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Post Occupancy Evaluation of Daylighting in Libraries: An Experimental Approach

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Abstract:
The study is plunge on the adequacy of lighting for Library activities in Ibrahim Badamasi Babangida library, Modibbo Adama University of Technology Yola (IBB library). The library is a one storey building. Total enumeration of the spaces was executed. A digital light meter was used to evaluate the light level in the spaces as well as a digital camera for photographs. The major factor considered in the research is the level of illumination on the work plane in the interior of the building. The data collected was analyzed using tables and figures. Findings show that library area with natural lighting below 500 lux for office and reading halls as well as 20 lux for ancillary spaces amounts to 2262.32square meters (96.49% of the total library area). Dark zones in the building are apparent during power outages. Some recommendations from the research includes retrofitting of the building to allow for natural lighting as well as installation of USG majestic acoustical reflective ceiling panels to replace the former as well as replacement of light color glazed granite tiles with the terrazzo floor, and installation of roller shade blinds which can be easily controlled for optimum light penetration.

Keywords: *Daylighting, comfort, illuminance, library, light level*

1. Introduction

The phenomenon environmental sustainability has become a global concern because of the state of the world's ecosystem and the library is not left out in this because of the vital role it plays in any nation. The instability caused by man's conscious and unconscious actions has necessitated different individuals, governmental and non-governmental organizations across the globe accepting environmental sustainability as a social responsibility which is increasingly becoming an interest for libraries and librarians all over the world. In attempting to ensure this, a novel concept popularly called greening has evolved (Adetoun and Adefunke, 2013).

Sustainable energy is critical to sustainable development (Hussaini, et al 2014)a substantial amount of evidence shows that daytime light exposure affects mood and alertness, influences social behaviors and cognitive performance. (Velux, 2013). The level of awareness of greening initiatives among Nigerian librarians is still relatively low, however, Nigerian libraries are implementing "green" measures at minimal level and rather unconsciously, it then calls for increased awareness and environmental literacy among library users and the entire community to build better green momentum in Nigerian libraries (Adetoun and Adefunke, 2013).

The effective use of natural lighting as an architectural principle is basic to building design. The advantages attached to adequate daylight and view in buildings includes but is not limited to; improved health of occupants, increased Productivity in the offices, improved perception of safety and worker's preferences concerning the location of windows (National Renewable Energy Laboratory, 2002). Lack of adequate lighting may lead to insufficient illumination, excessive contrast and glare (Labour Department, 2008). Artificial lighting is usually provided with lamps such as filament lamps, low voltage halogen lamps, high pressure discharge lamps and fluorescent lamps (Baiche and William, 2000). Other examples are fiber optic sources, light emitting diodes – LED, liquid crystal displays - LCD (Addington and Schodek,2005). In view of the fact that at some distance away from the windows natural lighting reduces considerably, lamps are usually required to support natural lighting (Baiche and Walliman, 2000).

1.1. Statement of the Research Problem

Natural lighting is a critical component of building design. In Nigeria, the problem of epileptic power supply implies that libraries need windows that open directly outside for maximum access to natural lighting during day work hours (Between 8am and 5pm). This concept can only be supported by narrow blocks with or without courtyards. Grid massing of rectangular shapes without courtyard, which is the principle guiding the design of the IBB library indeed contradicts this principle, thus artificial source of lighting is required to support natural lighting, especially in areas where the proximity of space to windows is severe or windows do not open directly outside.

The Vitruvian principles of firmitas*, utilitas,* and *venustas* are fundamental in any architectural design, thus buildings are required to be strong, useful, and beautiful according to the Historical Dictionary of Architecture, (2008). Lighting requirement in the interior of

the IBB library is expected to make the structure useful as a library space for the users. During a preliminary study it was discovered that most libraries could not function when the artificial power is off, but it's not certain about the level of the deficiency.

1.2. The Research Aim

The purpose of the study is to evaluate the natural lighting levels in the IBB library, with a view to improving light levels in the dark zones of the building.

1.3. The Research Objectives

The above aim can be achieved by the following:

i. Review the lighting requirements for library buildings.
ii. Carry out post occupancy daylight evaluation of the library using digital light meter.
iii. Compare the existing situation of the library buildings with the required standard.

1.4. Scope of the Study

The scope of the study is limited to natural lighting issues within the library halls and ancillary spaces. All rooms in the ground and first floors were analyzed.

1.5. Expected Contribution to Knowledge

The lighting assessment is expected to generate data for built environment professionals. The documentation of light levels in an existing library building is expected to ignite inquiry nature of architects, as to ways of improving daylight levels in buildings, in the absence of adequate power generated for artificial lighting and ultimately the reduction of energy load required in buildings in Nigeria, which is also replicable in the West African Region.

1.6. Justification for the Study

The lack of adequate energy generation in Nigeria to power artificial lighting, presumes that the little energy that is generated should be judiciously managed. At present, the installed electrical capacity in the Nigerian generating stations is 8644MW with the current average power generation,1,327MW (Premium times, 2015) which is shared amongst a population of 167 Million people in Nigeria (National Population Commission, Nigeria, 2011). There exists a huge shortfall of supply which is evident in everyday living condition in the country.

Improving the required light level to international standard would increase user's performance in the building. This position has been put forward by Hapner and Boser (2006) in their analysis of linking specific Leadership in Energy and Environmental Design, Indoor Environmental Quality (LEED, IEQ) items most associated with productivity, the findings reported that 'daylight for 75% of the spaces' and 'views for 90% of the spaces' were ranked1stand 2ndout of 17 LEED , IEQitems, by 180 experienced architects that have designed LEED registered commercial environments in 2004.In the tropics, Dodo and Zinkandar (2011) in reviewing the criterion for rating green commercial office buildings, classified day lighting that a total of 25 points out of 100 could be earned by optimizing day lighting according to Green Building Index Malaysia rating.

1.7. Research Methodology

Experiment and digital camera was used. Primary data was collected through the use of a digital light meter– an illuminance measuring device and a digital camera for photographs as well as a measuring tape for physical measurement of the building for architectural drawings. Secondary data was collected through journals, books, publications of associations connected with lighting and online resources.

1.8. Research Design

The illumination in each space was measured along the work plane using the digital light meter. The artificial lights in each space were put off to allow for natural lighting only. Thereafter, the average illumination is calculated for the library halls offices and ancillary space in the IBB library.

1.9. Variable Definition

The variables to be studied are: Average light level, the area offloor and ceiling and the area of windows.

1.10. Research Questions

1. How effective is the day lighting system?
2. Are minimum light levels being metin each space?
3. How could the lighting system be improved?

1.11. Research Population

The total building area excluding the external walls was used as the population; itsvalue was2,481.52sq.m. Thiswas the research population.

1.12. Sampling Technique and Size
Total enumeration of the spaces was used for the research.

1.13. Procedure and Instrument for Data Collection
Post occupancy evaluation method using digital light meter was used to gather primary data. The experiment was carried out on the 9 and 10September, 2015, between 11 a.m. and 1p.m. this time would allow almost balanced reading when the sun is overhead in the tropics. The reading was taken at the work plane, which is 850mm (for reading and office task areas) from the finished floor level and between 300mm to 2060mm (for books shelves), facing up (Thompson, 1991)and one meter from the wall on the sides of the spaces. For the reading hall ten points were taken in a grid tie of five parallel points taken at equal distance to each other. (Sa'id, et al, 2014). Thereafter the average of the readings for each space was arrived at by simple addition and dividing the number of readings, the average illumination was recorded in this report. The work plane is where the most important tasks in the spaceare performed. (Engineering toolbox, 2015). The sky conditions on both days were clear; there was no rain on both days.

1.14. Precautions
The precautions are as stipulated by the manufacturers (lux-meter, 2015):
i. It is critical that the test leads be in the proper jacks for the measurement the researcher is making. In this case the test leads are specified to be in the lux position.
ii. Keep the fingers on body behind the sensors when making the measurements.
iii. To avoid false readings, replace the battery as soon as the battery indicator appears.

1.15. Methods of Data Analysis
The result was analyzed using simple descriptive tools; tables and figures.

1.16. Research Limitations
The research is limited to data obtained on the 9 and 10September, 2015, between 11 am and 1pm.

2. Literature Review
The Dictionary of Architecture and building Construction (2008) defines lighting as the provision of light for spaces in a building by the controlled placing of lights, windows etc. for illumination. A rather technical definition is put forward by Addington and Schodek (2005) as 'visually evaluated radiant energy'. Radiant energy, or electromagnetic radiation, is energy movement through space in the form of oscillating or fluctuating electric and magnetic disturbances. Light is thus the physical phenomenon most responsible for humans' perception of the world. Baiche and William (2000) reports that the visible spectrum is between 380 and 780nm that is between ultraviolet and infrared radiation. A basic characteristic includes the ability of light to travel in a straight line between two points. When light strikes a surface, it can be absorbed, transmitted and/or reflected (Addington and Schodek, 2005). The design which fails to meet essential practical requirements will fail as a building and as architecture. The requirement for lighting is a functional objective. Windows may be introduced primarily as a means of admitting adequate sunlight into building. (Smithes, 1995).
Library is a room, building, or institution where a collection of books or other research materials is kept (Encarta Dictionary, 2009). The Dictionary of architecture and building construction (2008) also defines a library as a building, part of a building or room where books, papers and periodicals are stored and maybe read or lent out. A library is a collection of sources of information and similar resources, made accessible to a defined community for reference or borrowing. It provides physical or digital access to materials and may be a physical building or room virtual space or both. (Wikipedia, 2015).
Fadeyi and Taha (2010) investigated Occupants' feedback on adequacy of lighting in a factory office in Dubai. The writers investigated through observation and distribution of 22 questionnaires to members of staff, out of a total number of 36 in the office. The study focused on artificial lighting and natural lighting in the studio and at individual workstations. A three-point rating scale of "excellent", "average" and "poor" was used. Simple percentages were used to draw conclusions. Poor lighting distribution and illumination were observed. Furthermore, the integration between lighting distribution and furniture layout were questioned. The results show that occupants that rated the lighting in the office to be "excellent" were seated close to the windows which have a view of outside. Araloyin (2010) investigated the influence of environment on workers' productivity in Obafemi Awolowo University, Ife. The researcher using a 4-point rating scale in an interview of 253 workers out of a total academic staff strength of 1561 discovered that 66% of workers interviewed opined that the lighting condition of the offices are considered as "less adequate" and "not adequate". Simple percentages and frequency distribution techniques where used for the analysis. The researcher buttressed that lighting amongst other factors would allow workers to function effectively and efficiently. Hence the relativity of task in library also applied.

2.1. Recommended Library Light Levels
Light level or illuminance is the total luminous flux incident on a surface, per unit area. (Engineering toolbox, 2011). A similar definition by Illuminating Engineering Society of North America, (IESNA, 2000) as cited in National Renewable Energy Laboratory (2005) states that illuminance is defined as the area density of the luminous flux incident at a point on a surface. Illuminance is a measurement of radiation as sensed by the human eye. Every human eye senses radiation slightly differently, but a standard spectral response curve is defined by the Commission International de Éclair age (CIE, International Commission on Illumination as cited in National Renewable Energy Laboratory, Op cit). The lux is used to measure the adequacy of lighting for a task. The metric unit of

lluminance islux (in the metric SI system) which is the number of lumens per square meter (IESNA, op cit). Another unit is the foot-candle (ftcd, fc, fcd), which is the number of lumens per square foot. Thus; 1 lux = 1 lumen / sq meter =0.0001 phot = 0.0929-foot candle (ftcd, fcd). The outdoor light level is approximately*10,000 lux* on a clear day (see table 1). In the building, in the area closest to windows, the light level may be reduced to approximately*1, 000 lux*. In the middle area it may be as low as *25 – 50lux*. Additional lighting equipment is often necessary to compensate the low levels. (engineeringtoolbox.com,2011). The recommended librarylighting levels in the 1930s were around 269 lux, the 1960 recommended practice for office and library lighting guidelines advisedilluminance levels of between 1076 –1615 lux (Oldfield, Trabucco, & Wood,2009). Today the light level is more common in the range *500 - 1000 lux* -depending on activity. For precision and detailed works, the light level may even approach*1500 - 2000 lux* (See Table 2).

Condition	**Illumination*(ftcd)***	***(lux)***
Sunlight	10,000	107, 527
Full daylight	1,000	10, 752
Overcast day	100	1,075
Very dark day	10	107
Twilight	1	10.8
Deep twilight	0.1	1.08
Full moon	0.01	0.108
Quarter moon	0.001	.0108
Star light	0. 0001	0.0011
Overcast light	0.00001	0.0001

Table 1: Common light levels outdoor at day and night
Source: (www.engineering toolbox.com, 2011).

The National Building Code section 6.2.2.1 under its environmental and general building requirements recommends 50 lux for bathroom and toilet room lighting. It further specifies an average illumination of 64.58 lux for all habitable and occupiable rooms. The code discusses generally without specifying minimum average illuminations for specific tasks.
Ogunsote (2012) discussed the advantages of the reduced need for power and artificial lighting in his 'characteristics of climate sensitive buildings' which include:
1. Optimum size of openings,
2. Maintaining relatively small cooling loads through efficient cross ventilation of all rooms and by screening from sunlight.
3. Recessed windows.
4. Projected parapet wall casting deep shadows on the windows and by window fins.
5. Balconies – walkways especially around courtyards in buildings acting also as protection from driving rain.
6. Double volumes for extra cross ventilation
The Illuminating Engineering Society (IES) has published illuminance recommendations for various activities. These tables cover both generic tasks (reading, writing etc.), and 100's of very specific tasks and activities (such as drafting, parking, milking cows, blowing glass and baking bread). All tasks fall into 1 of 9 illuminance categories, covering from 20 to 20,000 lux, (2 to 2000 foot candles). The categories are known as A - I and each provide a range of 3 illuminance values (low, mid and high). See Table 2.

Activity	**Category**	**Lux**	**Foot-candles**
Public spaces with dark surroundings	A	20-30-50	2-3-5
Simple orientation for short temporary visits	B	50-75-100	5-7.5-10
Working spaces where visual tasks are only occasionally performed	C	100-150-200	10-15-20
Performance of visual tasks of high contrast or large size	D	200-300-500	20-30-50
Performance of visual tasks of medium contrast or small size	E	500-750-1000	50-75-100
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000	100-150-200
Performance of visual tasks of low contrast or very small size over a prolonged period	G	2000-3000-5000	200-300-500
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000	500-750-1000
Performance of very special visual tasks of extremely low contrast	I	10000-15000-20000	1000-1500-2000

Table 2: IES Illuminance categories and values - for generic indoor activities
Source: Bureau of Energy Efficiency, (2015)

A-C for illuminance over a large area (i.e. lobby space)
D-F for localized tasks
G-I for extremely difficult visual tasks
Using the task category Library illuminance is in category E.

2.2. Methods of Measuring Light Levels

The Performance Metrics Project of the U.S. Department of Energy commercial buildings research (2005) activity's goal is to standardize the measurement and characterization of building energy performance. Its main products are clearly defined energy performance metrics and standard procedures for determining the performance metrics; its intents are to define common language and to create standards that produce consistent results independently of the user. In order to achieve standardization and to avoid the common pitfalls of too few or too many data, two levels are suggested;

Tier 1: Simple calculations using standard measure like the electricity bills paid in the building.

Tier 2: A procedure that gives seasonal and/or hourly results and requireson-site measurements. Measurements for this metric should be taken over 3 to 4 days, two weeks, but preferably one year of data collection, is typically required to obtain results. Shorter measurement periods will increase the uncertainties in the results. Illuminance is measured on several horizontal surfaces within the building. The purpose of this measurement is to show the illuminance on horizontal working surfaces under various conditions throughout the year. Photodiodes are the most common sensors for illuminance measurements. They have a nearly linear output and are very stable. The Installed Lighting Power (LPD) and lighted floor area showing number of lamps and the lamp type are also recorded. A central data logger might be required to store data, because of the memory capacity and dependable nature.

Joseph (2011) advises that measurement should be carried out at a work plane of 1m and describes the locations for the measurement. In a single room with a single luminary, the room is sub divided into four sections. The measurement point *p1*, *p2*, *p3*, *p4*where none is directly under the light sources (windows or lamps). The average for the four points is termed, the average illuminance, *p* in the area. Dodo& Zinkandar (2011) identified methods for quantifying day lighting levels as the scale model, daylight calculation by hand, computer day lighting models and other engineering software. The effects of daylight and dark areas in an interior environment was further described that "light-zone has the potential of 'revealing' space, form, and matter, whereas deep shadows and darkness conceal…thus an interior light-zone's intensity as a 'field of energy' will depend upon the size, shape/form and placement of the opening, as well as the attributes of the space 'illuminated surfaces".

The floor plans in Figure 5 and 6, shows the points determining the illuminance and luminance level are depicted by the blue circular spot.

2.3. Site Location and Building Description

The library is adjacent the old school of pure and applied sciences to the left and back while school of technology and science education bound it by the right with a road separating them. To the front is the university commercial center.The building has a total floor area of 2,344.72sq. metres and a total height of the building is 10.73meters. The spaces are partitioned by plastered sandcrete walls that are painted basically off white and cream colors as well as ply wood partition on the first floor. And windows in the building are projected aluminum windows.

According to Filibus, (2011)Ibrahim Badamasi Babangida library of the Modibbo Adama University of Technology, Yola was founded in 1982 and commences full operation in 1983 previously the library was operating at the temporary building on the present school of post graduate studies. On October, 1990 it was moved to its present location. The library is a one storey building with two reading halls, several administrative offices and conveniences located on both floors. Automation of the IBB library started in 2002/2003 session, and was fully automated by 2007 at the time prof. B.S.H. Womboh was theuniversity librarian. At optimum utilization, the library was design for 750 readers and has the capacity to housed 50,000 volumes of books. It has 56 titles of current journals on subscription with 3700 journals.

Figure I and II shows the floor plans of the building with the blue circular print as lux meter positions. Figure III and IV are the sections of the IBB library.

Figure 5 and 6 shows pictures of the study building.

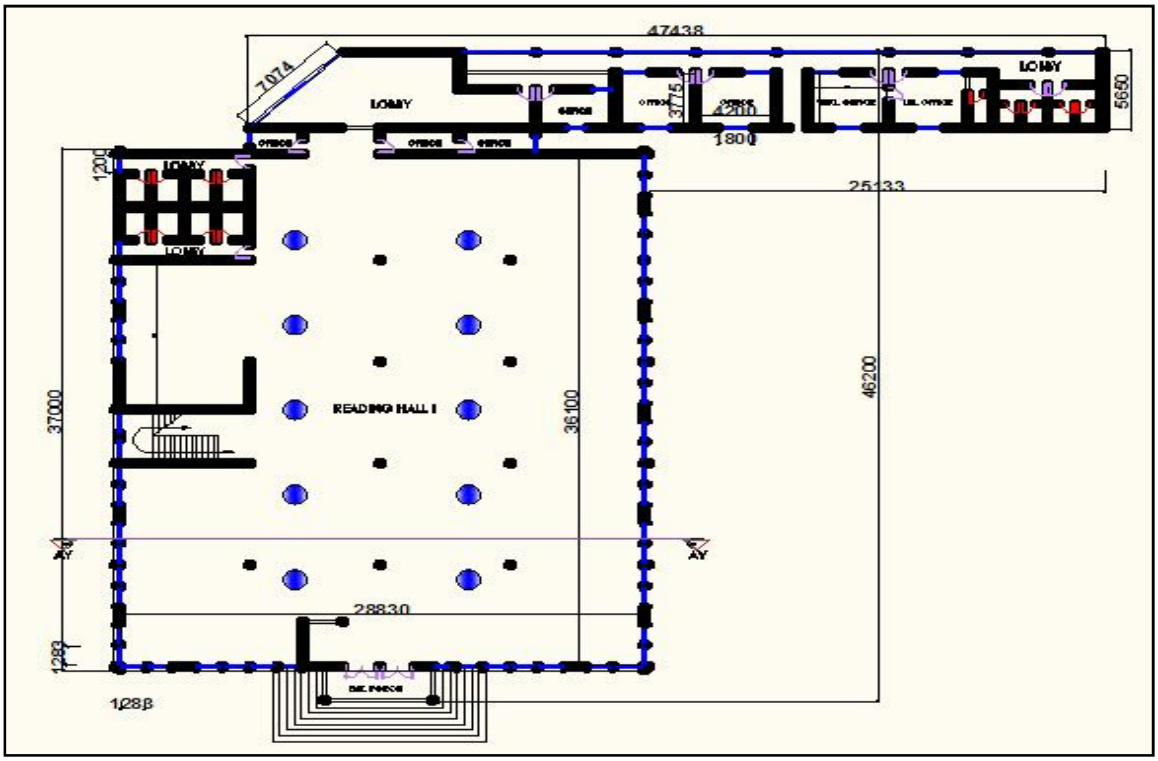

Figure 1: Ground floor plan of the IBB library showing positions of lux meter
Source: Researchers field work (2015)

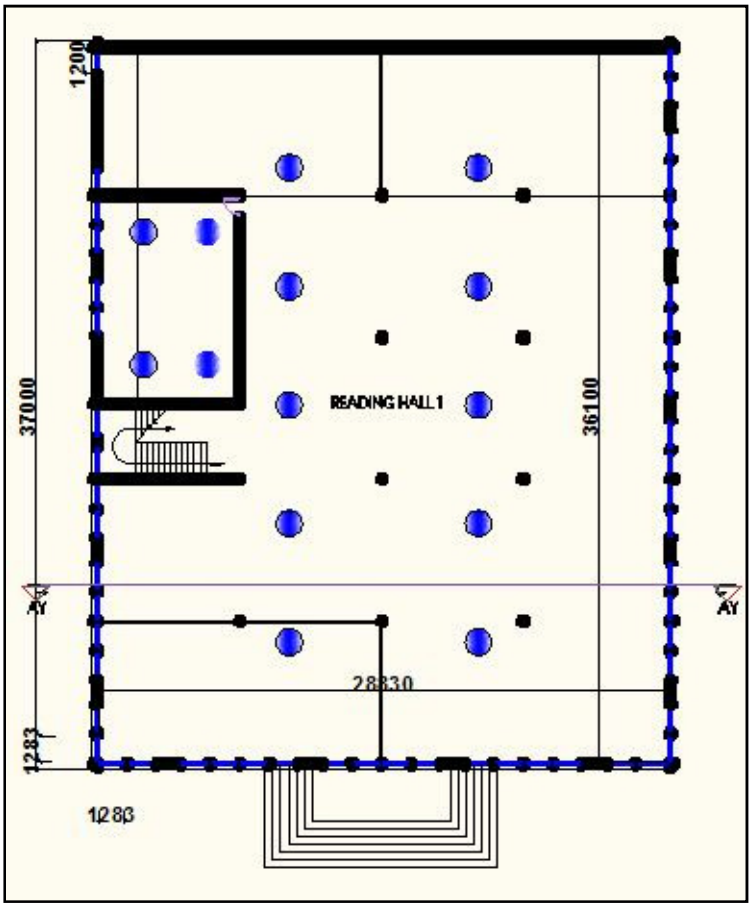

Figure 2: First floor plan of the IBB library showing positions of lux meter.
Source: Researchers field work (2015)

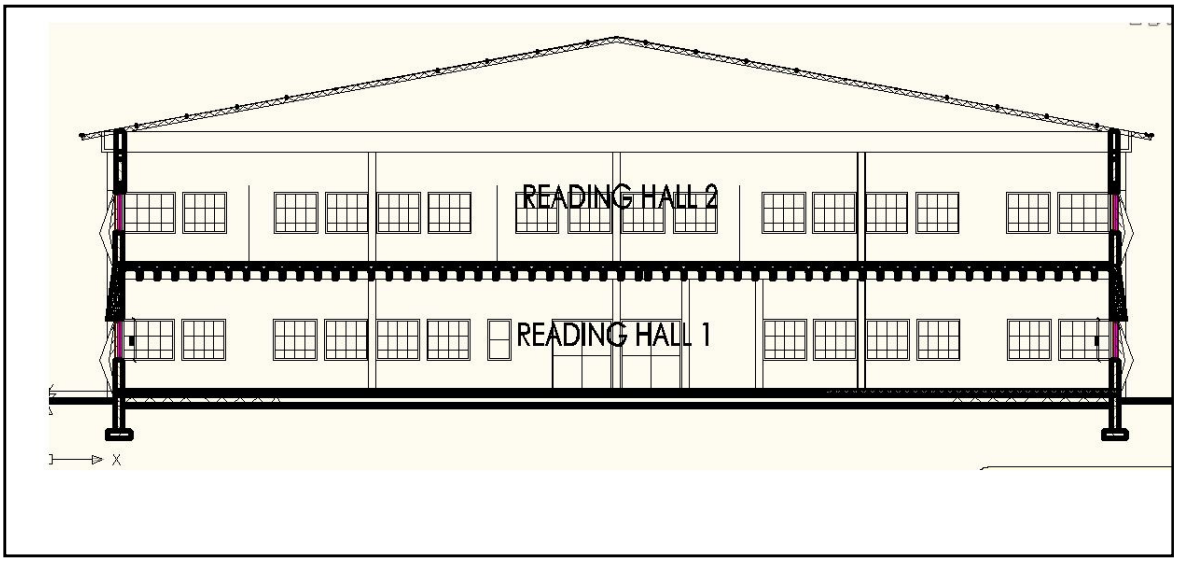

Figure 3: Section AY-AY of the IBB library
Source: Researchers field work (2015)

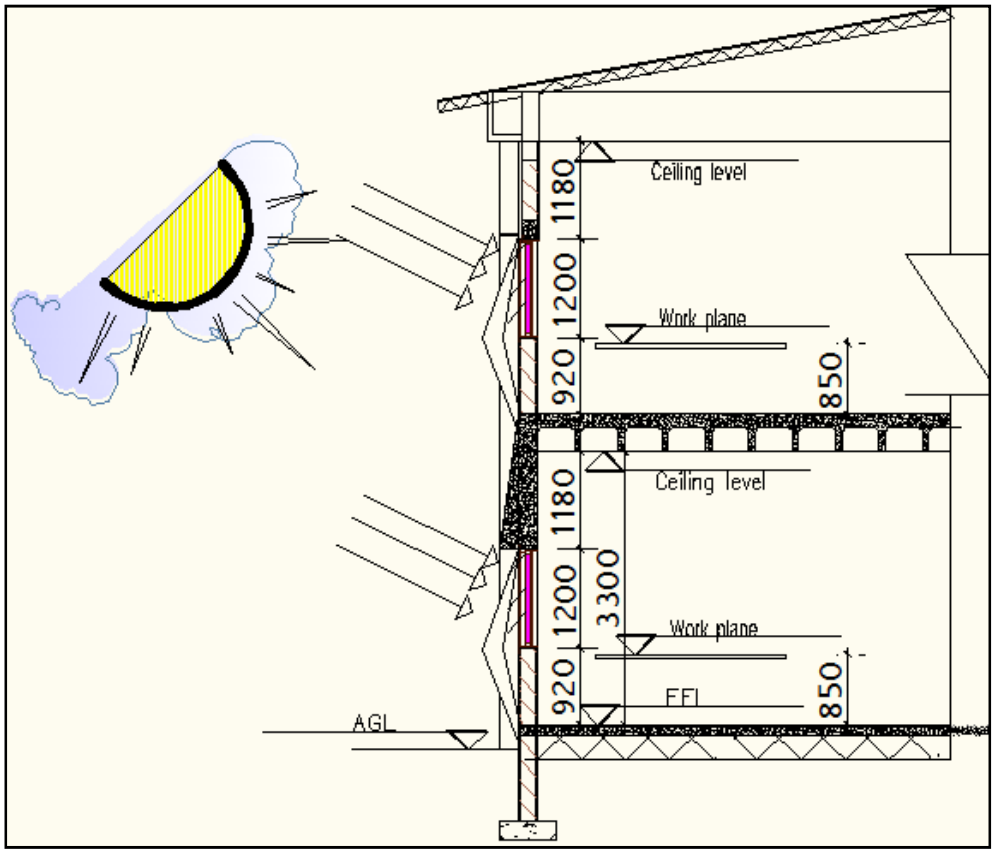

Figure 4: Detail Section AY-AY of the IBB library showing daylight penetration and work plane.
Source: Researchers field work (2015)

Figure 5: Perspective view of the IBB library at the Eastern side
Source: Researchers field work (2015)

Figure 6: Perspective view of the IBB library at the North- West
Source: Researchers field work (2015)

Figure 7: Digital camera used for taking photographs

Figure 8: Digital lux meter for light measurement

2.4. The climate of Yola, Adamawa state

Adamawa state is located at the eastern part of Nigeria, it lies between latitude 7 and 11N of equator and between longitude 11 and 14 east of Greenwich meridian. It shares boundary in the south and west with Taraba state and in the northeast with Gombe while in the north it bordered Borno. Adamawa state was created from the defunct Gongola state on august 27, 1991. Jimeta is representing the administrative capital while Yola is the principal capital. (Filibus, 2011).

According to Adebayo & Tukur, (1999) as reported in Filibus, (2011) Adamawa has a monthly mean sunshine hour of 220hrs between January to April, there is a decline in sunshine hours between May and September due to increasing cloudiness over the state. The average mean sunshine is 8. 3hrs.The mean temperature of Yola range from 26.7-27.0 degree Celsius. The relative humidity is extremely low (20%- 30%) and it starts toincrease from April and reaches 80% in august and September. More so, it states to decline as from October due to cessation of rain.

3. Data Analysis, Presentation and Discussion

The lighting analysis of the building in use reveals that much of the space recorded an average illumination level below the recommended standard. The research reveals that locating windows on the external walls of buildings increases the illuminance levels in the spaces. The dark spaces are usually affected during power outages which are a common feature in some part of the building. The circulation areas in the building however have adequate lighting. These spaces include, the 'Toilets' and the lobby. The requirement for a public space with dark surrounding is 20 lux. Tables 3a, 3b, and 3c presented the data collected.Doors openings in the reading hall is considered because of it transparent nature.

S/no	Description	Window area (Sq.m)	Average Illumination (lux)	Floor area(Sq.m)	Percentage (%)
1	Lobby, Stairwell and toilets area with natural lighting to the value of 20 lux minimum.	19.08	21.50	98.80	100.00
2	Lobby, Stairwell and toilets area with natural lighting below the value of 20 lux.	19.08	Nil	0.00	0.00
	Total			98.80	100.00

Table 3a: Lighting levels in the library ancillary spaces.
Source: Researcher's field work (2015)

S/no.	Description	Window area (Sq.m)	Average Illumination (lux)	Floor area(Sq.m)	Percentage (%)
1	Office Area with natural lighting to the value of500lux minimum.	25.92	508.2	39.60	24.09
2	Office Area with natural lighting below 500 lux.	25.92	110.20	124.80	75.91
	Total			164.40	100.00

Table 3b: Lighting levels in the offices within the library.
Source: Researcher's field work (2015)

S/no	Description	Window area (Sq.m)	Average Illumination (lux)	Floor area(Sq.m)	Percentage (%)
1	Reading halls area with natural lighting to the value of 500lux minimum.	149.34	520.50	42.80	02.06
2	Reading halls with natural lighting below 500 lux.	149.34	85.20	2038.72	97.94
	Total			2081.52	100.00

Table 3c: Lighting levels in the library halls.
Source: Researcher's field work (2015)

S/no.	Description	Floor area (Sq.m)	Percentage (%)
1	Average area with natural lighting to the value of recommended standard.	82.40	03.51
2	Average area with natural lighting below the recommended standard	2262.32	96.49
	Total	2,344.72	100.00

Table 3d: Area with recommended light level and summary of measured light level.
Source: Researcher's field work (2015)

The IBB library has the following building composition as shown in table 3e.

S/N	Components	Dimension (m)	Quantity	Type	Area (m^2)	Material finishing
1	Window	1.20 x 1.2	49	Projected window	69.12	Transparent glass
2	Door	1.80 x 2.10	2	Double leaf single swing door	7.56	Transparent glass
3	Floor	36.10 x 28.83	1	Terrazzo floor	1040.76	Opaque floor
4	Window sill height	0.92 x 1.20	49	Hollow block wall		Opaque sandcrete wall
5	External shading device	0.15 x 2.00		Vertical and horizontal shading device		Precast concrete
6	Building geometry			Rectangular form		Grey color texcote paint

Table 3e: IBB Library Building Composition
Source: Researcher's field work (2016)

By design some spaces especially the offices and ancillary spaces have moderate access to natural lighting and have recorded higher levels of illumination
According to Dubois (2011) as cited in Sa'id, et al (2014) performance indicators are as in table 4

Performance Indicator	Interpretation
1 Work plane illuminance	
< 100 lx	Too dark for paper and computer work
100-300 lx	Too dark for paper work / acceptable for computer work
300-500 lx	Acceptable for paper work / ideal for computer work
> 500 lx	Ideal for paper work / too bright for computer work
2 Daylight factor	
< 1 %	Unacceptably dark, negligible potential for daylight utilization
1-2 %	Acceptable, small potential for daylight utilization
2-5 %	Preferable, large potential for daylight utilization
> 5 %	Ideal for paper work, too bright for computer work, total daylight autonomy

Table 4: Lighting Performance Indicator
Source: Sa'id, et al (2014).

3.1. Recommendations
The simple LED alternative lighting source that backs up power while PHCN supply is available and discharges when there is power outage is a temporary solution. Various models are available in the market. The vertical fabric blinds may come tothe rescue where drapes would reduce drastically the limited lighting level. Alternatively, installation of roller shade blinds which can be easily controlled for optimum light penetration. Also, translucent panel could be used to replace the transparent panels. In areas such as post graduate reading room, Computer/digital media library, where a unit is enclosed fully to headroom with solid wooden board partition prevents natural lighting from reaching some spaces, remodeling sections of the building to allow for natural lighting, this may have achieved using2100mm high aluminum or wooden partitions combined with translucent infill panels. And the ceiling should be replaced with USG majestic acoustical reflective ceiling panels. Increasing window opening up to 67% could allow for better Natural lighting especially at the North elevation. The terrazzo floor finish should be replaced with light colored glazed granite tiles.

3.2. Conclusions

Library buildings in the tropics should be designed in such a way as to enable sufficient natural lighting in the interiors.

3.3. Areas for Further Research

Analysis of natural lighting in the library buildings of other universities in Nigeria could be carried out. Furthermore, survey methods could be used to gather data from members of users; this may as well serve as feedback for the research.

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