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

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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, morale and learning while reducing eyestrain and saving energy. The current study investigated the daylight condition of 12 reading spaces to determine the influence of architectural daylight parameters on the daylight condition. The climate-based daylight modelling (CBDM) approach was used to determine useful daylight illuminance (UDI), daylight autonomy (DA) and total annual illumination (TAI). The study employed the VELUX Daylight Visualiser (VDV) simulation software. The results showed that the mean UDI 300 DA to 500 DA for Hall H was 84% and 69% (pass), TAI was 4,314 kWh 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, Lighting

INTRODUCTION

A 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). Daylight combines all direct and indirect light originating from the sun during the day. A daylighted space combines high occupant satisfaction with the visual and thermal environment, with low overall energy use for lighting, heating and cooling (Anderson et al., 2014).

Daylighting causes improved mood, enhanced morale, less fatigue, reduced eyestrain, decreased stress, improved learning process and energy savings

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(Robbins, 1986; Chartered Institution of Building Services Engineers, 2011; Pikas, Thalfeldt and Kurnitski, 2014). Studies have shown that daylighted interior spaces result in more effective learning in libraries, schools and workspaces (Heschong, Wright and Okura, 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 (Anderson et al., 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, Hunter and Howlett, 2003). Of the total solar energy received on the surface of the Earth, over 40% is visibly radiated and the rest is ultraviolet and infrared wavelengths (Anderson et al., 2014).

Maximising 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 (Chartered Institution of Building Services Engineers, 2011). According to Anderson et al. (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 16% to 20% and 60% (Galasiu et al., 2007; Mardaljevic, Andersen and Roy, 2012).

The condition of daylight in reading spaces is considered a driving factor for the well-being of users. 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 for volumes and surfaces illuminated with daylight, providing glare-free light in reading spaces (Dean, 2005). The recommended daylight level for library reading and studying areas is between 300 lx and 500 lx (Illuminating Engineering Society, 2013; European Committee for Standardization, 2021).

In tropical regions, especially in Nigeria with its hot and humid climate, daylight levels in interior spaces have been identified to be grossly inadequate, not consistent and sometimes with glare despite the abundance of sunlight (Ayoosu, Lim and Leng, 2020). According to their research, most lecture or reading spaces do not have specific models for daylight designs. Also, according to Kent and 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 according to the National Building Code of Nigeria may not have quality daylight in reading spaces since the code does not require that. Therefore, most buildings were designed and constructed without consideration of optimised daylighting strategies in their interior spaces. Based on these, there is a need to determine the daylight conditions of existing interior spaces.

OBJECTIVES OF THE STUDY

This study aimed to investigate the daylight conditions of 12 reading spaces in a federal university located in a tropical climate. The objectives were to (1) identify their architectural design parameters for daylighting, (2) evaluate the daylight conditions of those reading spaces using the climate-based daylight modelling (CBDM) approach and (3) determine the influence of the identified architectural design parameters on the daylight conditions.

Climate-Based Daylight Modelling

CBDM is the prediction 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, 2000; Reinhart and 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 CBDM to investigate the daylight condition of a room space. Daylight factor (DF) is another criterion used to predict the daily daylight condition, which will not determine UDI, unlike the CBDM approach.

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 (Anderson et al., 2014). UDI is the annual occurrence of illuminances across the work plane range that are useful to the users. UDI in the range of 100 lx and 300 lx is effective as the sole source or in conjunction with artificial lighting. UDI in the range of 300 lx and 3,000 lx is often perceived as desirable (Mardaljevic, Andersen and Roy, 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. The values are promoted by the Illuminating Engineering Society of North America (Illuminating Engineering Society, 2013). TAI measures all the visible daylight energy incidents on the surface or occupancy period evaluated (Mardaljevic, 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.h/year for "moderately sensitive items" and 100,000 lx.h/year for "sensitive items".

The objectives of the current studies were 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.

The Study Area

A library building housed 12 spaces and had an orientation of 450°NE. It had four floors, with reading areas occupying three floors (first, second and third floors), with front and rear wings in each. The study area was in the hot-humid tropical environment of Enugu, one of the major cities in southeastern Nigeria, which lies within latitudes 6°16′ N and 6°31′ N and longitudes 7°20′ E and 7°41′ E of the Greenwich Meridian. The city covers an area of about 630 km^2 (Onunkwo, Onyekuru and Nwankwor, 2012).

In the tropical region, but unlike in some others, there are similarities between seasons. There is a minor variation in the daylight time and the temperature differences between summer and winter. The average daytime temperature range is between 30°C and 37°C, with the temperature rising to 43°C in some parts, depending on the season. In some regions during the cold season, the monthly mean temperature drops to 18°C (World Data, 2023). According to Weather Spark (2023), the mean percentage of the sky covered by clouds creates significant seasonal variation over the year. The clear part of the year starts around 20th November and lasts for three months, ending around 18th February. The clearest month is December, during which the sky is clear, substantially lucid or partially cloudy conditions 46% of the time. The cloudier part of the year starts around 18th February and lasts for nine months, ending around 20th November. The cloudiest month is May, during which the sky is overcast or substantially cloudy conditions 85% of the time (Weather Spark, 2023).

The current study area presented three sky conditions: (1) clear sky, (2) intermediate sky and (3) overcast sky, with outdoor sky illuminance distributions of > 10,752 lx, 10,752 lx, and 1,075 lx, respectively (Engineering ToolBox, 2023).

MATERIALS AND METHODS

The current research employed VELUX Daylight Visualiser (VDV) simulation software to investigate the daylight condition of the selected reading spaces. 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 building information modelling or computer-aided design software. EN 17037 was not used based on the location but on the required standard of daylight within internal reading space for users, which is in the range of 300 lx and 500 lx (European Committee for Standardization, 2018). VDV 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 were generated using VDV. EnergyPlus Weather (EPW) file format was utilised to predict the direct daylight of the study area. The hourly diffuse sky component was from TMY weather data. Other data sources included site and field studies, direct measurements of spaces or things, relevant sketches and photographs of the spaces and a review of published and unpublished materials such as books, journals, magazines, monographs, seminars, conference papers and meteorological data, among others.

Sample Selection

Sample selection was employed to obtain the number of reading spaces that could represent the simulation of the reading spaces. Determining the daylight condition depends on the level of illuminance. There is a strong relationship between window-floor ratio (WFR) and daylight illumination levels (Nedhal, Fadzil and Adel, 2016). Therefore, of all the architectural design features, WFR was chosen as a reliable factor to consider when determining a sample. The actual WFR percentage for any learning and educational space should be between 20% and 25%. A stratified random sampling technique was employed and WFR percentage ranges were in five groups: (1) 1% to 9% (Very Low), (2) 10% to 14% (Low), (3) 15% to 19% (Slightly Moderate), (4) 20% to 25% (Moderate) and (5) 26% and above (High). All the reading spaces were in the same group, 10% to 14%, since their WFR was between 10% and 12.8%. Among those reading spaces, one was used to represent others. The selected reading space was Hall H.

Data Collection

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. 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 SketchUp software and imported into VDV for simulation to determine daylight conditions and luminance levels.

VELUX Daylight Visualiser Validations

The software was validated using the CIE 171:2006 test cases and assessment of the accuracy of lighting computer programmes. Its simulation results were verified by the National School of State Public Works to detect the accuracy of the lighting and examine the Daylight Calculations in Practice SBI 2013:26. Further validation was done 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 MBE percentage is less than 20% and RMSE percentage is less than 32%. Also, McNeil and Lee (2012) deemed this threshold acceptable. Therefore, for this study, a threshold of 20% MBE and 32% RMSE in illuminance simulation are standard in all daylight research. The equations for MBE and RMSE were formulated (refer to Equations 1 and 2):

$$\text{Percentage of RSME} = \frac{100}{M}\sum\frac{(S-M)^2}{N} \qquad \text{Eq.2}$$

$$\text{Percentage of MBE} = \frac{100}{M}\sum\frac{(S-M)}{N} \qquad \text{Eq.1}$$

where, M was the measured value of illuminance, S was the simulated value and N was the number of observations.

The percentages of MBE and RSME of Hall H were calculated and compared to validate simulation values. Hall H was divided into nine locations, each with a sensor point (as shown in Figures 1 and 2) to calculate the measured values (M).

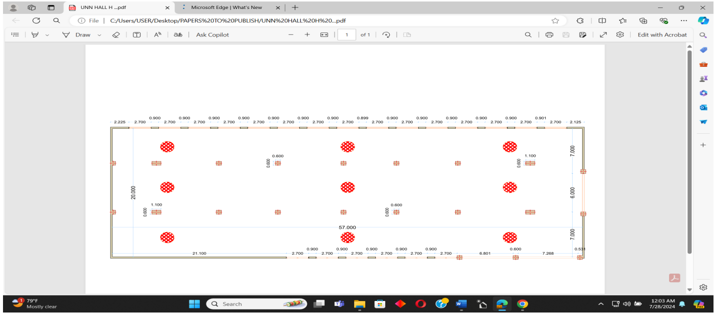

Figure 1. Floor plan of Hall H with nine sensor points indicated with red circles

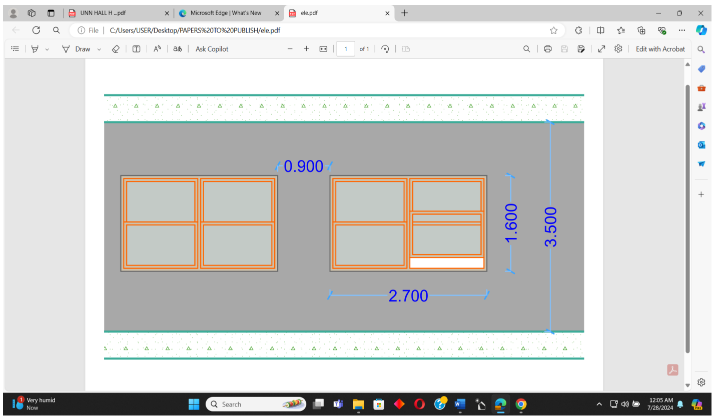

Figure 2. Typical elevation of Hall H with nine sensor points indicated with red circles

The division covered more than 80% of the reading hall. A total of nine light tools (lux H1010) were placed at the designated sensor points on the work plane of 850 mm (considering the height of a reading desk was 750 mm). The field measurement was conducted on 13th June, during the cloudiest period of the year. The electric lights were turned off, and measurements occurred every 15-minute interval from 8:00 a.m. to 4:00 p.m., which was the reading hours at the library. The mean values were calculated for every two hours (8:00 a.m. to 10:00 a.m., 10:00 a.m. to 12:00 p.m., 12:00 p.m. to 2:00 p.m. and 2:00 p.m. to 4:00 p.m.). Hourly daylight illuminances at height across the ground floor were rigorously validated using the daylight coefficient technique (Mardaljevic, 2000). For simulated values (*S*), VDV was set at the exact location using EPW file on the same month of the year orientation and sky condition for one hour. The mean values were calculated at every two-hour interval.

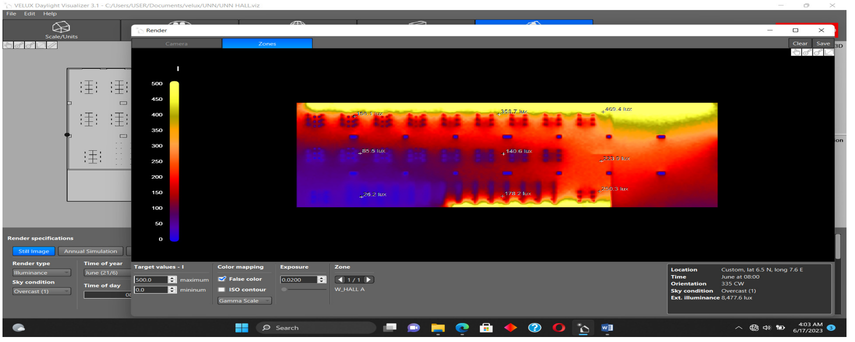

Figure 3. Simulated values of Hall H at 8:00 a.m.

Figure 3 shows the simulated values at 8:00 a.m. Blue represents very low lux levels (0 lx to 100 lx), red represents low to moderate levels (100 lx to 250 lx), orange represents moderate levels (250 lx to 400 lx) and yellow represents high lux value (> 400 lx). The values obtained from the measured and simulated points showed that the percentages of MBE and RSME did not exceed 20% and 37%, respectively, with the percentage of MBE was between 7% and 15% and the percentage of RSME was between 9% and 30%.

Simulation Procedure

To determine the daylight condition (UDI, DA and TAI), VDV was adjusted by importing the EPW file, according to the site orientation. The simulation was conducted adhered to three sky conditions in the study area, namely: (1) intermediate (February), (2) overcast (May) and (3) clear sunny (November). The simulation software was automatically set at the 21st of each month. The work plane was placed 850 mm above the ground to determine the annual percentage of the UDI per fraction of the work plane and percentile of the reading spaces. UDI depicts the annual occurrence of daylight falling within a given range. Observations showed that useful daylight condition is within the threshold of 300 lx to 2,000 lx (Nabil and Mardaljevic, 2005). However, the useful range can be extended to 3000lx as 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 that they prefer little daylight 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. The standard highlights that the fraction of space for a target level (spatial scale) should be at least 50% of the floor area. Therefore, the target DA was set at 50% for 300 lx, 500 lx and

750 lx, with the minimum target DA at 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, a minimum of UDI within the range of 300 lx and 50 0lx should be between at least 50% of the working year.

RESULTS

Architectural Design Parameters of the Reading Spaces

The architectural design parameters of the 12 reading spaces of the library are presented in Tables 1, 2 and 3. There are 25 parameters in total.

Table 1. Reading spaces on the first floor

Reading Spaces: First Floor						
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.	Location 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 colour	Cream	Cream	Cream	Cream	Cream
11.	Furniture provided	• Conference table • Chairs	• Reading table • Chairs	• Reading table • Chairs • Shelves	• Reading table • Chairs	• Reading table • Chairs

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Table 1. *Continued*

Reading Spaces: First Floor						
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)**
12.	Furniture arrangement	One seating	Six seatings	Six seatings	Six seatings	Six seatings
13.	Height of furniture: (a) Shelves (b) Tables	(b) 0.75 m	(a) 2.25 m (b) 0.75 m	(a) 2.25 m (b) 0.75 m	(b) 0.75 m	(b) 0.75 m
14.	Type of door	Panelled wooden	Open space	Panelled wooden	Panelled wooden	Panelled 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.	Windowsill level	0.45 m	0.45 m	0.45 m	0.45 m	0.45 m
20.	Window widths	2.7 m	1.9 m to 3.5 m	2.7 m	2.7 m	2.7 m
	Window height	2.1 m	2.1 m	2.1 m	2.1 m	2.1 m
19.	Floor area	489.00 m^2	290.00 m^2	881.68 m^2	588.35 m^2	562.45 m^2
20.	Wall area (no openings)	276.6 m^2	197.0 m^2	355.0 m^2	276.0 m^2	276.0 m^2
	Wall area	220.0 m^2	162.4 m^2	241.6 m^2	208.0 m^2	196.6 m^2
21.	Number of windows	10	6	20	12	13
22.	Windows total area	56.70 m^2	34.65 m^2	113.40 m^2	68.04 m^2	73.70 m^2
23.	Window-wall ratio (WWR)	20.0%	17.0%	32.0%	24.0%	27.0%
24.	WFR	12.0%	12.0%	12.8%	12.0%	13.0%
25.	Main source of light	Daylight and electricity	Daylight and electricity	Daylight and electricity	Daylight and electricity	Daylight and electricity

(Continued on next page)

Table 2. Reading spaces on the second floor

Reading Spaces: Second Floor					
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.	Location of windows	Two sides	Two sides	Two sides	Two sides
7.	Glazing transmittance	6mm single clear	6mm single clear	6mm single clear	6mm single clear
8.	Shading devices	Wall fins	Wall fins	Wall fins	Wall fins
9.	Wall Finishing	Painted	Painted	Painted	Painted
10.	Wall colour	Cream	Cream	Cream	Cream
11.	Furniture provided	Shelves Tables Chairs	Shelves Tables Chairs	Reading table Shelves Chairs	Reading table Shelves Chairs
12.	Furniture arrangement	One seating	Four seatings	Six seatings	Six seatings
13.	Height of furniture: (a) Shelves (b) Tables	(a) 2.25 m (b) 0.75 m	(a) 2.25 m (b) 0.75 m	(a) 2.25 m (b) 0.75 m	(a) 2.25 m (b) 0.75 m
14.	Type of door	Open entrance	Open entrance	Panelled wooden	Panelled wooden
15.	Floor finish	Ceramic tiles	Ceramic tiles	Ceramic tiles	Ceramic tiles
16.	Ceiling material	Plaster of Paris	Plaster of Paris	Plaster of Paris	Plaster of Paris
17.	Source of obstruction	None	None	None	None
18.	Head room	3.5 m	3.5 m	3.5 m	3.5 m

(Continued on next page)

Table 2. *Continued*

Reading Spaces: Second Floor					
No.	**Architectural Design Parameters**	**Hall F (Newspaper Section)**	**Hall G (Serial Section)**	**Hall H (General Reading Section)**	**Hall I (General Reading Section)**
19.	Windowsill level	0.45 m	0.45 m	0.45 m	0.45 m
20.	Window widths	2.7 m	2.7 m	2.7 m	2.7 m
	Window height	2.1 m	2.1 m	1.6 m	1.6 m
19.	Floor area	1,148.0 m^2	1,185.0 m^2	1,185.0 m^2	1,005.5 m^2
20.	Wall area (no openings)	535.5 m^2	544.6 m^2	544.6 m^2	493.5 m^2
	Wall area	405.0 m^2	425.5 m^2	414.2 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.	WWR	24%	22%	24%	24%
24.	WFR	11.3%	10.0%	11.0%	11.8%
25.	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				
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.	Location of windows	Two sides	Two sides	Two sides

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Table 3. *Continued*

Reading Spaces: Third Floor				
No.	**Architectural Design Parameters**	**Hall J (Digital Section)**	**Hall K (Depository Section)**	**Hall L (Africana Section)**
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 colour	Cream	Cream	Cream
11.	Furniture provided	Tables Chairs	Reading table Chairs Shelves	Reading table Chairs Shelves
12.	Furniture arrangement	Row seating	Six seatings	Six seatings
13.	Height of furniture (a) Shelves (b) Tables	(a) 2.25 (b) 0.75m	(a) 2.25m (b) 0.75m	(a) 2.25m (b) 0.75m
14.	Type of door	Open entrance	Panelled wooden	Panelled wooden
15.	Floor finish	Ceramic tiles	Ceramic tiles	Ceramic tiles
16.	Ceiling material	Plaster of Paris	Plaster of Paris	Plaster of Paris
17.	Source of obstruction	None	None	None
18.	Head room	3.5 m	3.5 m	3.5 m
19.	Windowsill level	0.45 m	0.45 m	0.45 m
20.	Window widths Window height	2.7 m 2.1 m	2.7 m 1.6 m	2.7 m 1.6 m
19.	Floor area	2,333.0 m^2	1,185.0 m^2	1,005.5 m^2
20.	Wall area (no openings)	1,080.0 m^2	544.6 m^2	493.5 m^2
	Wall area	405.0 m^2	414.2 m^2	374.4 m^2
21.	Number of windows	44	23	21
22.	Windows total area	249.5 m^2	130.4 m^2	119.1 m^2
23.	WWR	23.0%	24.0%	24.0%
24.	WFR	11.0%	11.0%	11.8%
25.	Main source of light	Daylight and electricity	Daylight and electricity	Daylight and electricity

The architectural design for reading spaces on the first floor are summarised in Table 1, second floor in Table 2 and third floor in Table 3. The images of the reading spaces are shown in Figure 4.

Hall A (General Reading Section)

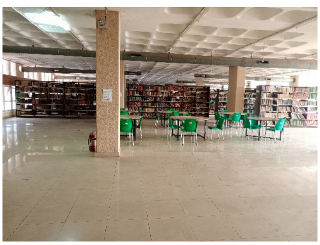
Hall B (General Reading Section)

Hall C (Science and Technology Section)

Hall D (Circulation Section)

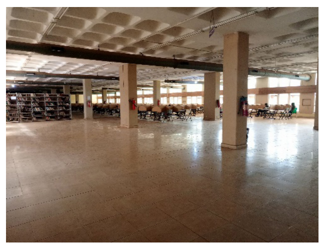
Hall E (Reference Section)

Hall F (Newspaper Section)

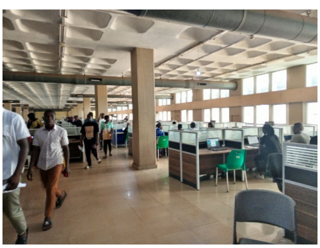


Hall G (Serial Section)

Hall H (General Reading Section)

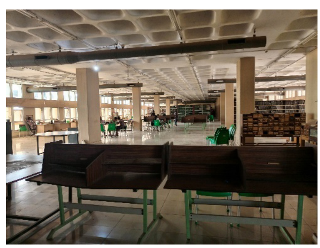


Hall I (General Reading Section)



Hall J (Digital Section)

Hall J (Depository Section)



Hall J (Africana Section)

Figure 4. The images of reading spaces

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 had a minimum of 0.6 m by 0.6 m columns (as shown in Figure 5).

Figure 5. Floor plan of Hall H (57 m × 20.8 m, WFR 11%)

The four sides of the walls had cream-coloured paint. The wall area was 544.6 m^2. The headroom was 3.5 m. The exterior sides of the walls accompanied shading devices in the form of wall. The floor was with ceramic tiles. The floor area was approximately 1,185 msq. The ceiling is a suspended ceiling made up of plaster of Paris and was 3.5 m from the ground level. The windows were on the two opposite sides of the walls (side-lighting). The window was a clear-glazed projected type with glazing transmittance equivalent to a glass of 6 mm thickness and they are 23 in number. The furniture identified were reading tables, chairs and bookshelves. The furniture was arranged in three rows, with the bookshelves on the first row, and the tables and six-seating chairs each on the remaining two rows. The heights of tables and shelves were 0.75 m and 2.25 m, respectively. Provisions were for both daylight and natural light.

Daylight Condition of Hall H Using Simulation

In this simulation, VDV was set at the study location using an EPW file, taking note of the orientation and sky conditions. The results came in pictures and automated reports. The pictorial view from the simulation represented the UDI distributions with grading from 0% to 100% and colour differentiation. The reports indicated the values obtained from the simulation and also established the percentage of passes and failures from the values.

Figure 6 summarises the UDI simulation results for Hall H. It indicated that the percentage of UDI 300 lx and 2,000 lx in colours from blue (0.00%) to bright yellow (100%). Blue represents low UDI levels (0% to 20%), red indicates moderate levels (20% to 60%), orange corresponds to slightly higher values (60% to 70%), mint green represents high levels (70% to 85%) and yellow denotes the highest range (85% to 100%).

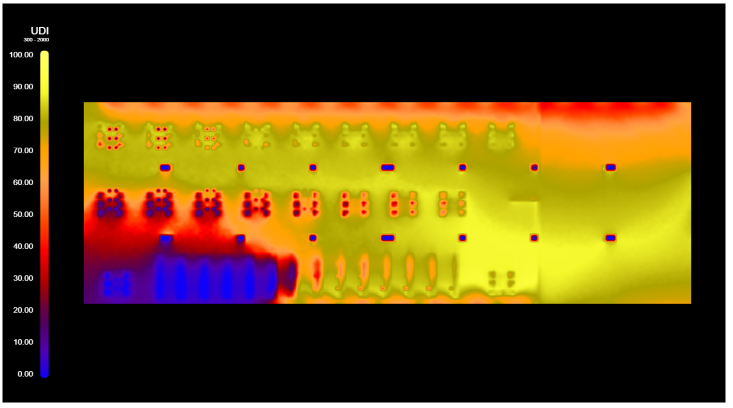


Figure 6. Pictorial view of Hall H UDI simulation

From the results, the reading space showed more of a mint green to yellow in the reading area. Blue was more in the space provided for the 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 were ≥ 5% UDI 300 lx–2,000 lx (96.99%), ≥ 10% UDI 300 lx–2,000 lx, ≥ 15% UDI 300 lx–2,000 lx (94.48%), ≥ 20% UDI 300 lx–2,000 lx (92.86%), ≥ 25% UDI 300 lx–2,000 lx (91.66%), ≥ 30% UDI 300 lx–2,000 lx (90.08%), ≥ 35% UDI 300 lx–2,000 lx (88.27%), ≥ 40% UDI 300 lx–2,000 lx (86.48%), ≥ 45% UDI 300 lx–2,000 lx (85.04%), ≥ 50% UDI 300 lx–2,000 lx (83.21%), ≥ 55% UDI 300 lx–2,000 lx (81.08%), ≥ 60% UDI 300 lx–2,000 lx (74%), ≥ 65% UDI 300 lx–2,000 lx (68.31%), ≥ 70% UDI 300 lx–2,000 lx (62.27%), ≥ 75% UDI 300 lx–2,000 lx (54.32%), ≥ 80% UDI 300 lx–2,000 lx (36.41%), ≥ 85% UDI 300 lx–2,000lx (9.97%), ≥ 90% UDI 300 lx–2,000 lx (0%) and ≥ 95% UDI 300 lx–2,000 lx (0%).

Also, the percentile position (PCTL) explained the values of the associated DA and 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 the Hall H UDI simulation

		DA%	TAI
5th PCTL	UDI 300–2,000	8.42%	718.64 klx·h
10th PCTL	UDI 300–2,000	25.41%	1,068.21 klx·h
15th PCTL	UDI 300–2,000	40.14%	1,346.39 klx·h

(Continued on next page)

Table 4. *Continued*

		DA%	TAI
20th PCTL	UDI 300–2,000	51.90%	1,651.77 klx·h
25th PCTL	UDI 300–2,000	59.09%	2,000.36 klx·h
30th PCTL	UDI 300–2,000	63.58%	2,235.12 klx·h
35th PCTL	UDI 300–2,000	67.97%	2,488.75 klx·h
40th PCTL	UDI 300–2,000	71.55%	2,730.10 klx·h
45th PCTL	UDI 300–2,000	74.66%	2,967.78 klx·h
50th PCTL	UDI 300–2,000	76.79%	3,274.24 klx·h
55th PCTL	UDI 300–2,000	78.26%	3,587.30 klx·h
60th PCTL	UDI 300–2,000	79.32%	3,825.94 klx·h
-65th PCTL	UDI 300–2,000	80.25%	4,106.14 klx·h
70th PCTL	UDI 300–2,000	81.00%	4,477.25 klx·h
75th PCTL	UDI 300–2,000	81.76%	5,003.55 klx·h
80th PCTL	UDI 300–2,000	82.72%	5,808.44 klx·h
85th PCTL	UDI 300–2,000	83.81%	7,013.30 klx·h
90th PCTL	UDI 300–2,000	84.98%	8,419.02 klx·h
95th PCTL	UDI 300–2,000	86.55%	10,896.20 klx·h

Table 4 shows the UDI, DA and TAI results, indicating their mean, median, minimum illuminance, maximum illuminance, uniformity 1 and uniformity 2. A reading space needs an illuminance level of 300 lx to 500 lx was achieved for 84% and 69% of the working year, respectively, and the mean UDI 300 lx to 2,000 lx (useful illuminance) was achieved for 66% of the working year with TAI of 4,131.32 klx.h. 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%) was Fplane, % ≥ DA 100, T = 99%; Fplane, % ≥ DA 300, T = 84%; Fplane, % ≥ DA 500, T = 69%; and Fplane, % ≥ DA750, T = 50%. This indicated that:

1. For 99% of the working year, there were instances where one or more of the workplaces were equal to or greater than 100 lx, which is considered a pass.
2. For 84% of the working year, there were instances where one or more of the workplaces were equal to or greater than 300 lx, which is considered a pass.
3. For 69% of the working year, there were instances where one or more of the workplaces were equal to or greater than 500 lx, which is considered a pass.

4. For 44% of the working year, there were instances where one or more of the workplaces was equal to or greater than 750 lx, which is considered a failure.

For the evaluation of the daylight condition of Hall H, UDI, DA and TAI, the result for UDI 300 lx to 2,000 lx DA was 66.1%, and TAI was 4,132.32 klx.h. The values of the daylight condition (using the global standard of required daylight level of UDI 300 lx to 500 lx) for Hall H were 84% and 69% of the working year. TAI achievable for a working year was 4,314 klx.h.

The Influence of Architectural Design Parameters on Daylight Condition

The identified architectural design parameters with their unique contributions are 25. The daylight condition obtained in this study was UDI 300 lx to 2,000 lx DA and TAI values. Based on this, UDI 300 lx to 2,000 lx DA was used as the dependent variable, while all the architectural design parameters were the independent variables. In calculating the WFR and WWR, headroom, windowsill, window width, floor area, wall area, number of windows and window total area were used. As such, they were 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. As a result, a conceptual model was developed with the study's independent variables influencing the dependent variable (daylight condition) (as shown in Figure 6).

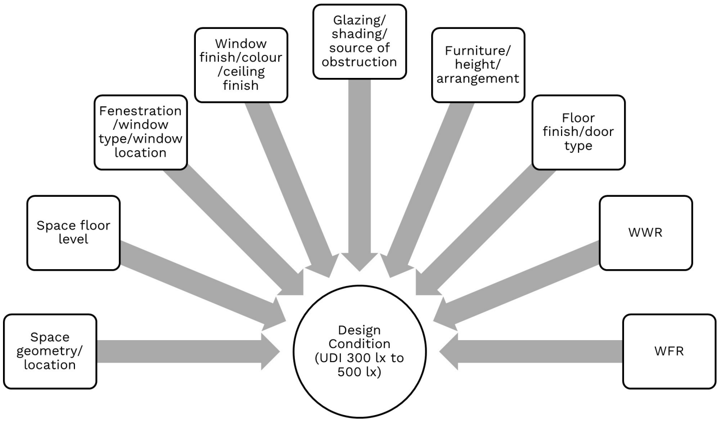


Figure 6. A conceptual model for daylight conditions

Results from the regression analysis showed that 100% of the variance in UDI was accounted for by 25 predictors collectively, $F(9,2) = 1{,}017.130$, $p < 0.001$ (as shown in Table 5). Looking at the unique individual contribution of the predictors (as shown in Table 6), the result showed that space geometry/location (β = 0.001, f = 0.000), space floor level (β = 0.019, f = 0.007), fenestration/window type/location (β = 0.051, f = 0.024), wall finish/colour/ceiling finish (β = 0.077, f = 0.035), glazing/shading/source of obstruction (β = 0.088, f = 0.045), furniture/height/arrangement (β = 0.001, f = 0.000), floor finish/door type (β = 0.004, f = 0.000), WWR (β = 0.061, f = 0.395) and WFR (β = 1.016, f = 6.300).

Table 5. Results from the regression analysis

Analysis of Variance	Sum of Squares	df	Mean Square	*F*	Sig.
Regression	11.997	9	1.333	1,017.130	0.001
Residual	0.003	2	0.001		
Total	12.000	11			

Table 6. Coefficient table

	Standardised Coefficients		df	*F*	Sig.
	Beta	Bootstrap (1,000) Estimate of Std. Error			
Space geometry/location	–0.001	0.399	1	–	0.999
Space floor level	–0.019	0.225	1	0.007	0.942
Fenestration/window type/location	0.051	0.328	1	0.024	0.892
Wall finish/colour/ceiling finish	–0.077	0.412	1	0.035	0.869
Glazing/shading/source of obstruction	0.088	0.415	1	0.045	0.851
Furniture/height/arrangement	0.001	0.277	1	–	0.998
Floor finish/door type	–0.004	0.293	1	–	0.990
WWR	0.061	0.395	1	0.024	0.891
WFR	1.016	0.405	1	6.300	0.129

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

SUMMARY AND DISCUSSION

To investigate the daylight condition of library spaces in the main library of the University of Nigeria, a total of 25 architectural design parameters were identified and analysed for 12 reading spaces. All the reading spaces were in a rectangular shape but were on different floors. The window types used were projected-glazed on one or two sides. There was no top lighting in the entire library. The library had walls as a shading device and were painted creamy. Even though variations in WFR were limited, there were differences in the WWR. The source of lighting was from both daylight and electricity. The simulation values of Hall H represented the remaining 11 reading spaces since they were in the same grouping of WFR (10% to 14%), because there was a strong direct relationship between WFR and daylight illumination levels.

The results showed that the mean UDI 300 DA to 2,000 DA was 66.10% and they passed. Since the global illuminance requirement for reading space is from 300 lx to 500 lx, the 300 DA to 500 DA 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 workplaces were equal to or greater than 300 lx and 500 lx. The result also showed that TAI for Hall H was 4,314 kWh.

The findings of the current study 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. WFR was first, followed by glazing/shading/source of obstruction, then wall finish/colour/ceiling finish. These were design parameters that contributed almost nothing to the daylight conditions, namely WWR, fenestration/window type/location and space floor level, space geometry/location and furniture/height/arrangement. Since the daylight conditions of these halls met the threshold, their design feature types could 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:

1. A WFR of not less than 10%.
2. The use of glazing transmittance of 6 mm clear single.
3. The use of walls as shading devices.
4. To reduce or avoid any form of daylight obstructions.
5. The wall colour can be cream or any brighter colour.
6. The ceiling finish should be an acoustic type and should be white.

Others to be adopted also are:

1. Window wall ratio should not be less than 17%.
2. Side lighting is highly recommended, especially with projected windows located on two sides of the walls and above.
3. 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 12 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 CBDM approach and determining the influence of the identified architectural design parameters on the daylight conditions. The architectural design parameters identified were 25. 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 WFR, followed by the glazing/shading/source of obstruction, then the wall finish/colour/ceiling finish. Others are WWR, fenestration/window type/location and space floor level. In designing for adequate daylighting in reading spaces in tropical regions, these properties of daylight parameters are acceptable.

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