfaction with the indoor environment. The main purpose of ventilation is to provide fresh air and to remove accumulated noxious gases and contaminants. Ventilation helps to remove heat generated in a working area by convection and cools the body [9]. The benefits of windows are enormous – it allows the passage of air through the envelope as ventilation and exhaust [10]. Any room space that does not have adequate provision for ventilation becomes hot and uncomfortable for the occupants especially when there is high external and internal temperature because of the cumulative effect of the heat that is generated and sweat (vapour) liberated by its occupants. The principal operating strategy for buildings in the tropics is the use of natural ventilation to enhance evaporative and convective cooling of occupants. Therefore, a building should impose as little resistance as possible to airflow through it [10].

Climate affects the human environment in two ways. It either provides thermal comfort or thermal discomfort on the individuals occupying the human environment. In an indoor space, thermal environment is constituted by the interaction of different factors of the climatic conditions, and the interaction of these conditions within the building spaces provide an indication of the level of indoor thermal comfort [11]. The various climate factors that are likely to affect an individual's feeling of thermal comfort in any room space are high temperature and humidity, and low wind velocity [4]. They cause thermal or cold sensation in the individual's body when the organ of touch is stimulated as the body is exposed to the medium that causes heat or cold. Temperature is the measurement in degrees of how hot or cold a place, body, thing or the atmosphere is

[12]. It can also be described as the degree of hotness, or sensible heat or coldness in a body or the atmosphere [13]. High temperature can generate heat and activate the sweat glands that produce moisture in the body of individuals and any further increase in temperature above individual's tolerable limit can increase sweat production in the body of an individual. The feeling of increase in sweat production creates body heat and a 'wettedness' sensation at high humidity [4]. Relative humidity is the moisture or damp or moderate degree of water vapour content in the air at a given temperature [9, 13]. High relative humidity affects the thermal comfort of individuals in a room space especially when vapour liberated through perspiring occupants carrying out various human activities is not evaporated as frequently as possible and this creates a sense of 'wettedness' in the individuals [4, 7]. Discomfort is experienced because of the inability of the occupants to dissipate metabolic moisture [14]. At high humidity, the undesirable side effects are dampness or 'wettedness' sensation and sometimes difficulty in breathing [4, 13]. Therefore, extreme conditions of humidity should be avoided since it will lead to other undesirable side effects. When the air is humid, evaporation of perspiration from the body is limited; a feeling of oppression so common in the humid tropic is created [15].

Wind on the other hand is air in motion, a natural air current or breeze [12]. Wind causes feeling of freshness and comfort of individuals in any given room space; but low wind movement causes inadequate ventilation. Air movement plays an important role in increasing the rate of evaporation, especially at high humidity where evaporative cooling is the only or main means of heat loss from the body [4]. Wind reduces the adverse effects of thermal discomfort resulting from high temperature and humidity. If the air is calm, the air layer close to the body becomes more or less saturated and little or no further evaporation takes place. But where there is considerable air flow; the constant replenishment of air around the body ensures that the evaporation process is maintained [15]. The availability of fresh air in a room space serves three purposes namely: to supply adequate level of oxygen for breathing; to dilute odours arising from bodies or industrial process; and to dilute air vitiated with bacteria [4]; and where the three purposes of air are not met, people will feel thermal discomfort in any room space.

In addition, thermal comfort is an important aspect of the building design process in a teaching-learning environment since students spend a long period of time in those indoor spaces. This is because, the amount of thermal comfort one want to provide in a room space is dependent on climatic conditions, the environment and the design of the building which has 75% role to play in it. But, most buildings today have thermal discomfort issues due to lack of design consideration [16]. Therefore, non-use of design criteria as guide for the design and construction is a major cause of thermal comfort problems in lecture theatres. Formulating design criteria and using such criteria for the design of buildings for thermal comfort will determine the amount of solar penetration into the building and radiant gain [9]. This involves the amount of insulation which influences the heat exchange between the building and the environment as well as the construction materials which influences a building's thermal performance.

However, the judgement of whether an individual feels thermally comfortable or not varies from one individual to another just as the effect of climatic indicators on individuals also vary from one geographical region to another. Furthermore, no two individuals in the same teaching-learning space will have the same feeling of thermal comfort even when they are exposed to the same environmental condition. This is because of variations in age, state of health, physical activity, type and amount of clothing, past climatic exposure or degree of acclimatization (4, 15, 17]. Thus, establishing a condition that will satisfy everyone is not likely to be achievable because of human physiological variance. Rather, the internal environment should be able to create conditions that can satisfy the largest number in the group of probable occupants. That is, the building being an environmental envelope should be to modify the natural or external environment to produce a satisfactory internal environment for human activities for majority of the users [18].

Where the thermal comfort of an individual is affected, the health, energy and comfort [19] as well as the physical and mental vigour of the individual is also affected [15]. In this regard, the likely effect of thermal comfort problems in a teaching-learning becomes very important because it is expected to actively stimulate human development socially, intellectually, physically and emotionally [20]. Furthermore, the environment should be able to actively and attractively suit the functions of education it serves which not only accommodates but contributes a very special environment for teaching and learning [21].

1.1. Objectives of the study

The specific objective is to:

1. Establish whether the seating capacity is appropriate for the existing lecture theatre.
2. Ascertain whether the door and window openings on the external walls of the lecture theatre will provide the coverage area required for ventilation.
3. Determine whether the combination of temperature, relative humidity and wind velocity readings in the lecture theatre will provide the required thermal comfort.
4. Establish the parameters for formulating design criteria for thermal comfort in the lecture theatre

1.2. Research questions

1. Is the seating capacity appropriate for the existing lecture theatre?
2. Will the door and window openings on the external walls of the lecture theatre provide required the required coverage area for ventilation?
3. Will the combination of temperature, relative humidity and wind velocity readings in the lecture theatre provide the required thermal comfort?
4. What are the parameters for formulating design criteria for thermal comfort in the lecture theatre?

2. Material and methods

2.1. Study area

The study area is the Niger Delta University, Wilberforce Island, Amassoma, Bayelsa State, Nigeria. It is located in the Tropical Humid Climate Zone and lies between latitude 4.5 North and longitude 6.07 East [22]. It is warm with high relative humidity and rainfall [23]. The climate type is characterized by two seasonal patterns: dry season-November to April; wet season-May to October. However, there is hardly any month that rain will not fall.

2.2. Choice of buildings

The three lecture theatres (LT 1, 2 and 3) were used for the study because it accommodates large classes for students from various disciplines who offer common courses. The buildings have raked seating arrangement with an internal measurement of 22.75 m x 13.50 m. The height is 4.50 m from the front row while at the back row, it is 3.00 m. The volume of the room space decreases from the front row seats until it gets to the back row seats. It has a volume of 1,150 m^3. There are fourteen ceiling fans in each lecture theatre; though they are hardly used because of the epileptic electricity supply situation; and most of them are out use due to lack of maintenance. For the purpose of this study, the fans are not used.

2.3. Data collection

The data collected were drawings of the lecture theatre showing the floor plan (Fig. 1) and cross-section (Fig. 2) as well as door and window openings and seating arrangement with the respective dimensions was provided by the researcher.

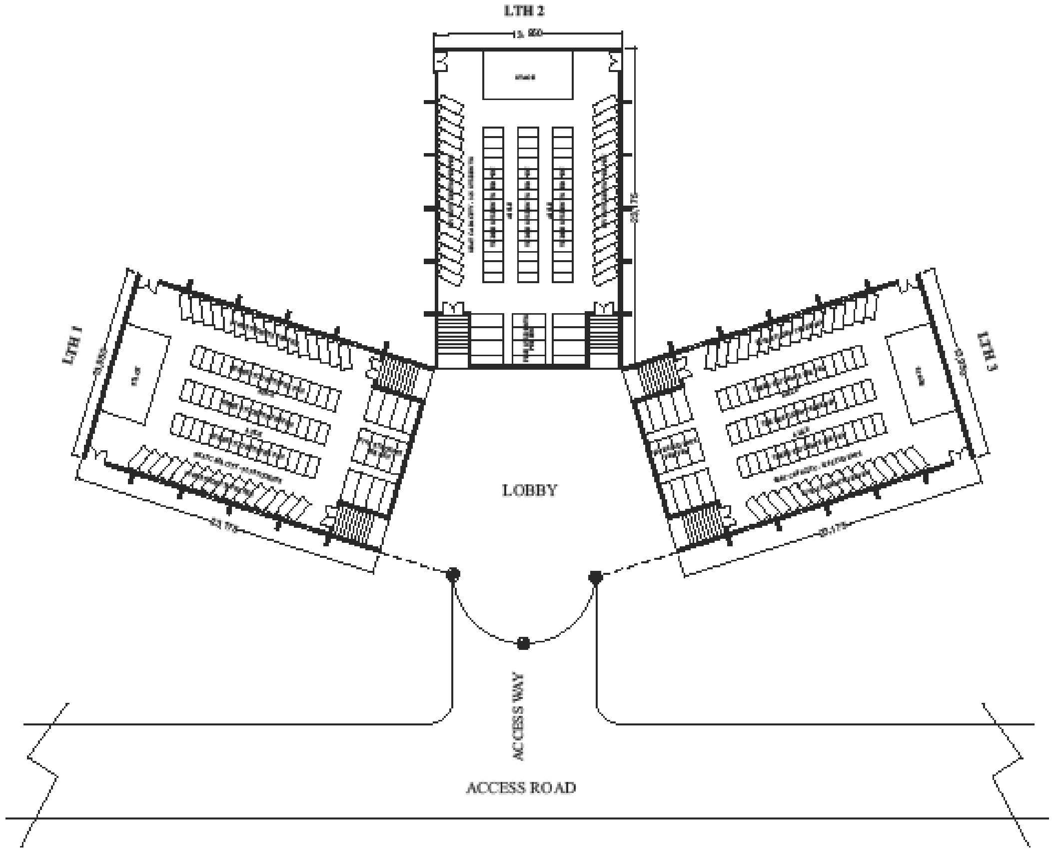

Fig. 1: Floor Plan Of Lecture Theatre

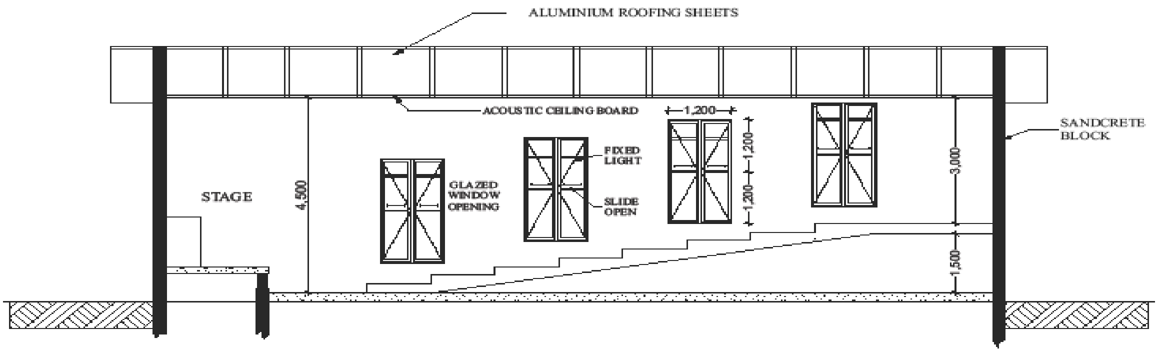

Fig. 2: Cross-Section Of Lecture Theatre

With the drawings, the recommended parameters for seating capacity, floor area per student and the area covered by the door and window openings on the external walls are provided. The lecture theatre was physically measured to establish the following data: floor area, seating capacity, floor area per student, area of the external walls, and area of external door and window openings.

The readings of temperature, humidity and wind velocity in the internal space of the lecture theatre was taken for 5 days. The results of the observed measurements are provided in Table 2. For the temperature, the dry and wet bulb mercury thermometer was used to measure the internal room temperature of the three lectures (LT 1, 2 and 3) between 8.00 am -12.00 noon, 12.00 noon-2.00 pm and 2.00 pm-6.00 pm in the morning, afternoon and evening respectively. For relative humidity measurement, the hygrometer which consisted of dry and wet bulb was used. The dry and wet bulb readings were read off on a humidity table [24] to arrive at the readings. In measuring the wind velocity, the AVM-305 Anemometer manufactured by TES Electrical Electronic Corp. of China with accuracy level of ± 0.3 was used for the measurement. However, the temperature and relative humidity reading were slightly higher in lecture theatre 2 by 1 ^{O}C when compared to that of 1 and 2; while the wind velocity reading was slightly higher in lecture theatres 1 and 3 by 0.04 m/s. Since the differences in various readings were negligible, the outcome of the results of the study will not be affected.

Table 1: Data on physical and climatic indicators measurement of the lecture theatre

Items measured	Measurements
Floor area	290 m^2
Seating capacity	325 seats
Floor area per student	0.89 m^2 per student
Doors on external walls (2 No.)	1.20 m x 2.10 m = approx. 5.0 m^2
Windows on external walls (8 No.)	1.20 m x 2.40 m = approx. 23.0 m^2
Area of external walls	approx. 258 m^2
Coverage area of door and window opening on external walls	28 m^2
% area covered by door and window opening on external walls	Approx. 11 %
Average temperature Dry-bulb Wet-bulb	32 ^{O}C 29 ^{O}C
Average relative humidity	78 %
Average wind velocity	**0.32** m/s

Source: Researcher's field work

4. Results and discussion

The analyzed data and results are presented in Table 2 according to the research questions.

4.1 Research Question 1

Is the seating capacity appropriate for the existing lecture theatres?

The results in Table 2 showed that, the lecture theatres have a seating capacity of 325 students; a floor area of 290 m^2 and floor area/student of 0.89 m^2. With a recommended floor area of 1.10 m^2/student [25, 26], the recommended seating capacity is 295 students. Therefore, the lecture hall space is overcrowded. In a room space where the occupants are active, the heat production is about 140 watts/ person/hour [23] and the amount of vapour liberated into the room space is about 0.2 kg per person per hour [29]. It means that, the space shall produce 45,500 watts of heat per hour and liberate 65 Kg per person per hour of vapour for the 325 seat capacity instead of 41,300 watts and 59 Kg per person per hour for 295 seat capacity respectively as recommended. Therefore, in a crowded room space without adequate ventilation, people will give off carbon-monoxide, water vapour, dead skin cells, and unpleasant odours leading to thermal discomfort [9]. Also, overcrowding can cause arousal conditions that can stimulate skin conductance leading to palmer sweat [8], restlessness, inattentiveness and sometimes respiratory irritation such as coughing and sneezing [8]. This will invariably create thermal comfort problems in the teaching-learning lecture theatre.

Table 2: Data on physical and climatic indicators measurement of the lecture theatre and recommended requirements

Items	Parameters	Existing Data	Remarks	Recommended	Reference
Room space capacity	Seating capacity	325 seats	Overcrowded floor area	295 seats (1.10 m^2 /student)	[25,26]
	Floor area	290 m^2		264 m^2	
	Floor area per student	0.89 m^2		1.10 m^2	
Window and door openings	External wall area	258 m^2	Inadequate eternal wall openings	Nil	
	Window and door coverage	28 m^2		103-206 m^2	[23]
	Percentage windows and door coverage of external walls	11 %		40-80%	
Climatic indicators	Average maximum room temperature	32 ^{O}C	Indicators above comfort limit for 70-100 % humidity	27 ^{O}C	
	Average minimum room temperature	29 ^{O}C		22 ^{O}C	
	Average room relative humidity	78%		Nil	
	Average room wind velocity	**0.32** m/s	May not provide effective and pleasant cooling effect	0.5 to 1.0 m/s	[23,28,29]
Heat input	Heat production 140 watts/person/hour	45,500 watts for 325 seat capacity/hour	Space will be hot and stuffy	41,300 watts for 295 seat capacity/hour	[23]
Vapour input	Vapour liberation: 0.2 Kg per person per hour	65 Kg per person per hour		59 Kg per person per hour	[29]

4.2. Research Question 2

Will the door and window openings on the external walls of the lecture theatre provide the required coverage area for ventilation? The results of the data on the external wall area and the area covered by window and door openings are presented in Table 2. The results indicated that, the lecture theatre has a wall area of 258 m^2 and the area covered by doors and window openings is 28 m^2 representing 11% of the total external wall area. However, with recommended external wall openings of 40-80% [23] representing 103-206 m^2, the openings on the external wall were inadequate. Ventilation determines thermal comfort and provides satisfaction in the indoor environment. Ventilation helps remove heat generated in a working area by convection and cools the body, provide fresh air and remove accumulated noxious gases and contaminants [9]. Thus, without adequate provision for ventilation, a given room space becomes hot and uncomfortable especially when the occupants generate heat and liberate sweat (vapour) the environment is characterized by high external and internal temperature and relative humidity. For a building to provide ventilation, it should not impose as much resistance as possible to airflow through it [10].

4.3 Research Question 3

Will the combination of temperature, relative humidity and wind velocity readings in the lecture theatre provide the required thermal comfort? The results in Table 2 showed that the average maximum and minimum temperature readings was 32 ^{O}C and 29 ^{O}C respectively while the average relative humidity reading was 78% . These values were above the thermal comfort limits of 27-22 ^{O}C for humidity between 70-100 % [23, 27]. In addition, the measured average wind velocity in the space was **0.32** m/s and this value was also below the required wind velocity of 0.5 to 1.0 m/s required for feeling of thermal comfort [23, 27, 28, 29]. The implication is that, the lecture theatre space will not provide the required thermal comfort. This means that the available air in the room space will be utilized quickly without any corresponding replenishment occasioned by the low wind velocity. When an increase in temperature and humidity is experienced in a room space, combined with low wind velocity, the ventilation of the room space can never be assured except where artificial ventilation is used. The effect is stuffy room environment with body odour from the sweat of the occupants leading to a contaminated room space that will likely affect thermal comfort. Thus, the common denomination of these buildings is that large number of people assembled in an enclosed space for appreciable period of time. The primary problem is to furnish sufficient air and to distribute it properly Greenberg [30].

4.4 Research Question 4

What are the parameters for formulating design criteria for thermal comfort in the lecture theatre? In formulating parameters for design criteria for thermal comfort in the lecture theatre, data for thermal comfort limits, indicators for thermal comfort requirements and the analyzed data for climatic indicators in relation to thermal comfort indicators provided in Tables 3,4 and 5 will be used.

4.4.1. Thermal Comfort Limits

The thermal comfort limits for different relative humidity groups and temperatures are presented in Table 3. This data will be used in establishing the thermal comfort requirements.

Table 3: Data on thermal comfort limits

Monthly Average Relative Humidity %	Humidity Group	Reference	Annual Average Temperature					
			Over 20 °C		15 °C -20 °C		Under 15 °C	
			Day	Night	Day	Night	Day	Night
0-30	1	[23]	26-34	17-25	23-32	15-23	21-30	14-21
30-50	2		25-31	17-24	22-30	15-22	21-27	14-20
50-70	3		23-29	17-23	21-28	15-21	.19-26	14-19
70-100	4		22-27	17-21	20-25	15-20	18-24	14-18

4.4.2. Requirements for Thermal Comfort

In Table 4, the thermal comfort requirements for humid, arid and cold indicators using thermal stress and humidity indicators are provided. The data provided in the table will be used in formulating parameters for design criteria for thermal comfort in the lecture theatre.

Table 4: Indicators for thermal comfort requirements

Indicators	Code	Thermal Stress Day and Night	Humidity Group	Rainfall	Requirements for Thermal Comfort	Reference
Humid	H1	Mean monthly maximum temperature, above day comfort limits combined with humidity over 70% or humidity between 30-70%	4		Air movement essential	[23]
	H2	Mean monthly maximum temperatures within day comfort limits with humidities over 70%	2 or 3		Air movement desirable	
	H3			Over 200 mm	Rain protection necessary	
Arid	A1	Diurnal range of temperatures over 10 ^{O}C and humidity less than 70 %	1 or 2 or 3		Thermal storage necessary	
	A2	Mean monthly maximum temperatures above the night comfort limits and humidity below 50%	1 or 2		Outdoor sleeping desirable	
Cold	C1	Mean monthly maximum temperatures below day comfort limits	1 or 2		Solar radiation desirable	
	C2	Mean monthly maximum temperatures below 15 ^{O}C	1 or 2		Protection from cold heating required	

4.4.3. Climatic indicators in relation to thermal comfort indicators

In Table 5, under thermal stress, the Arid indicator (A 1) occurred 3 times: January, February and December when the humidities were less than 70%. However, the thermal stress conditions for Humid indicator (H 1) occurred 9 times, from March to November when the humidities were above 70%. In addition, Humid indicator (H 3) being the monthly rainfall above 200 mm occurred 6 times. The values under Arid indicator (A 1), Humid indicators (H1) and (H 3) will be used to interpret Table 6 to arrive at the design criteria.

Table 5: Analysis of climatic indicators in relation to thermal comfort indicators

Indicators	Reference	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Average
Relative humidity %	[35]	62	65	72	75	80	82	87	86	85	82	76	67	70
Monthly mean maximum temperature ^{O}C		33	35	34	33	31	30	29	28	29	30	31	36	32
Day comfort:	[23]													
Upper limit °C		29	29	27	27	27	27	27	7	27	27	27	29	28
Lower limit °C		23	23	22	22	22	22	22	22	22	22	22	23	22
Monthly mean minimum temperature°C	[35]	19	21	23	24	23	23	22	24	23	23	22	21	22

Night comfort: Upper limit °C Lower limit °C	[23]	23 17	23 17	21 17	21 17	21 17	21 17	21 17	21 17	21 17	21 17	21 17	23 17	25 17
Thermal stress: Day Night		Al Al	Al Al	H1 H1	H1 H1	H1 H1	H1 H1	H1 H1	H1 H1	H1 H1	H1 H1	H1 H1	A1 Al	
Rainfall (mm)	[35]	24	34	108	146	234	260	370	344	380	214	70	10	
Arid indicators: Al		x	x										x	3
A2														Nil
Cold indicators: C1 C2														Nil Nil
Humid indicators: H1				x	x	x	x	x	x	x	x	x		9
H2														Nil
H3						x	x	x	x	x	x			6

4.4.4. Parameters for design criteria of the lecture theatre

The design parameters are provided in Table 6 and in conjunction with the indicators for thermal comfort requirements; the criteria to be used in designing lecture theatre for the tropics will be established.

Table 6: Design criteria for Thermal Performance

Indicators	H1	H2	H3	A1	A2	C1	C2	Item code	Design Criteria	Recommen dation
Total	9		6	3						
A: Layout alternatives						0-2		A-1	Building oriented on East-West axis	
			11-12			0-4		A-2	Compact courtyard planning	
	6-12							A-3	Building oriented on North-South axis	Yes
B: Spacing for breeze	11-12							B-1	Open spacing for breeze penetration	
	2-12							B-2	Open spacing with some precautions against cold or hot dry winds	Yes
								B-3	Close to adjacent Buildings	

Table 6: Design criteria for Thermal Performance

Indicators	H1	H2	H3	A1	A2	C1	C2	Item code	Design Criteria	Recommen dation
D: Air movement	3-12			0-5				D-1	Rooms single banked, permanent provision for cross ventilation	Yes
		2-12			6-12			D-2	Double banked rooms, temporary provision for cross venation	
	0	0-1						D-3	Cross ventilation not essential	
E: Openings	2-12			0-1		0		E-1	Large, 40-80% of external wall area	Yes
			0-1					E-2	Medium, 20-40% of external wall area	
				11-12		0-3		E-3	Small, 10-12% of external wall area	

F: Position of openings	0-12			0-5				F-1	In North and South walls at body height on windward sides	Yes
	0	2-12		6-12				F-2	As above, openings also in internal walls	Yes
								F-3	In East and West walls	
G: Protection of openings						0-2		G-1	Exclude direct sunlight	
			2-12					G-2	Provide protection from rain	Yes
H: Outdoor sleeping					2-12			H-1	Spacing required for outdoor sleeping	
								H-2	Not a requirement	Yes
I: External walls				0-2				I-1	Light walls, low thermal capacity	Yes
				3-12				I-2	Heavy walls, over 8 hr. time-lag	
J: Roofs	9-12			0-2				J-1	Light, reflective surfaces	Yes
				0-9	6-12			J-2	Heavy, over 8 hr. time lag	
						3-12		J-3	Well insulated, 3 hr. time lag	

A. *Layout alternatives*: H1 between 6-12 months, under Item code A-3; the design criteria is that buildings should be oriented on North-South axis.

B. *Spacing for Breeze:* H1 between 2-12 months, under Item code B-2; the design criteria is for open spacing with some precautions against cold or hot dry winds.

C. Spacing for Solar Radiation: Not a requirement.

D. *Air Movement:* H 1 between 3-12 months and A 1 between 0-5 months, under Item code D-1; the design criteria is that rooms should be single banked and permanent provision for cross ventilation be provided.

E.*Openings:* H 1 between 2-12 months and A 1 between 0-5 months, under Item code E-1; the design criteria are large door and openings between 40-80% of external walls.

F. *Position of openings*: H 1 between 0-12 months and A 1 between 0-5, under Item codes F-1 and F-2; the design criteria is that openings should be provided in North and South walls at body height on windward sides and openings also in internal walls.

G. *Protection of openings*: H 3 between 2-12 months, under Item code G-2; the design criteria is to provide protection from rain.

H. *Outdoor Sleeping*: Is not a requirement.

I. *External walls*: A1 between 0-2 months , under Item code I-1; the design criteria is to provide light weight walls with low thermal capacity.

J. *Roofs*: H1 between 9-12 months and A1 between 0-2 months, under Item code J-1; the design criteria is to provide roofs with light reflective surfaces.

The findings revealed that thermal comfort can only be achieved in any learning-teaching lecture theatre in the tropics when the design and construction of such buildings comply with certain recommended design criteria. The incorporation of these criteria in the design of buildings will provide a reasonable level of thermal comfort. However, the lecture theatres selected for the study did not meet most of the design criteria recommended for thermal comfort.

On layout alternatives, it was recommended that buildings should be positioned in North and South axis in terms of orientation to increase the admittance of air into the building space. The implication of buildings not properly oriented is that, they will not have adequate ventilation. Inadequate ventilation of room space aggravates sweat liberation while the penetration of radiant heat into a learning-teaching space creates a sensational stimulation of the students' skin if it falls on the heads of the seated student. On orientation and solar radiation, glass facing the north receives least solar radiation, and glass facing south receives next least. Therefore, if a building can be oriented so that most of its glass faces North and South, it will have a much lower solar load than if the principal areas face East and West [30]. Further, south-facing units are premium and prevailing winds both local and regional, should be studied so that no building is entirely masked [31]. Therefore, to improve the penetration of ventilation, buildings should be designed accordingly in that direction [23, 29].

Also, by orientating the longer sides of the buildings to intercept prevailing winds and the shorter sides to face the direction of the strongest solar radiation, effective ventilation can be achieved, while thermal impact from solar radiation is minimised [32]. In addition, orientation and spatial organisation is very important because in the absence of that, the ability of a building to ventilate or receive solar radiation will be affected [33]. Spacing of buildings for breeze penetration was another recommendation for thermal comfort performance. Buildings that are not spaced apart tend to block the flow of breeze or air change rate in the room spaces of the adjacent buildings. This means, the buildings will not be assured of proper ventilation. Thus, natural air change rate within a building depends on several factors; speed and direction of wind at building site; the external geometry of the building and the adjacent surroundings [27]. All learning-teaching spaces should therefore have provision for air-movement.

With regard to air movement, the recommended design criteria were to have the room spaces to be single banked and have permanent provision for cross-ventilation [23]. It means that, windows should be located in the opposite walls on each external side-wall. The recommended design criteria for openings are that door and window openings should have 40 - 80% coverage of the external walls. Therefore, the admission of breeze into any room space depends on the location and size of the window openings [23, 27]. Furthermore, in the tropics with the humidity and temperature high above comfort limits practically throughout the year, window openings that will permit adequate air into a room space for thermal comfort is required [23].

In the case of design criteria for positioning of openings, it was recommended that, apart from locating the openings in North and South walls at body height on the windward and leeward faces of external walls for the building to be crossed ventilated, openings may also be provided in internal walls [23]. Further, ventilation is enhanced by placing windows in side walls due to the increased suction at these locations, and where windows are centered in a room; it forms a free jet [27]. Ventilation provides cooling by enabling convective heat transfer from a warm building's interior to a cool exterior [16]. That is, sufficiently high indoor air velocities give the occupants direct physiological cooling and in a natural system, ventilation is accomplished by either wind, buoyancy or a combination of wind and buoyancy.

With very high rainfall prevalence, the design criteria are to provide protection of the external walls and the internal space from rain by extending the roof over-hangs (roof eaves) very much beyond the external walls. Where external walls are not protected especially in very high rainfall areas, the paintings, wooden doors and frames will deteriorate, and metals shall corrode [29]. The design criteria for external walls and roof covering are to provide light weight walls with low thermal capacity. Light-weight walls and roofs are relevant in the tropical humid area because storage or conservation of heat is not required since the average annual maximum and minimum temperature of 19 °C and 36 °C respectively and relative humidity for thermal comfort between 62 – 87 % are above the thermal comfort limits of 27 ^{O}C and 22 ^{O}C [23, 29, 34]

5. Conclusion

It is concluded from the findings that in the tropics, various factors affect the thermal comfort of a teaching-learning environment. These factors are orientation, spacing of buildings for breeze, air movement, size and position of openings, protection of openings and the type of walling and roofing materials used. Also included is the size of the teaching-learning spaces in relation to the number of occupants. Therefore, it is appropriate to incorporate the recommended design criteria into the design of buildings used for teaching-learning to enhance thermal comfortable. In conclusion, the choice of proper site of the buildings, developing proper shape and size for the buildings, proper orientation of the buildings, providing adequate ventilation, providing adequate window sizes for natural ventilation and selecting appropriate building materials for construction will reduce thermal comfort problems that affect teaching-learning in lecture theatres in the tropics.

Conflict of interest
The authors declare no conflict of interest.

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References

[1] Lawal AF., Ojo OJ., 2011. Assessment of Thermal Performance of Residential Buildings in Ibadan Land, Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences.* 2 (4), pp. 581-586.

[2] ASHRAE, ANSI/ASHRAE Standard 55-2004., 2004. *Thermal environmental conditions for human occupancy*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

[3] Yaglou CP., 1968. Indices of comfort. In Newburgh LH, editor. *Physiology of heat regulation and the science of clothing*, pp. 268.

[4] Markus TA, Morris EN., 1980. *Buildings, climate and energy*. London: Pitman Publishing Ltd.

[5] Givoni B., 1981. *Man, climate and architecture.* London: Applied Science PublishersLtd.

[6] Dagostino FR., Wujek JB., 2009. *Mechanical and electrical Systems in architecture,Engineering and Construction (5th Edition)*. New-Jersey: Prentice Hall.

[7]. Sander MS, McCormick EJ., 1993. .*Human factors in engineering and design 7th edition*. Singapore: McGraw-Hill Book Company.

[8] Bell PA., Greene TC., Fisher JD., Baum A., 2005. *Environmental psychology 5th edition.* New York: Routledge, Taylor and Francis Group.

[9]. Bridger RS., 2008. *Introduction to ergonomics 3rd edition*. New York: Taylor and Francis Group.

[10] Heerwagen D., 2004. *Passive and active environmental control-Informing the schematic designing of buildings.* New York: McGraw-Hill Co. Inc.

[11] Adunola AO., Ajibola K., 2012. Thermal comfort considerations and space use within residential buildings in Ibadan, Nigeria. Proceedings of 7th Windsor Conference: *The changing context of comfort in an unpredictable world*, Cumberland Lodge, Windsor, UK, April. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk. pp.12-15.

[12] Hornby AS., 2015. *Oxford advanced learner's dictionary*. Oxford: Oxford UniversityPress.

[13] Anyakoha MW., 2008. *New school physics senior secondary schools*. Onitsha, Nigeria: Africana First Publishers Ltd.

[14] Yellot JI., 2008. Thermal comfort design. In Hoke WF. Editor. Ramsey/Sleeper architectural graphics Standards. New York: John Wiley & Sons Inc., pp. 65

[15] Ayoade JO., 2004. *Introduction to climatology for the tropics*. Ibadan: Spectrum Books Ltd.

[16] Chenvidyakarn T., 2007. Passive Design for thermal comfort in hot humid climates. *Journal of Architectural/ Planning Research and Studies*, 5, pp. 1-27.

[17] Charderton DV., 2013. *Building services engineering.* New York: Routledge, Taylor & Francis.

[18] Foster JS., Greeno R., 2006. *Structure and fabric part 1.* New York: Routledge, Taylor & Francis.

[19] Critchfield HJ., 1998. *General climatology*. New Jersey: Prentice Hall Inc.

[20] Perkins and Will Associates., 2008. Schools. In Hoke WF. Editor. *Ramsey/Sleeper architectural graphic standard.* New York: John Wiley and Son Inc, pp. 823 - 826

[21] Will P., Ovresat RC., 1980. Educational - elementary and secondary school. In De-Chiara J, Crosbie MJ. Editors. *Time saver standard for building types*. New York: McGraw-Hill Book Company; pp.169 – 172.

[22] Balogun OY., 2003. *Senior secondary school atlas. 2nd edition*. Ikeja, Lagos: Longman Nigeria Plc.

[23] Evans M., 2012. Tropical design. In Littlefield D. Editor. *New metric handbook: planning and design data.* New York: Routledge, Taylor & Francis, pp.402 - 511.

[24] Bunnett RB., Okunrotifa PO., 2003. *General geography in diagrams for West Africa.* Essex England: Longman Group Ltd.

[25] Jordan J., 2012. Higher Education. In Littlefield D. Editor. *New metric handbook: planning and design data.* New York: Routledge, Taylor & Francis, pp.204-273.

[26] Neufert E., Neufert P., 2012. *Architects' data 4th edition.* London:Wiley-Blackwell.

[27] Roberts WF., 2008. Natural Ventilation; In Hoke WF. Editor. *Ramsey/Sleeper Architectural graphic standards.* New York: John Willey & Sons Inc., pp. 713.

[28] Adler D., 2012. Thermal Comfort. In Littlefield D. Editor. *New metric handbook: planning and design data*. New York: Routledge, Taylor & Francis, pp.38 -401.

[29] Burberry P., 1997. *Environment and Services.* London: Longman Ltd.

[30] Greenberg A., 1983. Heating, ventilation and air conditioning. In Crosbie M, Watson D. Editors. Time saver standard for architectural design: technical data for professional practice 8th edition. New York: McGraw-Hill Professional, pp. 4/106 -194.

[31] Benneth R., 2008. Housing. In Hoke JR. Editor. *Ramsey/Sleeper architectural graphic standards-cumulative supplement.* New York: John Wiley & Sons Inc; pp.280-289.

[32] Leaurungreong V., Oranratmanee R., Sihalarth P., Insisiengmay S., 2005. The local intelligence for a dwellings comfort living in Chiang Mai & Luang Prabang. *Journal of Energy Research,* 2, pp. 17-38.

[33] Wongfun S., Chindavanig T. , Sreshthaputra A., 2006. Guidelines for utilization of natural air flow pattern of traditional Thai house in residence. *Journal of Energy Research,* pp. 31-50.

[34] Punmia EC., Jain AK., Jain AK., 2005. *Building construction.* New Delhi: Laxmi Publications.

[35] Department of Meteorological Services, Federal Ministry of Aviation, Port-Harcourt. 2002-2014.