International Journal of Architecture, Arts and Applications
2025, Vol. 11, No. 4, pp. 203–212
https://doi.org/10.11648/j.ijaaa.20251104.12

Research Article

Optimising Window Performance for Natural Lighting and Ventilation in Bauchi State Lecture Theatres

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Abstract

Lecture theatres are contributors of high energy consumption and the emission of greenhouse gases in Nigeria's public institution. This consumption of this excess energy came as a result of lightening and ventilating the lecture theatres through conventional means. Therefore, the need to optimise window performance for natural lighting and ventilation in the lecture theatres has become necessary in order to reduce energy consumption and greenhouse gases emission in the environment. The study is aimed at assessing window performance towards the provision of natural lighting and ventilation in lecture theatres within Bauchi state public institutions of learning. Lecture theatres in Abubakar Tafawa Balewa University (ATBU), Abubakar Tatari Ali Polytechnic (ATAP), Federal Polytechnic Bauchi (FPTB), and Sa'adu Zungur University (SAZU) were sampled out of the numerous learning institutions in the state. The purpose of the study is to reduce the excessive use of non-green energy and the CO_2 emissions associated to the building energy consumption in the lecture theatres. The window performance was assessed through accessing the occupants' perception in the provision of natural lighting and ventilation. Interviews, observation and questionnaires were used to assess their comfort level with natural ventilation and their satisfaction with natural lighting. The results from the study area identified that, the more occupants of the lecture theatres gets comfortable with window performance in the provision of natural ventilation, the more satisfied they become with the window performance in the provision of natural lighting. In conclusion the study recommends the integration of occupants' perception in the design of lecture theatres and a design model for building professionals that will effectively optimise energy efficiency in lecture theatres.

Keywords

Bauchi State, Energy Consumption, Lecture Theatres, Natural Lighting and Ventilation, Window Performance

1. Introduction

Attaining academic success in public institutions doesn't solemnly depend on the number of structures and human capital employed in the institutions but also having a serine environment with lecture theatres that are comfortable and conducive for learning [18]. In order to make this lecture theatres conducive, the indoor air quality and lighting of such lecture theatres must be in check to provide a healthy stay for the occupants [4]. Towards attaining the lighting and ventilation, a farce remains on the insufficient electrical energy to power the appliances. Bauchi state power supply in the recent years have being epileptic causing the government to have a re-think on using other source of energy or at the best adopt passive means of ventilating and lighting the lecture theatres [11].

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Received: 25 October 2025; **Accepted:** 10 November 2025; **Published:** 17 December 2025

Adopting passive means to provide an alternative to lighting and ventilation in Bauchi state lecture theatres has become necessary in order to curtail the rising energy demand and reduce greenhouse gas emissions [14]. There has been a clear global direction on limiting global warming through adopting renewable energy and other passive means in building energy use with the view to reduce CO_2 emissions from buildings [19]. The global energy demand has a 50% rise over few decades which is attributed to the population increase and economic successes [7]. The significant rise on the use of non-renewable energy consumption has influenced a substantial consequences on harming the environment through emission of greenhouse gases, speeding of climate change, intensifying global warming and economic rate [2].

Buildings in the entire globe have been identified to consume 20-40% of the world's total energy use, which makes them one of the highest energy consuming sector [8]. Most of the energy consumed by buildings is linked to heating, ventilation, and air conditioning (HVAC) systems for thermal adjustment and air quality which is projected by the year 2100 to increase to 64% [3, 1]. Such projected increase of 64% is directly linked to the increase in student's population in public institutions and economic development which has resulted in construction of more lecture theatres in Bauchi state public institutions and identifying the new opportunities and challenges in energy efficient designs [16, 10].

Considering all the potentials available for designing energy efficient lecture theatres, quite a number of the lecture theatres have not incorporated the passive design principles in their designs of lecture theatres which has led to unreasonably high energy consumption. Such characters are also found in public libraries [12]. In other to reduce the unreasonable high energy consumption in lecture theatres, adopting efficient passive design strategies for natural lighting and ventilation will reducing over reliance on conventional lighting and air conditioning systems [9].

Lecture theatres in Bauchi state are engulfed within hot and dry weather with seemingly epileptic power supply that seriously requires the adoption of passive design strategies. The adoption of passive design strategies in the design of lecture theatres in Bauchi state public schools will substitute a failed conventional means of lighting and ventilating lecture hall [11].

Windows are elements of passive design strategies that play a vital role in naturally lighting and ventilating the indoors of lecture theatres. The windows reduce the over reliance on air conditioners to improve indoor air quality and electrical lighting equipment [21]. Among key take away from windows are: their crucial role in ventilation and lighting, air circulation and cooling, maximising natural lighting, reducing the overdependence on artificial lighting and cooling, improving the indoor air quality, and enhancing occupants health and comfort [6].

Windows illuminate the interior of buildings as important elements of the initial design of a building. Their transparent nature makes lighting of interior easier and softly. A high window-to-wall ratio (WWR) increases the daylight but also increases cooling load while requiring a balance to prevent discomfort from glare and overheating [20]. For extreme climate like Bauchi, integrating natural ventilation and lighting with mechanical cooling and lighting systems is necessary for maintaining both comfort and energy efficiency. While larger openings areas generally improve natural ventilation and lighting, but optimisation is needed to avoid excessive solar gain [13]. The strategic design of windows with the consideration of size, placement and orientation, and with effective shading strategies can tremendously reduce the need for artificial lighting thereby improving indoor day lighting [15].

Thus, the study seek to assess the performance of windows in the various lecture theatres of public institutions in Bauchi state, Nigeria in other to optimise natural lighting and ventilation with the view to limit greenhouse gas emissions and save energy. Saving energy will help curtail the high energy demand in Bauchi state and also promote its economic performance towards Gross Domestic Product (GDP) while reducing greenhouse emission will limit global warming by improving the air quality within lecture theatres and providing a healthier environment for the occupants'. Architecturally, when windows are properly integrated into passive designs in public institutions, the occupants' health and comfort becomes an improved policy thereby, improving energy efficiency [17]. For learning environments in focus, optimizing natural lighting and ventilation in lecture theatres not only supports visual and thermal comfort but also supports students' daily learning, promoting better commitment and behaviour [5].

2. Material and Methods

Based on Koppen-Geiger climate classification, the study area, Bauchi state Nigeria is classified as a tropical savanna region which is characterised by hot and dry weather condition. Bauchi state constitutes a number of twenty local government area with Bauchi as the headquarters. Bauchi state is located on latitude $10^{0}17^{1}$N and longitude $09^{0}49^{1}$E. It is geo-politically located in the Nort-East Nigeria covering an area of 45, 837 square kilometers and bordering states of Plateau, Gombe, Kano, Kaduna, Taraba, Jigawa and Yobe. At the period of the study, indoor temperature of the selected lecture theatres was recorded with maximum to be 32.02°C, minimum 25.04°C and mean temperature of 28.2°C. At the time the respondents attended to the questionnaires, Accusense F900 was used to capture the data from the indoor air velocity. Maximum air velocity was recorded at 0.1m/s, minimum 0.03m/s and the mean was 0.07m/s.

A mixed method of quantitative and qualitative research was employed to collate data from the respondents who were basically the occupants (students and lecturers) of the various lecture theatres. Four lecture theatres were selected based on capacity, each from ATBU (1000 seat capacity), ATAP (500 seat capacity), FPTB (544 seat capacity), and SAZU (500 seat capacity). Furthermore, the four institutions were used for the study because they have the most populated students and bigger capacity lecture theatres that consume more energy than the others. Questionnaires were used to collate data quantitatively while observation and interview were used to collate data qualitatively.

Part 1 of the Questionnaire contains respondent's demographic data while part 2 contains the general information on lecture theatre space conditions. Other parts; C, D, E, and F constitute information derived from the respondents with regards to window orientation and placement, window size and type, high-performance glazing and shading, internal layout and occupancy, and design considerations. Closed-ended questions were used to assess the window performance in optimizing natural lighting and ventilation in the selected lecture theatres. Questionnaires were administered based on the respondent's consent which took them four days to respond back. The idea to allow the questionnaire stayed for four days was to allow them fill at their convenience, in order not to affect their academic activities. The patient idea of four days waiting came out successfully with all the 120 questionnaire retrieved.

A likert scale of six (6) points was used to assess the window performance on the comfort level of the occupants with natural ventilation through (1= Very Comfortable, 2= Comfortable, 3= Slightly Comfortable, 4= Slightly Uncomfortable, 5= Uncomfortable, and 6= Very Uncomfortable). Furthermore, a likert scale of seven (7) points was used to assess the window performance in optimizing natural lighting satisfaction through (1= Very Satisfied, 2= Moderately Satisfied, 3= Slightly Satisfied, 4= Neutral, 5= Slightly Dissatisfied, 6= Moderately Dissatisfied, and 7= Very Dissatisfied). The purpose of employing the performance satisfaction scale was to allow every participant to respond freely to their level of satisfaction with natural lighting condition in the lecture theatres. To validate the questionnaire, reliability statistics were piloted for the variables in the questionnaire and 0.5 was obtained as the Cronbach alpha value. This further validates the reliability of the result outcome from the findings.

3. Data Presentation and Analysis

A physical observation on the lecture theatres were carried out with emphasis on the window's ceiling height, dimensions, window-wall ratio (WWR), raked and sill height, and the floor plan's capacity, shape, shade and roof eves. The observation was purposely conducted to validate other variables from the qualitative perspective of data collection. The questionnaire survey assessed the window performance through adopting the descriptive and inferential analysis with SPSS version 25. Analysis of data on demographic records were presented via the frequency schedule.

Table 1. Demographic Information of the Respondents from Sampled Lecture Theatres.

Institution (Theatre)		ATBU N=30	(%)	ATAP N=30	(%)	FPTB N=30	(%)	SAZU N=30	(%)	Total N=120	Total (%)
Gender	Male	25	83.3	22	73.3	20	66.7	28	93.3	95	79.15
	Female	5	16.7	8	26.7	10	33.3	2	6.7	25	20.85
Age	20-30	15	50	25	83.3	20	66.7	20	66.7	80	66.70
	31-40	12	40	2	6.7	8	26.7	8	26.7	30	25.00
	41-50	2	6.7	1	3.3	1	3.3	2	6.7	6	5.00
	>50	1	3.3	2	6.7	1	3.3	0	0	4	3.30
Years in Bauchi	< 1 year	8	26.7	2	6.7	1	3.3	0	0	11	9.20
	>1 year	22	73.3	28	93.3	29	96.7	30	100	109	90.80
Education level	Diploma	1	3.3	15	50	13	43.3	1	3.3	30	25.00
	HND	0	0	15	50	17	56.7	1	3.3	33	27.50
	Degree	29	96.7	0	0	0	0	28	93.3	57	47.50

Table 1 above describes the various attributes from the respondents of the study area. The results outcome showed the male respondents account for the highest frequency of responses. Out of the 120 respondents from the four lecture theatres, 95 respondents were all male which rates to a total of 79.15%. The female are the least with only 25 respondents which narrates to 20.85%. Majority of the respondents are within the age range of 20-30 years. Out of the 120 respondents, 80 came from age range of 20-30 years with 66.7%, 30 respondents came from the age range of 31-40 years with 25%, 6 respondents came from age range of 41-50 years with 5%, and the least respondents came from above 50 years with only 4 respondents constituting only 3.3%. 109 respondents have stayed more than a year in Bauchi amounting to 90.8% while 11 respondents have not stayed up to a year, constituting 9.2%. Out of the 120 respondents, 30 participants have diploma, 33 have higher national diploma (HND), and 57 participants have degree with corresponding percentages of 25%, 27% and 47%.

Table 2. Window configuration of theatre by dimensions of floor, window, WWR and windowsill.

S/No	Name	Plan Dimension L×B (m)	Window dimension (m) W×H	Window-wall ratio (WWR) %	Windowsill height (m)
1.	Lecture theatre ATBU	27.00 ×14.50	1.50 ×2.00	12.5	0.85
2.	Lecture theatre ATAP	18.00 × 10.00	1.40 ×1.60	8.6	0.89
3.	Lecture theatre FPTB	20.00 ×12.00	1.50 ×1.80	15.5	0.90
4.	Lecture theatre SAZU	18.50 ×13.50	1.20 ×1.80	10.0	0.90

Table 2 identified the various configuration of windows in the lecture theatres. ATBU Lectures theatre appears to be bigger in floor area and window dimension but with 12.5% WWR and 0.85m window sill. Bigger windows gives more illumination and air inflow to interiors of lecture theatres, especially when it has a large number of occupants. ATAP lecture theatre appears to be the least in floor area and window size and carrying WWR OF 8.6% and 0.89m windowsill. Even though, ATAP's floor area is the least, provision of adequate sizeable windows were considered to optimise natural lighting and ventilation.

Table 3. Window configuration of theatres by raked height, capacity, plan form and roof eve.

S/No	Name	Plan shape (Linear)	Plan shape (Polygonal)	Capacity	Ceiling height (m)	Raked height (m)	Roof eve (mm)
1.	Lecture theatre ATBU	1	0	1000	6.0	1.2	600
2.	Lecture theatre ATAP	1	0	500	3.8	1.1	1000
3.	Lecture theatre FPTB	1	0	544	3.5	1.6	600
4.	Lecture theatre SAZU	0	1	500	4.0	1.5	900

Table 3 shows the various configurations of functional spaces within the theatres. ATBU has the highest capacity with 1000 seats and characterised by sliding windows and fixed windows. It has a linear shape plan with ceiling heights and raked ceiling to be 6 and 1.2m respectively. FPTB is next in terms of capacity with 544 seats while both ATAP and SAZU have 500 capacity. While other theatres are linear in plan shape, SAZU is the only theatre that its plan shape is polygonal. A good raked and ceiling height helps in optimising natural lighting and ventilation while extended roof eve buffers sun radiation into the interiors of theatres. FPTB is characterised by awning windows, ATAP is sliding, and SAZU awning. Awning windows is typically hinged at the top and opening outwards. Awning windows helps in controlling ventilation and prioritising air circulation. Fixed windows provides unobstructed views and permits abundant natural lighting and casement provides excellent airflow, controlled ventilation and unobstructed views. While sliding windows obstructs view and lighting, they provide strength to densely capacitated theatres.

Table 4. *Occupants Perception on window performance with natural ventilation in lecture theatre.*

Response		Wind Direction		Window Size		Window Type		Sun Protection		Interior Layout		Ventilation Balance	
		Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)
Lecture Theatre ATBU	1	3	10	7	23.3	2	6.7	1	3.3	5	16.7	2	6.7
	2	15	50	14	46.7	4	13.3	1	3.3	16	53.3	10	33.3
	3	8	26.7	5	16.7	7	23.3	2	6.7	5	16.7	10	33.3
	4	2	6.7	3	10.0	10	33.3	16	53.3	2	6.7	5	16.7
	5	2	6.7	1	3.3	6	20.0	8	26.7	1	3.3	2	6.7
	6	0	0.0	0	0.0	1	3.3	2	6.7	1	3.3	1	3.3
		30	100	30	100	30	100	30	100	30	100	30	100
Lecture Theatre ATAP	1	5	16.7	2	6.7	6	20.0	5	16.7	4	13.3	3	10.0
	2	10	33.3	5	16.7	16	53.3	15	50.0	13	43.3	4	13.3
	3	13	43.3	5	16.7	5	16.7	8	26.7	11	36.7	5	16.7
	4	2	6.7	5	16.7	2	6.7	2	6.7	1	3.3	10	33.3
	5	0	0.0	10	33.3	1	3.3	0	0.0	1	3.3	8	26.7
	6	0	0.0	3	10.0	0	0.0	0	0.0	0	0.0	0	0.0
		30	100	30	100	30	100	30	100	30	100	30	100
Lecture Theatre FPTB	1	4	13.3	3	10.0	5	16.7	3	10.0	4	13.3	3	10
	2	14	46.7	16	53.3	13	43.3	8	26.7	10	33.3	15	50
	3	10	33.3	8	26.7	10	33.3	9	30.0	9	30.0	11	36.7
	4	1	3.3	2	6.7	1	3.3	8	26.7	5	16.7	1	3.3
	5	1	3.3	1	3.3	1	3.3	2	6.7	1	3.3	0	0
	6	0	0.0	0	0.0	0	0.0	0	0.0	1	3.3	0	0.0
		30	100	30	100	30	100	30	100	30	100	30	100
Lecture Theatre SAZU	1	4	13.3	2	6.7	6	20	4	13.3	7	23.3	4	13.3
	2	12	40	15	50	10	33.3	12	40.0	8	26.7	12	40
	3	11	36.7	12	40	10	33.3	9	30.0	8	26.7	11	36.7
	4	2	6.7	1	3.3	3	10.0	5	16.7	5	16.7	2	6.7
	5	1	3.3	0	0	1	3.3	0	0	2	6.7	1	3.3
	6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
		30	100	30	100	30	100	30	100	30	100	30	100

Table 4 illustrates the various data collated from attributed variables of occupants' perception on window performance with natural ventilation in the lecture theatres. A descriptive statistics was used for data capturing, a cumulative response from various respondents where frequency and percentage were used for ranking and the results were obtained. The results obtained from ATBU lecture theatre shows that 86.7% respondents were comfortable with the wind direction of the windows while 13.3% were not comfortable. Results from window size on natural ventilation indicated that 86.7% were comfortable with the sizes while 13.3% were not comfortable. Respondents from window type towards provision of natural ventilation indicated that 43.3% were comfortable while 56.7% were not comfortable. Respondent's reaction with sun protection towards optimising natural ventilation in the lecture theatre indicated that 13.3% were comfortable while 86.7% were actually not comfortable. Results obtained on interior layout shows that 86.7% occupants were comfortable with interior arrangement towards optimising natural ventilation while 13.3% were not comfortable. At the time of the study, the results on ventilation balance indicated that 73.3% of the occupants were comfortable while 26.7% were not comfortable.

Results obtained from occupants' perception with window performance with natural ventilation at ATAP's lecture theatre indicated that 93.3% were comfortable with the window wind direction while 6.7% were not comfortable. 40% were comfortable with window sizes while 60% were not comfortable. 90% were comfortable with window type while only 10% were not comfortable with the type. While 93.3%, 93.4% and 40% were comfortable with the sun protection, interior layout and ventilation balance, 6.7%, 6.6% and 60% were not comfortable.

Results from respondents of FPTB lecture theatre shows that 93.4% were comfortable with window's placement to wind direction while 6.6% were not comfortable. 90% were comfortable with the window size while 10% were not comfortable with the window size in optimising natural ventilation. 93.4% were comfortable with the window type while only 6.6% found it uncomfortable the window type. Results from the sun protection shows that 66.7% were comfortable while 33.3% were not comfortable, 76.6% were comfortable with interior layout while 23.4% were not comfortable. Results from ventilation balance indicated that 96.7% were comfortable while only 3.3% were not comfortable with ventilation balance in the lecture theatre.

Furthermore, results from SAZU lecture theatre indicated good comfortable level from the variables than uncomfortable level and the ventilation balance indicted a 90% comfortable level with 10% uncomfortable level. From the results obtained, ATBU and ATAP has the lowest ventilation balance. This is attributed to the fact that ATBU has fixed windows that are permanently closed. Fixed windows are advantageous to natural lighting but disadvantageous towards obtaining natural ventilation. Poor sun protection was also observed with ATBU lecture theatre which has contributed to the discomfort of the occupants staying for the period of sunrise and sunset. ATAP lecture theatre low ventilation balance is attributed to the fact that, the windows are of small sizes and are sliding in design. Even though, sliding windows are structurally stable when placed at wall, their openings does not effectively provide natural ventilation.

Table 5. Occupants Perception on window performance with natural lighting in lecture theatre.

Response		Lighting Penetration		Window Size		Window Type		Sun Protection		Interior Layout		Lighting Balance	
		Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)
Lecture Theatre ATBU	1	5	16.7	10	33.3	11	36.7	0	0.0	3	10.0	11	36.7
	2	15	50	14	46.7	10	33.3	0	0.0	11	36.7	11	36.7
	3	8	26.7	5	16.7	5	16.7	2	6.7	12	40	6	20
	4	1	3.3	0	0.0	1	3.3	0	0.0	2	6.7	0	0.0
	5	1	3.3	1	3.3	2	6.7	10	33.3	1	3.3	1	3.3
	6	0	0.0	0	0.0	1	3.3	13	43.3	1	3.3	1	3.3
	7	0	0.0	0	0.0	0	0.0	5	16.7	0	0.0	0	0.0
		30	100	30	100	30	100	30	100	30	100	30	100
Lecture Theatre ATAP	1	0	0.0	0	0.0	4	13.3	5	16.7	3	10.0	2	6.7
	2	2	6.7	1	3.3	14	46.7	12	40	10	33.3	3	10.0
	3	4	13.3	2	6.7	8	26.7	11	36.7	13	43.3	2	6.7
	4	1	3.3	1	3.3	1	3.3	0	0.0	2	6.7	1	3.3
	5	12	40.0	11	36.7	2	6.7	1	3.3	0	0.0	10	33.3
	6	9	30.0	10	33.3	1	3.3	1	3.3	2	6.7	9	30.0
	7	2	6.7	5	16.7	0	0.0	0	0.0	0	0.0	3	10
		30	100	30	100	30	100	30	100	30	100	30	100

Response		Lighting Penetration		Window Size		Window Type		Sun Protection		Interior Layout		Lighting Balance	
		Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)	Freq.	(%)
Lecture Theatre FPTB	1	4	13.3	12	40.0	5	16.7	0	0.0	3	10.0	5	16.7
	2	14	46.7	11	36.7	11	36.7	0	0.0	11	36.7	11	36.7
	3	9	30.0	6	20.0	10	33.3	3	10.0	12	40.0	12	40.0
	4	0	0.0	0	0.0	1	3.3	2	6.7	2	6.7	0	0.0
	5	2	6.7	1	3.3	2	6.7	10	33.3	1	3.3	1	3.3
	6	1	3.3	0	0.0	1	3.3	12	40.0	1	3.3	1	3.3
	7	0	0.0	0	0.0	0	0.0	3	10.0	0	0.0	0	0.0
		30	100	30	100	30	100	30	100	30	100	30	100
Lecture Theatre SAZU	1	6	20	7	23.3	5	13.3	5	16.7	3	10.0	5	16.7
	2	9	30	9	30.0	14	46.7	12	40	9	30.0	12	40.0
	3	9	30	10	33.3	8	26.7	11	36.7	14	46.7	9	30.0
	4	1	3.3	1	3.3	0	3.3	0	0.0	1	3.3	2	6.7
	5	2	6.7	2	6.7	2	6.7	1	3.3	0	0.0	1	3.3
	6	3	10.0	1	3.3	1	3.3	1	3.3	2	6.7	1	3.3
	7	0	0.0	0	0.0	0	0.0	0	0.0	1	3.3	0	0.0
		30	100	30	100	30	100	30	100	30	100	30	100

Table 5 demonstrates the various outcome from the occupants' perception on window performance with natural lighting in lecture theatres. Results from ATBU lecture theatre indicated that 96.7% of the respondents were satisfied with the lighting penetration while 3.3% were not satisfied. The high satisfaction came as a result of their big size of windows and the type. The respondents were satisfied with the window size and type at 96.7% and 90% respectively while 3.3% and 10% were not satisfied with window size and type. The sun protection recorded a poor satisfactory result, only 6.7% of the respondents were satisfied with the sun protection and 93.3% were not satisfied with the sun protection. Such results are associated with the design of the theatres and window placements. The respondents were satisfied with the interior layout and lighting balance at 93.4% while 6.6% were not satisfied with the interior layout and lighting balance.

4. Discussions and Limitations

The outcome of results from ATAP lecture theatre shows that only 23% of the respondents were satisfied with the lighting penetration while 76.7% were dissatisfied with situation. They had small sizes of windows and highly protected with shades. To that effect, only 13.3% of the respondents were satisfied with the window size and 86.7% were not satisfied. Despite the dissatisfaction level from the sizes of the windows, 90% were satisfied with the window type while 10% were not satisfied with the window type. Results from the sun protection stood at 93.4% satisfactory level while 6.6% were not satisfied and interior layout recorded a positive satisfactory level of 93.3% with 6.7% dissatisfactory level. The lighting balance result showed that 26.7% of the respondents were satisfied while 73.3% were not satisfied with the lighting balance.

Result from FPTB indicates that 90% of the respondents were satisfied with the lighting penetration while 10% were not satisfied, 96.7% were satisfied with the window size while 3.3% were not satisfied, and 90% of the respondents were satisfied with the window type while 10% were not. The sun protection result recorded a 16.7% satisfactory level and 83.3% dissatisfactory level, interior layout and lighting balance recorded the same satisfactory result of 93.4% and 6.6% dissatisfactory levels.

Furthermore, results from SAZU recorded an 83.3% of satisfactory level on the lighting penetration and 16.7% dissatisfactory level, window size and type recorded the same results from the respondents with a 90% satisfactory level and 10% dissatisfactory levels. Results from sun protection showed that 93.4% of the respondents were satisfied while 6.6% were not satisfied, 90% were satisfied with the interior layout while 10% were not satisfied. The final results from the lighting balance shows that 93.4% of the respondents were satisfied while 6.6% were not satisfied.

The study recommends a further study that would use simulation as a tool and method to mock-up energy bench marks for the lecture theatres while other research should focus on the window type and size to be used for lecture theatres.

Table 6. *Correlation result of window performance between natural ventilation and lighting.*

		Natural Lighting
Natural Ventilation	Person Correlation	.602**
	Sig. (2-tailed)	.000
	N	720

**. Correlation is significant at the 0.01 level (2-tailed)

Table 6 presents the correlation results of window performance between natural ventilation and lighting in the study areas. The correlation of window performance between natural ventilation and lighting was measured between the respondents comfort with natural ventilation and the respondents' satisfaction with natural lighting. The correlation results shows that the occupants comfort and satisfaction submits a moderate strong relationship ($r = 0.602$, $p<0.001$, $R^2 = 26\%$). The results identifies that, the more occupants of lecture theatres gets comfortable with windows performance with natural ventilation, the more satisfied they become with the window performance in the provision of natural lighting. Furthermore, the results explains how window performance of natural ventilation services to enlighten 26% of the variance respondents' score on lighting satisfaction.

5. Conclusion

The study uses occupants' survey and physical observation at the lecture theatres of ATBU, ATAP, FPTB, and SAZU to optimise their window performance in the provision of natural lighting and ventilation. Result collated from the respondents suggested that bigger and fixed windows provided more lighting while the same big and fixed windows lowers the lighting penetration in the lecture theatres (the case has being confirmed with the ATBU lecture theatre). Awing windows provides optimal ventilation and lighting but when the sun is not protected from them, it affects the natural ventilation through indoor heating (the case has been established for FPTB lecture theatre). Relatively, sliding windows are good for lightening interiors of lecture theatres but when they appear too small of size, it does not always achieve its optimal purpose of lighting and ventilation (the situation is observed with ATAP Lecture theatre). It is of the best advantage for natural ventilation and lighting when right, sizeable and sun protected windows are designed for a lecture theatre, with good interior layouts that are well positioned within wind direction and proper lighting waves (such advantages were noticed with SAZU lecture theatres).

The occupants' perception to window performance in the lecture theatres were generally positive despite the air temperature within the lecture theatres at the point of study are outside the recommended range. Generally, the ventilation balance for ATBU was comfortable at 73%, ATAP 40%, FPTB 96.7%, and SAZU 90%. While the lighting balance was recorded at 93.4% for ATBU, 26.7% for ATAP, 93.4% for FPTB, and 93.4% for SAZU. Lecture theatres of FPTB was very low on ventilation balnce and ATBU very low on lighting balance.

The importance of this study further reveals the need to adopt greener source of energy while postulating green technology to various professional within the building industry. While Bauchi state and Nigeria as a country is lacking sufficient electricity, the need to curtail the excessive use of such energy has become important not only to conserve energy, but also make our environment free of global warming.

6. Recommendations

1) Occupants' perception on window performance with ventilation and lighting should be integrated in the design of lecture theatres and top placed windows that provide lighting should be designed with openings to allow air flow.
2) Bigger windows that provide optimal lighting should be shaded against direct solar radiation and roof eves should not be less than 800mm.
3) Window to wall ratio should not be less that 15% while floor area openings should not be less than 30% and sky lights roofing should be encouraged.
4) To develop a design model for building professionals that will effectively optimise energy efficiency in lecture theatres.
5) The need to develop bench marks for tropical climate designs that will effectively fit into occupants' thermal comfort in lecture theatres.
6) The need to educate to populace about building energy consumption and the dangers associated to greenhouse gas emissions; a paramount purpose of adoptive passive design strategies.

When the above recommendations are implemented, occupants' (students) of public institutions shall be comfortable with ventilation level, and be satisfied with lighting levels in their various lecture theatres. When the students are comfortable with ventilation and satisfied with lighting when taking lectures, their education performance will improve and lecturers will find it easier to impact knowledge. Furthermore, adopting the use of windows for natural lighting and ventilation shall reduce the building energy consumption in lecture theatres and our environment shall be healthy free of CO_2 and other greenhouse gas emissions. Such actions will support Bauchi state and Nigeria in reducing global warming.

Abbreviations

WWR	Window-to-Wall Ratio
ATBU	Abubakar Tafawa Balewa University
ATAP	Abubakar Tatari Ali Polytechnic
BSU	Bauchi State University
FPTB	Federal Polytechnic Bauchi
FUHSA	Federal University of Health Sciences Azare
SAZU	Sa'adu Zungur University
GDB	Gross Domestic Product
HND	Higher National Diploma
HVAC	Heating Ventilation and Air Conditioning

Author Contributions

Abdullahi Yusuf is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

There was not any conflicts of interest.

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