Journal of Construction in Developing Countries

Manuscript Title Investigation of Indoor Daylight Condition of Library Reading Spaces in a Tropical Climate

Authors Chiamaka Okwuosa, Amaka-Anolue Basil, Eziyi Ibem and Ogechi Okwuosa

Investigation of Indoor Daylight Condition of Library Reading Spaces in a Tropical Climate

*Okwuosa Chiamaka Christiana[1], Basil Amaka-Anolue Martha[2], Ibem Eziyi Offia[3], and Okwuosa Ogechi Emeka[4]

[123]Department of Architecture, Faculty of Environmental Studies, University of Nigeria, Enugu Campus Nigeria.

[4]Department of Chemical Engineering, Enugu State University of Science and Technology, Enugu, Nigeria.

chiamaka.ugwu@unn.edu.ng

ABSTRACT

Reading spaces in the library require proper lighting for the comfort of the users. Good daylight conditions in the library help to improve mood, enhance morale, reduce eyestrain, improve the learning process, and save energy. The paper investigated the daylight condition of the twelve reading spaces labelled from HALL A to HALL L and determined the influence of architectural daylight parameters on the daylight condition. With the use of the Climate-based daylight modelling (CBDM) approach, it determined their Useful Daylight Illuminance (UDI), Daylight Autonomy (DA), and Total Annual Illumination (TAI). The study employed Velux Daylight Visualizer (VDV) simulation software. The results showed that the mean UDI 300 – 500DA for Hall H was 84% and 69% (pass), TAI was 4314 klus hrs, and the luminance mean value was 255 cd/m2 (moderate). The daylight parameters collectively influenced this result. However, the ones that influenced the result more were window floor ratio (WFR), glazing /shading/ source of obstruction, and wall finish/colour/ceiling finish. Since the daylight conditions of these halls studied met the design threshold, it showed that these design parameter strategies should be adopted when considering a new design of reading spaces in tropical regions.

Keywords: Daylight, Illuminance, Library, Reading spaces

1. INTRODUCTION

The condition of daylight in reading spaces is considered a driving factor for the well-being of the users. Daylight combines all direct and indirect light originating from the sun during daytime. Of the total solar energy received on the surface of the earth, over 40% is visibly radiated, and the rest is ultraviolet (UV) and infrared (IR) wavelengths (Velux,2014). The library contributes to education and societal development. Reading tasks in libraries require adequate lighting. Proper lighting is crucial to the overall success of a library (Malman, 2005). Good lighting design in library buildings results from both technical skill and art on the part of the designer (Malman, 2005). A daylighted space combines high occupant satisfaction with the visual and thermal environment, with low overall energy use for lighting, heating, and cooling (Velux, 2014). Daylighting causes improved mood, enhanced morale, less fatigue, reduced eyestrain, decreased stress, improved learning process, and energy savings (Robbins (1986); The Chartered Institution of Building (CIBSE) (2011); Pikas et al. (2014)). Studies have shown that daylighted interior spaces result in more effective learning in libraries, schools, and workspaces (Heschong (2002) & Christoffersen et al. (1999). Daylighting design considerations should include orientation and building site characteristics, facade and roof characteristics, size and placement of window openings, glazing and shading systems, and geometry and reflectance of interior materials used for the surfaces. Proper daylighting design ensures adequate light during the daytime (Velux, 2014). Although some electric light sources closely resemble some specific daylight intensity, no light source manufactured can replicate the variations in the light spectrum that arise with daylight at various times, during different seasons, and in various weather conditions (Boyce et al., 2003). Maximizing natural lighting (daylighting) can significantly reduce artificial lighting and energy consumption. A good daylight quality in a building is highly desirable for the well-being and productivity of the users (CISBE, 2011). According to Velux (2014), daylighting systems can be so simple, from combining window design with appropriate internal and external shading to systems designed to redirect sunlight or skylight to areas where it is required, such as sun tunnels. Daylighting has the potential to reduce energy costs significantly. Several studies in buildings have recorded the energy savings for electric lighting from using daylight to be between 20% and 60% (Galasius et al.,2007) and range of 16% and 20% (Mardeljevic et al., 2012).

In the library, daylight creates an ambience of quiet contemplation and visual comfort, which links the modern library user with the pre-technological past. For centuries, memorable libraries have been known with volumes and surfaces illuminated with daylight, providing glare-free light in reading spaces (Edward, 2005). The recommended daylight level for library reading and studying areas is between 300 lx and 500 lx (The Illuminating Engineering Society of North America (IESNA) (2013); European Standard for Lighting Requirements (EN-12464-1).

In tropical regions, especially in Nigeria with its hot and humid climates, despite the abundance of sunlight, daylight levels in interior spaces have been identified to be grossly inadequate, not consistent, and sometimes with glare (Ayoosu et al., 2020). According to their research, most lecture or reading spaces do not have specific models for daylight designs. Also, according to Kent & Jakubiec (2021), buildings in these climates are often heavily shaded to prevent overheating as the cooling required is much higher than lighting, and this might cause insufficient daylight because shading reduces it significantly. However, buildings designed with the National Building Code of Nigeria may not have quality daylight in reading spaces since the code does not have that. Therefore, most buildings were designed and constructed without consideration of optimized daylighting strategies in their interior spaces. Based on these, there is a need to determine the daylight conditions of existing interior spaces.

2. THE RESEARCH AIM

This paper aimed to investigate the daylight condition of twelve reading spaces in a federal university in a tropical climate. The objectives are to identify their architectural design parameters for daylighting, to evaluate the daylight conditions of those reading spaces using the Climate-Based Daylight Modelling (CBDM) approach, and to determine the influence of the identified architectural design parameters on the daylight conditions.

2.1. Climate-Based Daylight Modelling

Climate-based daylight modelling is the predictions of various radiant or luminous quantities (e.g. irradiance, illuminance, radiance, and luminance) using sun and sky conditions obtained from standard meteorological datasets. Its principles have been highly described around the turn of the millennium (Mardaljevic, 2002; Reinhart &Herkel, 2000). Annual location-based weather data helps to calculate lux levels. However, targets are adjusted relative to the needs of the users. Useful daylight illuminance (UDI), spatial daylight autonomy (DA), and total annual illumination (TAI) are the three main criteria in climate-based daylight modelling to investigate the daylight condition of room space. Also, daylight factor (DF) is another criterion used to predict the daily daylight condition, which will not determine useful daylight illuminance, unlike the CBDM approach. Useful daylight illuminance (UDI) is a daylight availability metric that indicates the percentage of the occupied time for a target range of illuminances at a point in space (Velux, 2014). Useful daylight illuminance (UDI) is the annual occurrence of illuminances across the work plane range that are useful to the users. Daylight illuminances in the range of 100 and 300 lx are effective as the sole source or in conjunction with artificial lighting. Daylight illuminances between 300 lx and 3000 lx are often perceived as desirable (Mardaljevic et al., 2012). Spatial daylight autonomy (SDA) is a daylight availability metric that shows the percentage of the occupied time for the target illuminance at a point in space (Reinhart and Walkenhorst, 2010). A target illuminance of 300 lx and a threshold DA of 50%, meaning 50% of the time that daylight levels are above the target illuminance. They are values promoted by the Illuminating Engineering Society of North America (IESNA, 2014). Total annual illumination (TAI) measures all the visible daylight energy incidents on the surface or occupancy period evaluated (CIBSE National Conference, 2006). The exposure to illumination is known to influence the preservation of books and papers each year. For example, the Scottish Museums Council recommends a maximum exposure of 450,000 lx hours per year for "moderately sensitive items" and 100,000 lx hours per year for sensitive items. As stated earlier, the objectives are to identify the architectural design features, investigate the daylight condition by obtaining the UDI, SDA, and TAI, and determine the influence of architectural design features on daylight conditions.

3. THE STUDY AREA

The library building houses the twelve reading spaces and has an orientation of 450N-E. The building has 4 (four) floors, but the reading areas occupy three floors (first, second, and third floors) with front and rear wings in each. The study area is in the hot-humid tropical environment of Enugu, one of the major cities in southeastern Nigeria, which lies within latitudes 60161 N and 60311north of the equator and longitudes 70201 and 70411east of the Greenwich Meridian that covers an area of about 630km2 (Onunkwo-Akunne et al., 2012).

In the tropical region, but unlike in some others, there are similarities between the seasons. There is a minor variation in the daylight time and the temperature differences between summer and winter, which is minimal. The average daytime temperature range is between 300C and 370C, depending on the season. The temperature rises to 43 °C in some parts. In some regions during the cold season, the monthly mean temperature reduces to 18°C (World Data, 2023). According to weather-spark, concerning the cloud cover of the study area, the mean percentage of the sky covered by clouds creates significant seasonal variation over the year. The clear part of the year starts around November on the 20th day and stays for 3.0 months, stopping around February on the 18th day. The most clear month is December, during which the sky is clear, substantially lucid, or incompletely cloudy 46% of the time. The cloudier part of the year starts around February on the 18th day and stays for 9.0 months, stopping around November on the

20th day. The cloudiest month is May, during which the sky is overcast(heavy) or substantially cloudy 85% of the time(Weather Spark, 2023). With this, the study area presented itself with three sky conditions (clear sky, intermediate sky, and overcast sky conditions). These sky conditions have the outdoor sky illuminance distributions as >10,752 lx, 10,752 lx, and 1075 lx, respectively (Engineering Tool Box. 2023).

4. THE MATERIALS AND METHODS

The research employed Velux Daylight Visualizer (VDV) simulation software to investigate the daylight condition of the selected reading space. This daylight simulation software is ideal for evaluating compliance with the European Standard for Daylight in Buildings EN 17037 (European Standard for Daylight Requirements in Buildings, 2018), and this can work with any BIM/CAD software. EN 17037 is not used based on the location but on the required standard of daylight in the internal reading space for the users, which is in the range of 300 lx and 500 lx). Velux Daylight Visualizer Software has other standards, although the EN 17037 standard has a UDI level equivalent to the globally accepted level of illuminance (300 lx and 500 lx). Automated reports are gotten using VDV software. It uses Energyplus Weather Format (EPW FILES) to predict the direct daylight of the study area. The hourly diffuse sky component was from TMY weather data. Other data sources are from site/ eld study and observation, measurements of spaces or things in a direct manner and relevant sketches, taking photographs of the spaces, and review of published and unpublished materials such as books, journals, magazines, monographs, seminars, conference papers, meteorological data, among others.

4.1 Sample Selection

Sample selection was employed to obtain the number of reading spaces that can represent the simulation of the reading spaces. Determining the daylight condition depends highly on the level of illuminance. There is a strong relationship between Window-Floor-Ratio (WFR) and daylight illumination levels (Al-Tamimi et al., 2016). Therefore, of all the architectural design features, the Window-Floor-Ratio (WFR) was chosen as a reliable factor to consider in determining the sample size. The actual WFR percentage for any learning and educational space should be between 20% -25%. A stratified random sampling technique was employed, and WFR percentage ranges were in ve groups. They were, 1% - 9% (shown as very low), 10 % - 14% (shown as low), 15% - 19% (slightly moderate), 20% - 25% (shown as moderate), and 26% - above (high). All the reading spaces were found in the same group (10%-14%) since their WFR is between 10% and 12.8%. Among those reading spaces, one was used to represent others. The selected reading space is HALL H.

4.2 Data Collection Procedure/Process

The data were primarily from published and unpublished materials, existing records, and meteorological data. Observation schedules, measuring tape, paper, and cameras were tools used at the site during the first stage of the site visit. And their accuracy was determined by the researchers. The second stage involved visits for data collection with the research tools. In the early hours of the day, with the help of other research assistants, different dimensions of the walls and daylight features were noted using an observation schedule. The reading spaces were drafted using sketch-up software and imported to Velux daylight Visualizer for simulation to determine daylight conditions and luminance levels.

4.3 Velux Daylight Visualizer Validations

The software was validated using the CIE 171:2006 test cases and assessment of the accuracy of lighting computer programs. Its simulation results were verified by ENTPE (National School of State Public Works) in detecting the accuracy of the lighting and also in the investigation - Daylight Calculations in Practice SBI 2013:26.

Further validation was done by the author using Mean Bias error (MBE) and Root Square mean Error (RMSE). MBE and RSME estimate the average bias in the model by determining if the model can support subsequent operations. It is crucial to establish the acceptable magnitude of error when performing a validation study for a simulation. Reinhart and Walkenhorst (2001), while validating a simulation done with daylight simulation software, stated that simulation should be reliable if the Mean Bias Error (MBE) is less than 20% and the Root Mean Squared Error (RMSE) is less than 32%. Also, McNeil and Eleanor (2012) deemed this threshold acceptable. Therefore, for this study, a threshold of 20% Mean Bias Error (MBE) and 32% RMSE in illuminance simulation appear typical in all daylight research. The equations for MBE and RMSE are as shown below:

$$\%MBE = \frac{100}{M}\sum\frac{(S-M)}{N} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots EQN\ 4.1$$

$$\%RSME = \frac{100}{M}\sum\frac{(S-M)^2}{N} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots EQN\ 4.1$$

Where M is the measured value of illuminance, S is the simulated value, and N is the number of observations.

The %MBE and %RSME of the selected reading space (Hall H) were calculated and compared to validate the simulation values. For the measured values (M), the HALL H was divided into nine (9) locations/ sensor points (see Figure 1a and Figure 1b).

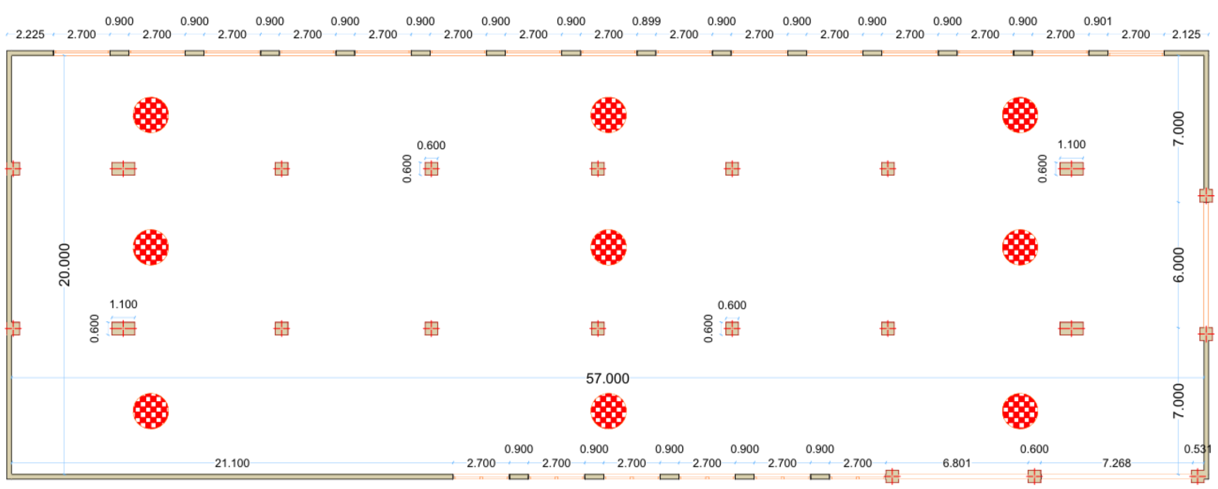


Figure 1a: Floor plan of UNN-HALL H with the 9 sensor points indicated with red circles.

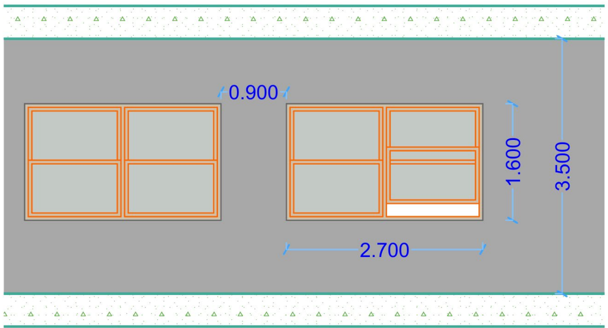


Figure 1b: Typical elevation of UNN-HALL H with the 9 sensor points indicated with red circles.

The division covered more than 80% of the reading hall. Nine (9) light tools (Lux H1010 light meter) were placed at those sensor points at the work plane of 850 mm (since the height of the reading desk is 750mm). The eld measurement happened on 13th June, during the cloudiest period (overcast) of the year. The electric light was off, and measurements occurred every 15-minute interval from 8 am to 4 pm (the reading hours in the library). The mean values were for every 2 hours (8 am -10 am, 10 am -12pm, 12 pm – 2 pm, and 2 pm – 4 pm). Hourly daylight illuminances at height across the ground floor using the rigorously validated daylight coefficient technique are okay (Mardaljevic, 2000).

For simulated values (S), the velux daylight software was set at the exact location using EPW le, the same month of the year, orientation, and sky condition, and was for every 1 hour. The mean was for every two-hour intervals.

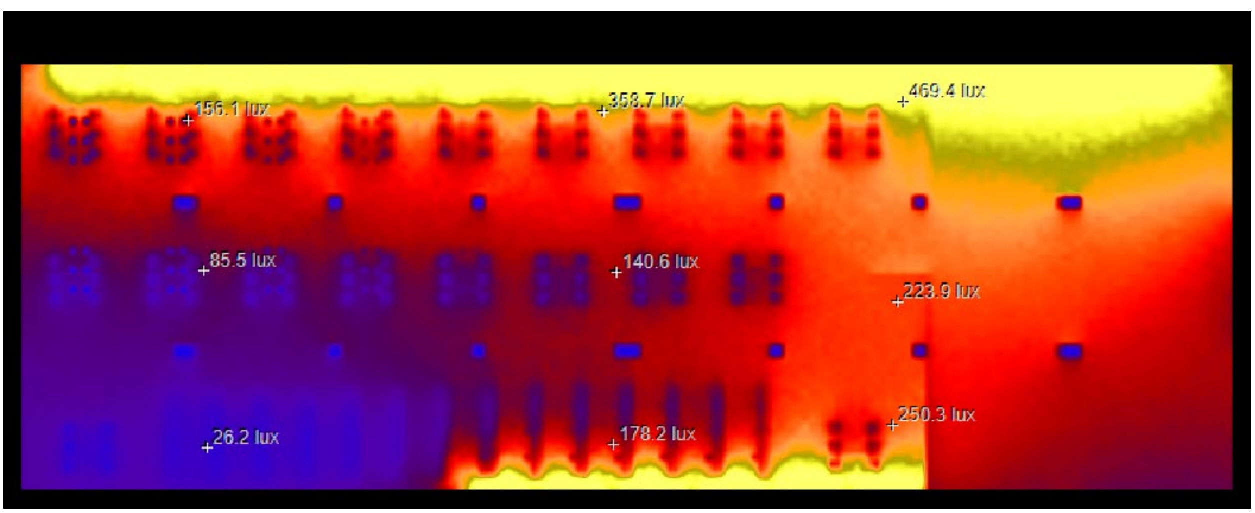


Figure 2: Simulated values of UNN-HALL H at 8am

Figure 2 shows the simulated values at 8 am. The blue colour represents very low lux (0 lx – 100 lx), the red colour (100 lx – 250 lx), the orange colour (250 lx-400 lx), and the yellow colour shows high lux value from 400 lx and above. The values obtained from the measured and simulated points showed that the %MBE and %RSME do not exceed 20% and 37%, respectively. The %MBE was between 7% and 15%, and the values of RSME were in the range of 9% and 30%.

5. SIMULATION PROCEDURE

In determining the daylight condition (UDI, DA, and TAI), the Velux daylight software was adjusted to the study location by importing the energy-plus weather (EPW) le, taking note of the site orientation. The simulation adhered to three sky conditions in the study area: intermediate (February), overcast (May), and clear sunny (November). The simulation software was automatically set for the 21st of each month yearly.

In determining the annual percentage of the UDI per fraction of the work plane and percentile of the reading spaces, the work plane was 850mm above the ground. The UDI depicts the annual occurrence of daylight falling within a given range. Observations showed that for daylight to be Useful to the users, it will be within the threshold of 300 lx – 2000 lx (Nabil and Mardaljevic, 2005). However, the Useful range has been extended to 3000 lx as the lower threshold may not reflect the use of glare protection devices found in modern buildings. In tropical buildings, Kent and Jakubiec (2021) found that occupants could be more sensitive to glare, which could also imply that occupants prefer little daylight so long as it meets their visual requirements. However, the standard EN 17037 states that space provides adequate daylight if a target illuminance level is across a fraction of the reference plane within a space for at least half the daylight hour. According to them, this "fraction" of space for the target level (spatial scale) should be at least 50% of the floor area. Therefore, the target daylight autonomy is 50% for 300 lx, 500 lx, and 750 lx. The minimum target daylight autonomy is 50% for 100 lx. Since the recommended light levels indicated that the required daylight level for library reading and studying spaces is between 300 lx and 500 lx, however, a minimum of Useful Daylight Illuminance (UDI) within the range of 300 lx and 500 lx should be between at least 50% of the working year.

6. RESULTS

6.1 Architectural Design Parameters of the Reading Spaces

The twelve reading spaces of the library are presented in Tables (1 - 3) to describe their unique architectural design parameters, and they are twenty-five (25) in number.

Table 1 Reading spaces on the first floor

READING SPACES – FIRST FLOOR						
S/ No	**ARCHITECTURAL DESIGN PARAMETERS**	**Hall A. (General reading section)**	**Hall B. (General reading section)**	**Hall C. (Science and tech. section)**	**Hall D. (Circulation section)**	**Hall E. (Reference section)**
1.	Space Geometry	Rectangle	Rectangle	Rectangle	Rectangle	Rectangle

2.	Location	Right-side rear wing	Middle rear wing	Left–side rear wing	Right-side front wing	Left-side front wing
3.	Space Floor Level	First Floor	First floor	First floor	First floor	First floor
4.	Fenestration	Side-lighting	Side-lighting	Side- lighting	Side-lighting	Side-lighting
5.	Type of windows used	Projected glazed/ aluminium	Projected glazed/ aluminium	Projected glazed/ aluminium	Projected glazed/ aluminium	Projected glazed/ aluminium
6.	Locaton of windows	One side	One side	One side	Two sides	Two sides
7.	Glazing transmittance	6 mm Single clear	6 mm Single clear	6 mm Single clear	6 mm Single clear	6 mm Single clear
8.	Shading devices	Wall fins	Wall fins	Wall fins	Wall fins	Wall fins
9.	Wall Finishing	Painted	Painted	Painted	Painted	Painted
10.	Wall color	Creame	Creame	Creame	Creame	Creame
11.	Furnitures provided	Conference table/ chairs	Reading table/ chairs	Reading table/ chairs/shelves	Reading table/ chairs	Reading table/ chairs
12.	Furniture arrangement	One-seating	Six-seating	Six-seating	Six-seating	Six-seating
13.	Height of furniture Shelves - Tables -	0.75 m	2.25 m 0.75 m	2.25 m 0.75 m	0.75 m	0.75 m
14.	Type of door	Paneled wooden	Open space	Paneled wooden	Paneled wooden	Paneled wooden
15.	Floor finish	Ceramic tiles	Ceramic tiles	Ceramic tiles	Ceramic tiles	Ceramic tiles
16.	Ceiling material	Acoustic ceiling	Acoustic ceiling	Acoustic ceiling	Acoustic ceiling	Acoustic ceiling

17.	Source of obstruction	None	None	Left front wing	Right rear wing	Left rear wing
18.	Head room	2.8 m	2.8 m	2.8 m	2.8 m	2.8 m
19.	Window sill level	0.45 m	0.45 m	0.45 m	0.45 m	0.45 m
20.	Window widths - Window height -	2.7m 2.1 m	1.9 m – 3.5m 2.1 m	2.7 m 2.1 m	2.7 m 2.1 m	2.7 m 2.1 m
19.	Floor area	489 m^2	290 m^2	881.68 m^2	588.35 m^2	562.45 m^2
20.	Wall area (no openings) – Wall area -	276.6 m^2 220 m^2	197 m^2 162.4 m^2	355 m^2 241.6 m^2	276 m^2 208 m^2	276 m^2 196.6 m^2
21.	Number of windows	10	6	20	12	13
22.	Windows total area	56.7 m^2	34.65 m^2	113.4 m^2	68.04 m^2	73.7 m^2
23.	Window – Wall – Ratio	20%	17%	32%	24%	27%
24.	Window – Floor – Ratio	12%	12%	12.8%	12%	13%
25.	The main source of light	Daylight and electricity	Daylight and electricity	Daylight and electricity	Daylight and electricity	Daylight and electricity

Table 2 Reading spaces on the second floor

READING SPACES – SECOND FLOOR					
S/ No	**ARCHITECTURAL DESIGN** **PARAMETERS**	**Hall F. (Newspaper section)**	**Hall G.** **(Serial section)**	**Hall H.** **(General reading section)**	**Hall I.** **(General reading section)**
1.	Space Geometry	Rectangle	Rectangle	Rectangle	Rectangle

2.	Location	Right-side rear wing	Left-side rear wing	Right–side front wing	Left-side front wing
3.	Space Floor Level	Second Floor	Second floor	Second floor	Second floor
4.	Fenestration	Side- lighting	Side- lighting	Side- lighting	Side-lighting
5.	Type of windows used	Projected glazed/ aluminium	Projected glazed/ aluminium	Projected glazed/ aluminium	Projected glazed/ aluminium
6.	Locaton of windows	Two sides	Two sides	Two sides	Two sides
7.	Glazing transmittance	6 mm Single clear	6 mm Single clear	6 mm Single clear	6 mm Single clear
8.	Shading devices	Wall fins	Wall fins	Wall fins	Wall fins
9.	Wall Finishing	Painted	Painted	Painted	Painted
10.	Wall color	Creame	Creame	Creame	Creame
11.	Furnitures provided	Shelves/few tables/chairs	Shelves/ few tables/ chairs	Reading table/ chairs/shelves	Reading table/ chairs/shelves
12.	Furniture arrangement	One-seating	Four-seating	Six-seating	Six-seating
13.	Height of furniture Shelves - Tables -	 2.25 m 0.75 m	 2.25 m 0.75 m	 2.25 m 0.75 m	 2.25 m 0.75 m
14.	Type of door	Open entrance	Open entrance	Paneled wooden	Paneled wooden
15.	Floor finish	Ceramic tiles	Ceramic tiles	Ceramic tiles	Ceramic tiles
16.	Ceiling material	Plaster of paris (POP)	Plaster of paris (POP)	Plaster of paris (POP)	Plaster of paris (POP)

17.	Source of obstruction	None	None	None	None
18.	Head room	3.5 m	3.5 m	3.5 m	3.5 m
19.	Window sill level	0.45 m	0.45 m	0.45 m	0.45 m
20.	Window widths - Window height -	2.7m 2.1 m	2.7 m 2.1 m	2.7 m 1.6 m	2.7 m 1.6 m
19.	Floor area	1148 m^2	1185 m^2	1185 m^2	1005.5 m^2
20.	Wall area (no openings) – Wall area -	535.5 m^2 405 m^2	544.6 m^2 425.5 m^2	544.6 m^2 414.2 m^2	493.5 m^2 374.4 m^2
21.	Number of windows	23	21	23	21
22.	Windows total area	130.4 m^2	119.1 m^2	130.4 m^2	119.1 m^2
23.	Window – Wall – Ratio	24 %	22%	24%	24%
24.	Window – Floor – Ratio	11.3 %	10%	11%	11.8 %
25.	The main source of light	Daylight and electricity	Daylight and electricity	Daylight and electricity	Daylight and electricity

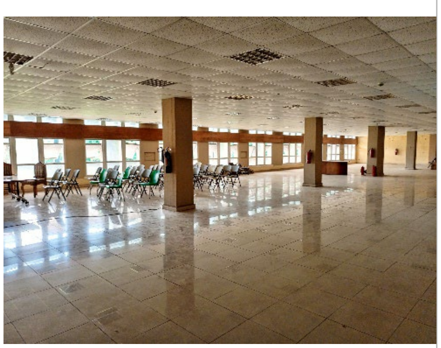
Table 3 Reading spaces on the third floor

READING SPACES – THIRD FLOOR				
S/ No	**ARCHITECTURAL DESIGN** **PARAMETERS**	**Hall J (Digital section)**	**Hall K.** **(Depository section)**	**Hall L.** **(Africana section)**
1.	Space Geometry	Rectangle	Rectangle	Rectangle

2.	Location	Both Right and left side of rear wing	Right–side front wing	Left-side front wing
3.	Space Floor Level	Third Floor	Third floor	Third floor
4.	Fenestration	Side- lighting	Side- lighting	Side-lighting
5.	Type of windows used	Projected glazed/ aluminium	Projected glazed/ aluminium	Projected glazed/ aluminium
6.	Locaton of windows	Two sides	Two sides	Two sides
7.	Glazing transmittance	6 mm Single clear	6 mm Single clear	6 mm Single clear
8.	Shading devices	Wall fins	Wall fins	Wall fins
9.	Wall Finishing	Painted	Painted	Painted
10.	Wall color	Creame	Creame	Creame
11.	Furnitures provided	Tables /chairs	Reading table/ chairs/shelves	Reading table/ chairs/shelves
12.	Furniture arrangement	Row-seating	Six-seating	Six-seating
13.	Height of furniture Shelves - Tables -	 0.75 m	 2.25 m 0.75 m	 2.25 m 0.75 m
14.	Type of door	Open entrance	Paneled wooden	Paneled wooden
15.	Floor finish	Ceramic tiles	Ceramic tiles	Ceramic tiles
16.	Ceiling material	Plaster of paris (POP)	Plaster of paris (POP)	Plaster of paris (POP)
17.	Source of obstruction	None	None	None
18.	Head room	3.5 m	3.5 m	3.5 m

19.	Window sill level	0.45 m	0.45 m	0.45 m
20.	Window widths - Window height -	2.7m 2.1 m	2.7 m 1.6 m	2.7 m 1.6 m
19.	Floor area	2333 m^2	1185 m^2	1005.5 m^2
20.	Wall area (no openings) – Wall area -	1080 m^2 405 m^2	544.6 m^2 414.2 m^2	493.5 m^2 374.4 m^2
21.	Number of windows	44	23	21
22.	Windows total area	249.5 m^{29}	130.4 m^2	119.1 m^2
23.	Window – Wall – Ratio	23 %	24%	24%
24.	Window – Floor – Ratio	11 %	11%	11.8 %
25.	Main source of light	Daylight and electricity	Daylight and electricity	Daylight and electricity

The reading spaces on the first floor are in Table 1, the reading spaces on the second floor are in Table 2, and the reading spaces on the third floor are in Table 3. Typical Images of the 12 Reading Spaces were all shown. Also, the images representing each reading space are in Figure 3.

		
	Hall B. (General reading section)	Hall C. (Science and tech. section)

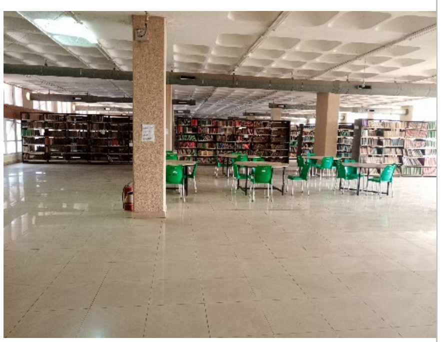
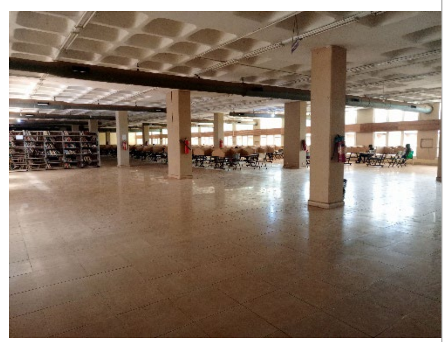
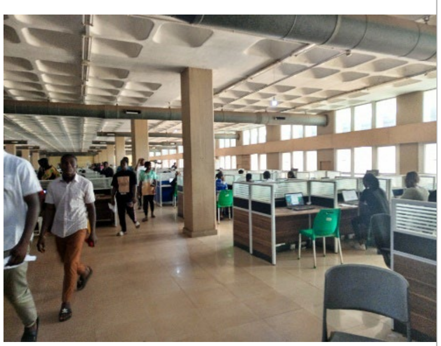
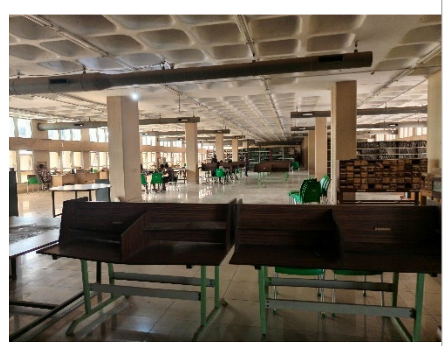
Hall A. (General reading section)		
		
Hall D. (Circulation section)	**Hall E.** **(Reference section)**	**Hall F. (Newspaper section)**
		
Hall G. (Serial section)	**Hall H. (General reading section)**	**Hall I. (General reading section)**
		
Hall J (Digital section)	**Hall J (Depository section)**	**Hall J (Africana section)**

Figure 3: Images of the reading spaces of the reading spaces

6.1.1 Brief Description of HALL H for Simulation

HALL H is a rectangular-shaped reading space located at the right-hand side of the front wing on the second floor with no obstructions. The space has a minimum of 0.6m by 0.6m columns (see Figure 4).

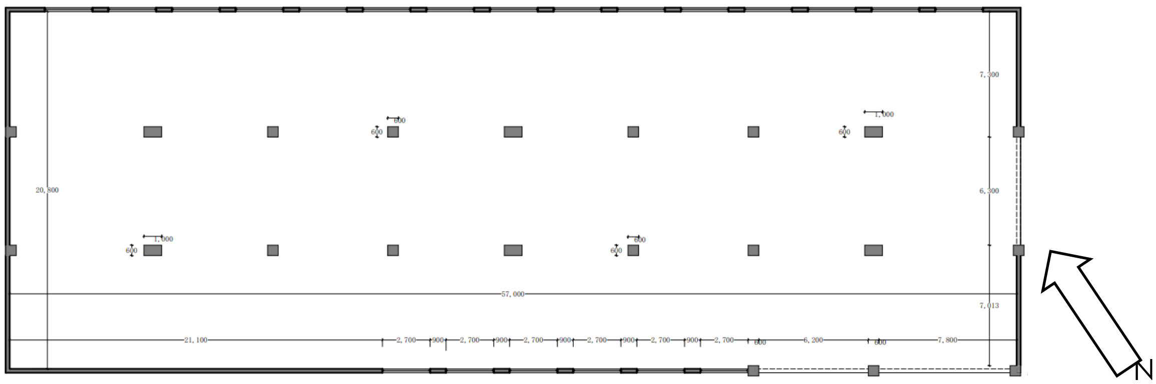


Figure 4: Floor plan of HALL H (57m x 20.8m, WFR = 11%)

The four sides of the walls had cream-coloured paint. The wall area is equal to 544.60 m2. The headroom is about 3.5m. The exterior sides of the walls have accompanied shading devices in the form of wall ns. The floor was with ceramic tiles on a level. The floor area is approximately 1185 m sq. The ceiling is a suspended ceiling made up of POP (plaster of Paris) and was 3.5m from the ground level. The windows were on the two opposite sides of the walls (side-lighting). The window is a clear-glazed projected type with glazing transmittance equivalent to a glass of 6mm thickness, and they are 23 in number. The furniture identified are reading tables, chairs, and bookshelves. The furniture is on three rows, the bookshelves on the first row, and the tables and chairs are six-seating each on the remaining two rows. The heights of tables and shelves are 0.75m and 2.25m, respectively. Provisions were for both daylight and natural light.

6.1.2 Daylight Condition of Hall H Using Simulation

In this simulation, the Velux daylight software was set at the study location (Enugu) using an Energy Plus Weather (EPW) le, taking note of the orientation and sky conditions. The results came in pictures and automated reports. The pictorial view from the simulation shows the UDI distributions with grading from 0% - 100% and colour differentiation. The reports indicated the value obtained from the simulation and also established the percentage of passes and failures from the values.

The UDI simulation result was for HALL H (see Figure 5). It indicated the percentage of UDI300lx - 2000lx in colours from blue (0.00 %) to bright yellow (100 %). The blue colour represents low % (0 – 20), the red colour (20 – 60), the orange colour (60-70), mint green (70-85), and the yellow colour (85 -100).

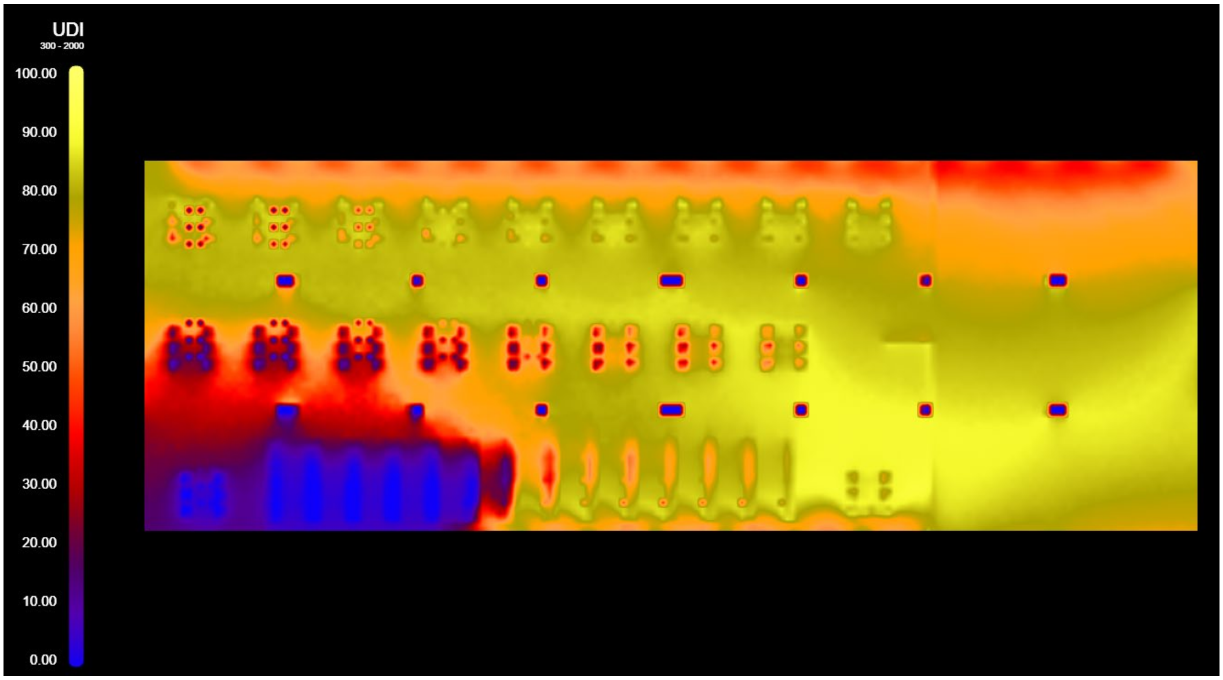


Figure 5: Pictorial view of HALL H UDI simulation

From the results, the reading space showed more of a mint green to yellow colour in the reading area. The blue colour was more in the space provided for shelves.

Further explanation of the UDI result of the HALL H indicated the annual percentage illuminance of different work plane fractions at 5% intervals. They are ≥ 05% $UDI_{300\ lx - 2000lx}$ (96.99%), ≥ 10% $UDI_{300\ lx - 2000lx}$, ≥ 15% $UDI_{300\ lx - 2000lx}$ (94.48%), ≥ 20% UDI300 lx – 2000lx (92.86%), ≥ 25% UDI300 lx – 2000lx (91.66%) ≥ 30% UDI300 lx – 2000lx (90.08%),≥ 35% UDI300 lx 2000lx (88.27%), ≥ 40% UDI300 lx – 2000lx (86.48%), ≥ 45% UDI300 lx – 2000lx (85.04%), ≥ 50% UDI300 lx – 2000lx (83.21%), ≥ 55% UDI300 lx – 2000lx (81.08%), ≥ 60% UDI300 lx – 2000lx (74%), ≥ 65% UDI300 lx – 2000lx (68.31%), ≥ 70% UDI300 lx – 2000lx (62.27%), ≥ 75% UDI300 lx – 2000lx (54.32%), ≥ 80% UDI300 lx – 2000lx (36.41%), ≥ 85% UDI300 lx – 2000lx (9.97%), ≥ 90% UDI300 lx – 2000lx (0%), and ≥ 95% UDI300 lx – 2000lx (0%).

Also, using the percentile (PCTL) position explained further the values of the associated daylight autonomy (DA) and total annual illuminance (TAI) as shown in Table 4 from the 5th PCTL to the 75th PCTL which accommodated all parts of the reading space.

Table 4 Percentiles in the study area in HALL H UDI simulation

		DA %	TAI
05^{th} PCTL	$UDI_{300-2000}$	8.42%	718.64 klux hrs
10^{th} PCTL	$UDI_{300-2000}$	25.41%	1068.21 klux hrs
15^{th} PCTL	$UDI_{300-2000}$	40.14%	1346.39 klux hrs
20^{th} PCTL	$UDI_{300-2000}$	51.90%	1651.77 klux hrs

25th PCTL	$UDI_{300-2000}$	59.09%	2000.36 klux hrs
30th PCTL	$UDI_{300-2000}$	63.58%	2235.12 klux hrs
35th PCTL	$UDI_{300-2000}$	67.97%	2488.75 klux hrs
40th PCTL	$UDI_{300-2000}$	71.55%	2730.10 klux hrs
45th PCTL	$UDI_{300-2000}$	74.66%	2967.78 klux hrs
50th PCTL	$UDI_{300-2000}$	76.79%	3274.24 klux hrs
55th PCTL	$UDI_{300-2000}$	78.26%	3587.30 klux hrs
60th PCTL	$UDI_{300-2000}$	79.32%	3825.94 klux hrs
-65th PCTL	$UDI_{300-2000}$	80.25%	4106.14 klux hrs
70th PCTL	$UDI_{300-2000}$	81.00%	4477.25 klux hrs
75th PCTL	$UDI_{300-2000}$	81.76%	5003.55 klux hrs
80th PCTL	$UDI_{300-2000}$	82.72%	5808.44 klux hrs
85th PCTL	$UDI_{300-2000}$	83.81%	7013.30 klux hrs
90th PCTL	$UDI_{300-2000}$	84.98%	8419.02 klux hrs
95th PCTL	$UDI_{300-2000}$	86.55%	10896.20 klux hrs

Table 4 shows the UDI, DA, and TAI results, indicating their mean, median, minimum illuminance, maximum illuminance, uniformity 1, and uniformity 2. The reading space that needs the illuminance level of from 300 lx to 500 lx was achieved for 84% and 69% of the working year, respectively, and the mean UDI300 lx – 2000 lx (useful illuminance) was for 66% of the working year with the TAI of 4131.32 k lx hrs. The score for HALL H using the standard that adequate daylight can be when a target illuminance level is across a fraction of the reference plane within a space for at least half of the daylight hours (50%) is Fplane,% ≥ DA100, TM(99%), Fplane,% ≥ DA300, T (84%), Fplane,% ≥ DA500, T (69%), and Fplane,% ≥ DA750, T(50%). The results showed that:

a) For 99% of the working year, there were instances where one or more of the workplace were equal to or greater than 100 lx, which is considered a pass.
b) For 84% of the working year, there were instances where one or more of the workplace were equal to or greater than 300 lx, which is considered a pass.
c) For 69% of the working year, there were instances where one or more of the workplace were equal to or greater than 500 lx, which is considered a pass.
d) For 44% of the working year, there were instances where one or more of the workplace was equal to or greater than 750 lx, which is considered a failure.

For the evaluation of the daylight condition of HALL H, the useful Daylight Illuminance (UDI), Daylight Autonomy (DA), and Total Annual Illuminance (TAI), the result for UDI300 lx – 2000lx DA is 66.1%, and TAI is 4132.32 klx hrs. The values of the daylight condition (using the global standard of required daylight level of UDI300 lx – 500 lx) for UNN-HALL H were 84% & 69% of the working year. The total annual illumination (TAI) achievable for a working year is 4314 klx hrs.

6.1.3 Influence of Architectural Design Parameters on Daylight Condition

The identified architectural design parameters with their unique contributions are 25 in number. The daylight condition obtained in this study is the UDI300 lx– 2000lx DA and TAI values. Based on this, the UDI300 lx – 2000lx DA was used as the dependent variable, while all the architectural design parameters were the independent variables. In calculating the WFR and WWR, headroom, window sill, window width, floor area, wall area, number of windows, and window total area were used. As such, they are not used in this analysis one by one. Also, from the remaining variables, the ones with zero variance helped to achieve better predictions. Those with zero variance were space geometry, fenestration, type of window, glazing transmittance, shading devices, wall finish, wall colour, ceiling finish, furniture provided, and furniture height. The influence of the independent variables on the dependent variable was determined using categorical regression analysis, and this gave rise to a conceptual model shown in Figure 6, showing the independent variables that can influence the dependent variable (daylight condition).

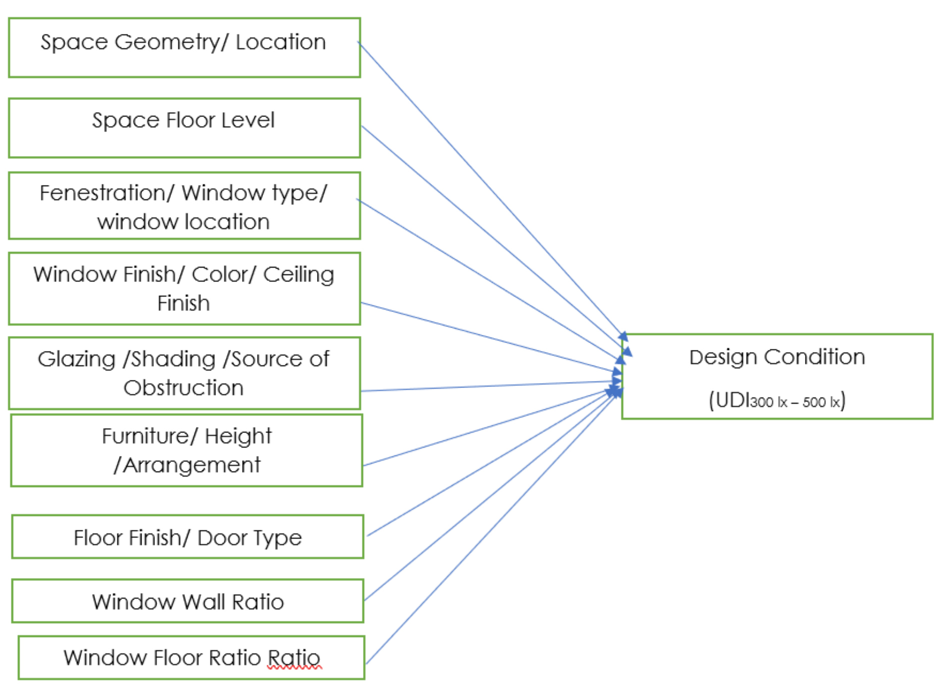


Figure 6: A Conceptual Model For Daylight Condition

After carrying out the regression analysis, results showed that 100% of the variance in UDI can be accounted for by the twenty-five predictors collectively, $F (9,2) = 1017.130$, $p< .001$ (Table 5). Looking at the unique individual contribution of the predictors (see Table 6), the result shows that space geometry/ location (β=.001, f =.000), space floor level (β=.019, f =.007), fenestration/ window type/ location (β=.051, f =.024), wall finish/colour/ ceiling finish (β=.077, f =.035), glazing/ shading/ source of obstruction (β=.088, f =.045), furniture/ height/ arrangement (β=.001, f =.000), floor finish/ door type (β=.004, f =.000), window wall ratio(β=.061, f =.395), and window floor ratio (β=1.016, f =6.300).

Table 5 Anova

	Sum of Squares	df	Mean Square	F	Sig.
Regression	11.997	9	1.333	1017.130	.001
Residual	.003	2	.001		
Total	12.000	11			

Dependent Variable: USEFUL DAYLIGHT

Predictors: SPACE GEO/ LOCATION SPACE FLOOR LEVEL FENESTRATION/ WINDOW TYPE/ LOCATION WALL FIN/ COLOR/ CEILING FINISH GLAZING /SHADING/ SOURCE OF OBSTRUCTION FURNITURE/ HEIGHT/ ARRANGEMENT FLOOR FIN/ DOOR TYPE WINDOW WALL RATIO WINDOW FLOOR RATIO

Table 6 Coefficient Table

	Standardized Coefficients				
	Beta	Bootstrap (1000) Estimate of Std. Error	df	F	Sig.
SPACE GEO/ LOCATION	-.001	.399	1	.000	.999
SPACE FLOOR LEVEL	-.019	.225	1	.007	.942

FENESTRATION/ WINDOW TYPE/ LOCATION	.051	.328	1	.024	.892
WALL FIN/ COLOR/ CEILING FINISH	-.077	.412	1	.035	.869
GLAZING /SHADING/ SOURCE OF OBSTRUCTION	.088	.415	1	.045	.851
FURNITURE/ HEIGHT/ ARRANGEMENT	.001	.277	1	.000	.998
FLOOR FIN/ DOOR TYPE	-.004	.293	1	.000	.990
WINDOW WALL RATIO	.061	.395	1	.024	.891
WINDOW FLOOR RATIO	1.016	.405	1	6.300	.129

Dependent Variable: USEFUL DAYLIGHT

However, none of the independent variables individually influenced the daylight condition, which implies they collectively predicted the value of daylight illuminance (daylight condition).

7.0 SUMMARY AND DISCUSSIONS

In investigating the daylight condition of the library spaces in the main library of the University of Nigeria, twenty-five architectural design parameters were identified and analyzed for the twelve reading spaces. All the reading spaces are rectangular but are on different floors. The window types used were projected-glazed on one or two sides. No top lighting was in the entire library. The library has wall ns as the shading device and is painted creamy. Even though variations in window floor ratio (WFR) are not much, there are many differences in the window wall ratio. The source of lighting is from both daylight and electricity. The simulation values of Hall H represented the remaining 11 reading spaces since they are in the same grouping of WFR (10%-14%) because there is a strong direct relationship between Window-Floor-Ratio (WFR) and daylight illumination levels.

The results showed that the mean UDI 300 – 2000 DA is 66.10%, and they passed. Since the global illuminance requirement for reading space is from 300lx – 500lx, the 300 – 500DA for Hall H is 84% and 69%, which also passed. It means that for 84% and 69% of the working year (daylight autonomy), there were instances where one or more of the workplace was equal to or greater than 300 lux and 500 lux. The result also showed that the total annual illumination (TAI) for Hall H is 4314 klus hrs.

The findings also showed that the 25 architectural design parameters collectively influenced the values of the daylight conditions. Although none of the independent variables individually influenced the daylight condition, some nearly influenced more than others (window floor ratio (WFR) comes first, followed by glazing /shading/ source of obstruction, then wall finish/colour/ceiling finish). All these can before the remaining design parameters (window wall ratio (WWR), fenestration/window type/ location, and space floor level. Space geometry/location and furniture/height/arrangement) contributed almost nothing to the daylight conditions. Since the daylight conditions of these halls studied met the threshold, their design feature types can be adopted when considering a new design of reading spaces in tropical regions. The design considerations that can be in the design of reading spaces for adequate daylighting are:

- A window wall ratio (WFR) of not less than 10%
- The use of glazing transmittance of 6mmn clear single
- The use of wall ns as shading devices
- To reduce or avoid any form of daylight obstructions
- The wall colour can be cream or any brighter colour
- The ceiling finish should be acoustic type and should be white.

Others to be adopted also are:

- Window wall ratio should not be less than 17%
- Side lighting is highly recommended, especially with projected windows located at two sides of the walls and above
- Locating the reading spaces above the ground floor should also be considered.

In conclusion, the study carried out an investigation of the daylight condition of twelve reading spaces in a federal university in a tropical climate by identifying their architectural design parameters for daylighting, evaluating the daylight conditions of those reading spaces using the Climate-Based Daylight Modelling (CBDM) approach, and determining the influence of the identified architectural design parameters on the daylight conditions. The architectural design parameters identified were 25 in number. The daylight conditions obtained met the required threshold. Although the daylight parameters collectively influenced the values of the daylight condition, some contributed more than others, such as the window floor ratio (WFR), followed by the glazing /shading/ source of obstruction, then the wall finish/colour/ceiling finish. Others are window wall ratio (WWR), fenestration/window type/ location, and space floor level. In designing for adequate daylighting in reading spaces in tropical regions, the properties of the already-mentioned daylight parameters are acceptable.

ACKNOWLEDGEMENT

The authors would like to thank the publishers for the opportunity to present this paper to the public. And also, to the anonymous referees for their valuable input to this paper.

REFERENCES

Al-Tamimi N., Fedzil S., Fairuz S., & Abdullah, A. (2016). Relationship between Window-to-Floor Area Ratio and Single-Point Daylight Factor in Varied Residential Rooms in Malaysia. 9(9). https://doi.org/10.17485/ijst/2016/v9i33/86216

Ayoosu M., Lim Y. and Leng p. (2020). Daylight performance assessment of side-lit university lecture theatres in the hot-humid climate of Makurdi in Nigeria. International journal of recent technology and engineering (IJRTE). 5(8). 2277 3878. doi - 10.35940/ijrte.E6793.018520

Boyce, P., Hunter, C. and Howlett, O. (2003) The Bene ts of Daylight through Windows, Lighting Research Center, Rensselaer Polytechnic Institute.

Christoffersen, J., Petersen, E., Johnsen, K., Valbjørn, O. and Hygge, S. (1999) Vinduer og dagslys – en feltundersøgelse i kontorbygninger (SBi - rapport 318) Hørsholm: Statens Byggeforskningsinstitut.

CIBSE National Conference (2006). Engineering the Future 21-22 March, Oval Cricket Ground, London, UK

CIBSE, (2011) Lighting Guide 5: Lighting for education. The Chartered Institution of Building

Edward, E. D. (2005). Daylighting Design in Libraries.

EN 12464-1 (2021). Lighting requirements: Light and lighting.

EN 17037 European Standard for Daylight Requirements in Buildings (2018).

Galasiu, A. D., Newsham, G. R., Suvagau, C., and Sander, D. M., (2007). Energy saving lighting control systems for open-plan of faces: A eld study. Leukos, 4(1) 7–29

Heschong, L. (2002) Daylighting and Human Performance, ASHRAE Journal, 44(6), 65-67.

IESNA (2013). LM-83-12: Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). The Illuminating Engineering Society of North America (IES). http://www.ies.org/store/product/approved-method ies-spatial-daylight-autonomy-sda-and-annual-sunlight-exposure-ase 1287.cfm (accessed: 2014-12-10)

Kent, Michael & Jakubiec, J.. (2021). Examination of Range Effects When Evaluating Discomfort Due to Glare in Singaporean Buildings. Lighting Research & Technology. 54. 147715352110472. 10.1177/14771535211047220

Malman, D. (2005). Lighting for Libraries. U.S. Institute of Museum and Library Services. http://www.iar.unicamp.br/lab/luz/ld/Arquitetural/diversos/Lighting for Libraries.pdf

McNeil, A. and Eleanor L. (2012). A Validation of the Radiance Three Phase Simulation Method for Modelling Annual Daylight Performance of Optically Complex Fenestration Systems. Building Performance Simulation.

Mardaljevic, J. (2000) The simulation of annual daylighting pro les for internal illuminance. Lighting Research and Technology. 32(3).

Mardaljevic, J., Andersen, M., Roy, N., Christoffersen, J. (2012) Daylighting, Arti cial Lighting and Non-Visual Effects Study for a Residential Building

Nabil, A. and Mardaljevic, J.(2005). Useful daylight illuminance: A new paradigm for assessing daylight in buildings. Lighting Res. Technol. 37(41–59).

Onunkwo-Akunne A., Onyekuru S. O., and Nwankwor G. I. (2012). Land capability index mapping for waste disposal and land use option using geographical information system (GIS) in Enugu area, South Eastern Nigeria. Journal of Geographical information system, 4, 444-461. http://dx.doi.org/10.4236/jgis.2012.45049.

Pikas E., Thalfeldt M., and Kurnitski J. (2014). Cost-optimal and nearly zero energy building solutions for of ce buildings. Journal of Energy and Buildings. 74, 30-42.

Reinhart, C. F. and Herkel, S. (2000). The Simulation of Annual Illuminance Distributions - A State-of-the-art Comparison of Six RADIANCE-based Methods, Energy and Buildings. 32(2) 167-187.

Reinhart C. F. and Walkenhorst O. (2001). Validation of dynamic RADIANCE based daylight simulations for a test of ce with external blinds, Energy, & Buildings. 33. 683–697

Robbins, C. L. (1986). Daylighting Design and Analysis, New York: Van Nostrand Reinhold Company.

Velux. (2014). Daylight, Energy, and Indoor Climate Basic Book (F. hansen@velux. co. Editorial team: Per Arnold Andersen, Karsten Duer, Peter Foldbjerg, Nicolas Roy, Jens Christoffersen, and Thorbjørn Færing Asmussen, (Ed.)).

Weather spark (2023) https://www. weatherspark.com

World data (2023) https://www.world data.info/Africa/Nigeria/sunset

Engineering Tool Box (2023) https://www.engineeringtoolbox.com/light-level