Influence of library building design features on daylighting of reading spaces

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Abstract. Library building design features contribute to the performance of indoor daylight. Reading spaces in library buildings require effective daylighting for high productivity. This study evaluated the indoor daylight quality of three reading spaces, namely Esut-Hall A, Esut-Hall C, and Esut-Hall F, located in the main library of Enugu State University of Science and Technology (ESUT). The research aimed to assess the influence of individual building design features on the daylight performance of these spaces. The study adopted case study research, in combination with building simulation with Velux daylight visualizer software. The first result identified sixteen building design features that influenced the daylight quality. The second result indicated that the daylight quality values of Esut Hall A and Esut Hall F passed the 50% threshold for mean $UDI_{300lux\text{-}2000\ lux}$ DA, $UDI_{300lux\text{-}500\ lux}$ DA, and DF, showing that they have good daylight quality. For the remaining reading space, it was recommended that the area of the effective windows should be increased, and top light windows should be introduced.

1. Introduction

The aspects of building design features that impact daylighting performance are geometry, material properties, orientation, glazing, shading, positioning, sun tunnel, etc. [1]. Also, climate, latitude, obstruction, and reflection are other aspects. The indoor daylighting of reading spaces relies on these features. The reading spaces in the library are used by academicians and non-academicians of the university as well as other research workers, and alumni outside the university [2]. The task of reading is the most important in the library, and it requires effective lighting. Proper lighting is very necessary for the overall success of any type of library [3]. A remarkable library reading space should be characterized by volumes and surfaces illuminated with glare-free natural or daylight [4]. Good daylight quality has been associated with so many benefits. Daylight and the spatial qualities of library reading spaces have profound effects on user behaviour and productivity [5]. Several other studies in buildings have recorded the energy savings for electric lighting from using daylight to be in the range of 20% and 60% [6] and range of 16% and 20% [7]. Gregg also made it clear that the benefits of a daylit building extend beyond simple energy savings but also reduce greenhouse gas emissions and slow fossil fuel depletion [8]. A study done by Veitch has shown that daylighted interior spaces result in more effective learning in libraries, schools, and workspaces [9]. And also, that daylight should be the primary light source for the sake of human health and well-being. Visual observation indicates that the library reading spaces that are under investigation use artificial lighting as the primary source of light, even though there are so many architectural daylight features existing.

However, the interest in investigating the daylight quality of this library arose because of its location in the tropics. It is one of the major public university libraries located in the tropical region. In this region, daylight availability is considered to be high and available throughout the year [10]. Despite the abundance of sunlight, research has shown that daylight levels in interior spaces are grossly inadequate, inconsistent, and sometimes with glare possibility [11]. Research has also shown that there has been a prevalent problem of severe electricity shortage due to a non-steady power supply [12]. Therefore, if this library reading spaces use electricity as the primary source of light, which is not consistent, then there is a need to investigate the indoor daylight quality of its reading spaces and to identify the impact of its building design features on the daylight quality. According to the Illuminating Engineering Society of North

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America [13], and [14], the required daylight level for library reading spaces and other reading spaces is between 300 lux and 500 lux. This study aimed to investigate the indoor daylight quality of the selected reading spaces and understand the influence of individual building design features on their daylight quality.
From the empirical studies conducted by Abigail and Pool on the evaluation of perforated façade for daylighting [15], Monteolivia et al. on daylighting metrics [16], and Khidmat et al. on the optimization of louvers shading devices [17], it is evident that daylight evaluation, assessment and investigation can be done using the climate-based daylight method (CBDM). Climate-based daylight modeling (CBDM) approach was used to determine daylight quality by obtaining the values of useful daylight illuminance (UDI) with its daylight autonomy (DA), daylight factor (DF), and total annual illumination (TAI). It 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 [18] [19]. Useful Daylight Illuminance (UDI) is a daylight availability metric that indicates the percentage of the occupied time when a target range of illuminances at a point in space is met by daylight [1]. Daylight Autonomy (DA) is a daylight availability metric that corresponds to the percentage of the occupied time when the target illuminance at a point in space is met by daylight [20]. Daylight Factor (DF) is a daylight availability metric that shows the percentage of the amount of daylight available inside a room (on a work plane) compared to the amount of unobstructed daylight available outside under overcast sky conditions [21]. While Total Annual Illumination (TAI) is a measure of all the visible daylight energy incidents on a surface during the year, or occupancy period evaluated.

2. The study area

The library building is the major library in a public university located in the hot humid tropical zone that lies within latitudes $6^0 16^1$ N and $6^0 31^1$ north of the equator and longitudes $7^0 20^1$ and $7^0 41^1$ east of the Greenwich Meridian covering an area of about 630km^2. The building has an orientation of 3^0 N-W. In the study area, the wet season is known for its warm, resilient, and overcast nature, while the dry season is known for its hot, humid, and partly cloudy nature. The study area has three prevalent sky conditions, they are the clear, intermediate, and overcast sky. This is summarised in the Table 1 below with the percentage of time spent:

Table 1. The percentage of time spent in each cloud cover band.

Fraction	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cloudier sky	58%	68%	79%	83%	85%	79%	78%	80%	81%	82%	70%	54%
Clearer sky	42%	32%	21%	17%	15%	21%	22%	20%	19%	18%	30%	46%

Source: Weather Spark (2024)

3. Methodology

The study adopted case study research, in combination with building simulation. The methods involved on-site measurements and identification of building design features, and building simulation using a Velux daylight visualizer software to determine the level of daylight quality. The software is validated following the CIE 171:2006 test cases and assessment of the accuracy of lighting computer programs [22]. Its simulation results have also, been validated by ENTPE (National School of State Public Works) in detecting the lighting computer programs accuracy, and also, in the investigation - Daylight Calculations in Practice SBI 2013:26. The study was performed on three reading spaces labeled Esut-Hall A, Esut-Hall C, and Esut-Hall F. It considered the following building design features: space geometry, space floor level, fenestration, window types, window locations, glazing transmittance, shading devices, wall finish, wall colour, door type, floor finish, ceiling material, obstructions, number of windows, window wall ratio (WWR) and window floor ratio (WFR).

4. Data presentation and analysis

4.1 Case Study of ESUT-Hall A

ESUT-Hall A is one of the reading spaces that is known as, the social science section. The pictorial views of this reading space are shown in Figure.1.
It is a rectangular-shaped reading space located on the left-hand side of the second floor with no source of obstructions in the site. The area has 3 columns that are located in the middle. The nine sides of the walls made it look like a bullet (see Figure 2), and are painted with cream-colored paint. The wall area is equal to 194.6 msq as shown in Figure 2.
The headroom is about 3.5m. The exterior sides of the walls have no shading device, one side has an obstruction that is still part of the building. The floor is finished with ceramic tiles on a level. The area of the floor is approximately 296.4msq. The ceiling is a white-painted slab and is located at a height of 3.5m from the ground level. The windows are located on the five sides of the walls (side lighting). The window is a clear-glazed/aluminum projected type with glazing transmittance equivalent to a glass of 6mm thickness, and they are 13 in number. The wall-window-ratio

(WWR) and wall-floor-ratio (WFR) were derived accordingly. The furniture identified are reading tables, chairs, and bookshelves. The furniture arrangement is on three rows with the bookshelves on one row, and the tables and chairs are in four-seating each on the remaining two rows. The heights of tables and shelves are 0.75m and 2.25m respectively. The light source is from both daylight and natural light.

Fig. 1. Pictorial views of ESUT-HALL A (Social science section – ground floor) Source: Author's fieldwork

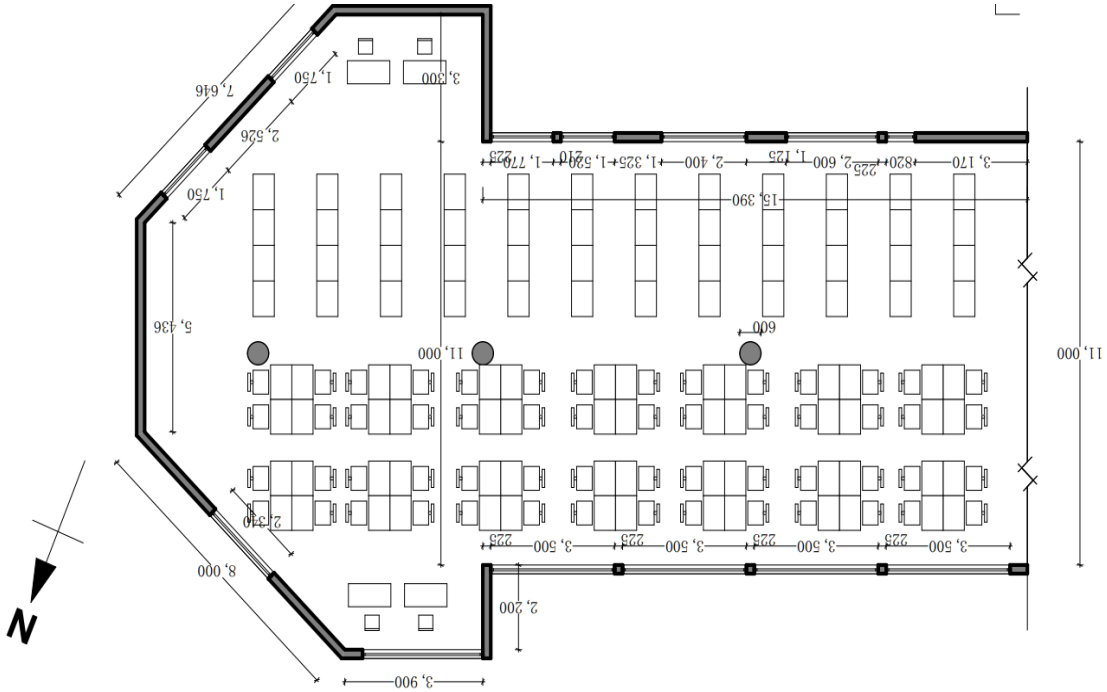

Fig. 2. Floor plan of ESUT-HALL A (296 m sq, WFR = 35%) Source: Author's fieldwork

4.2 Case study of ESUT-HALL C

ESUT-Hall C is also one of the reading spaces that is known as, the reference section. The pictorial views are displayed in Figure 3.

Fig. 3. Pictorial views of ESUT-HALL C (reference section – ground floor) Source: Author's fieldwork

It is a decagon-shaped reading space located at the rear side on the ground floor with no obstructions. The area has no obstructing columns. The ten sides of the walls are painted with cream-colored paint. The wall area is equal to 184.6 msq. This is shown in Figure 4.

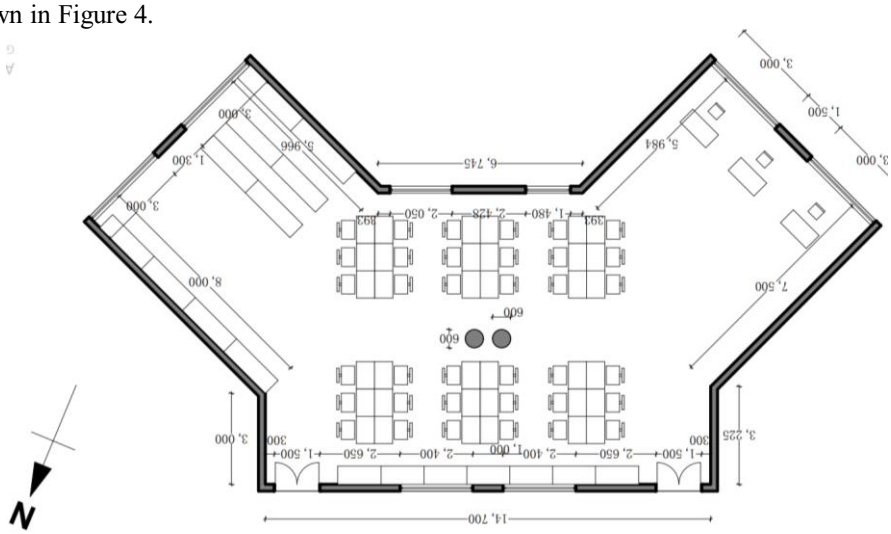

Fig. 4. Floor plan of ESUT-HALL C (216.8 m sq, WFR = 15%) Source: Author's fieldwork

The headroom is about 3.2m. The exterior sides of the walls have no shading device. The floor is finished with ceramic tiles on a level. The area of the floor is approximately 216.8msq. The ceiling is made of white PVC strips and is located at a height of 3.2m from the ground level. The windows are located on the four sides of the walls (side lighting). The side with two windows and two doors is obstructed by a long corridor making those windows ineffective. It can be said that the only effective windows are six in number. The window is a clear-glazed/aluminum projected type with glazing transmittance equivalent to a glass of 6mm thickness, and they are 8 in number. The wall-window ratio (WWR) and wall-floor ratio (WFR) were derived accordingly. The furniture identified are reading tables, chairs, and bookshelves. The arrangement is not sequential, and the tables-chairs are in six-seating each. The heights of tables and shelves are 0.75m and 2.25m, respectively. Light sources are from both daylight and natural light.

4.3 Case study of ESUT-HALL F

ESUT-Hall F is another selected reading space that is known as, the digital library. The pictorial view is shown in Figure 5

Fig. 5. Pictorial views of ESUT-HALL F (Digital library – second floor) Source: Author's fieldwork

It is a rectangular-shaped reading area located on the left side of the second floor with no obstructions. The area has 16 obstructing columns. The six sides of the walls are painted with cream-colored paint. The wall area is equal to 270.4 msq. This is shown in Figure 6.

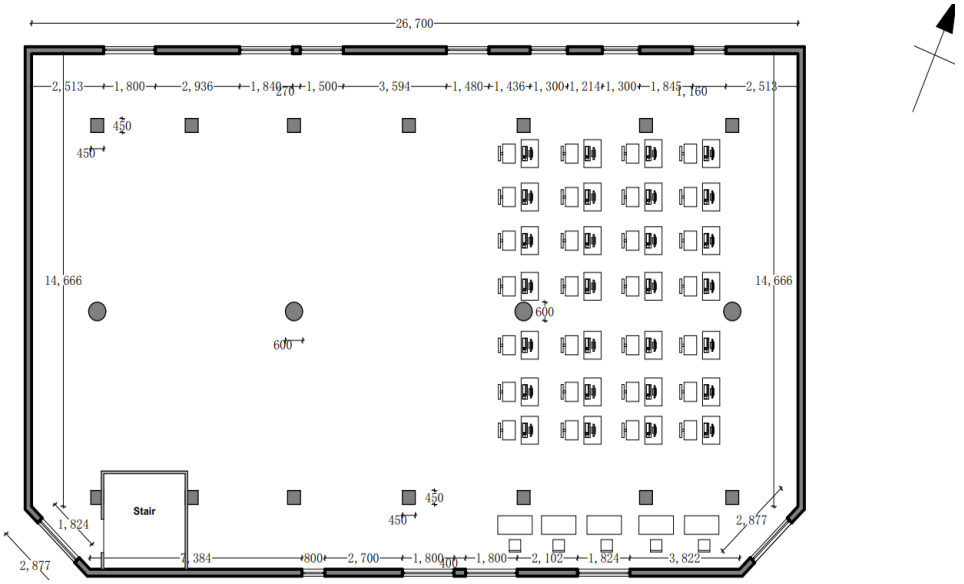

Fig. 6. Floor plan of ESUT-HALL F (442 m sq, WFR = 8%) Source: Author's fieldwork

The headroom is about 3.2m. The exterior sides of the walls have no shading device. The floor is finished with ceramic tiles on a level. The area of the floor is approximately 442msq. The ceiling is made of white PVC strips and is located at a height of 3.2m from the ground level. The windows are located on the two sides of the walls (side lighting). The window is a clear-glazed/aluminum projected type with glazing transmittance equivalent to a glass of 6mm thickness and is 13 in number. The wall-window ratio (WWR) and wall-floor ratio (WFR) are derived accordingly. The furniture identified are reading tables and chairs. The arrangement for table /chairs is one-seating each. The height of the tables is 0.75m. Provisions were made for both daylight and natural light.

4.4 The summary of the building design features

The building design features are sixteen in number and are summarized in Table 2.

Looking at the unique nature of the individual building design features of the selected three reading spaces, most of the variables showed no variance in their values. The variables that vary are to be considered when checking the influence of that type on the daylight quality.

Table 2. Summary of the building design features of the three reading spaces

S/ No	BUILDING DESIGN FEATURES	ESUT-Hall A (Social science section)	ESUT-Hall C. (Reference section)	ESUT-Hall F (Digital section)
1.	Space Geometry	Decagon	Decagon	Rectangle
2.	Space Floor Level	Ground Floor	Ground floor	Second floor
3.	Fenestration	Side- lighting	Side-lighting	Side- lighting
4.	Type of windows used	Projected glazed/ aluminium	Projected glazed/ aluminium	Projected glazed/ aluminium
5.	Locaton of windows	Three sides	Four sides	Three sides
6.	Glazing transmittance	6 mm Single clear (0.89 visible transmittance)	6 mm Single clear	6 mm Single clear
7.	Shading devices	None	None	None
8.	Wall Finishing	Painted	Painted	Painted
9.	Wall color	Creame	Creame	Creame
10.	Type of door	Opened from lobby	Metal Paneled	Opened from stair lobby
11.	Floor finish	Ceramic tiles	Ceramic tiles	Ceramic tiles
12.	Ceiling material	White painted slab	PVC strips	PVC strips
13.	Source of obstruction	Building wing / shelves arrangement/ burglary proof	Hall B from the inner windows	None
14.	Number of windows	13	8 (only 6 are effective)	13
15.	Window – Wall –Ratio	53 %	17 %	13 %
16.	Window – Floor – Ratio	35 %	15 %	8 %

Source: Author's fieldwork

5. Simulation analysis

In this study, the climate-based daylight modeling approach was used to determine the daylight condition (UDI, DA, TAI, and DF) that gives rise to daylight quality. Velux daylight visualizer software helped to determine the annual percentage of the UDI per fraction of the work plane (work plane at 850mm above the ground) and percentile of the reading spaces. The UDI depicts the annual occurrence of daylight falling within a given range. It is also noted that for daylight to be considered "useful", it will be within the threshold of 300 lux – 2000 lux [23] and the reading space threshold of 300lux - 500lux [24]. The target daylight autonomy is 50% for 300lux (DA300,T), 500lux (DA500,T), and 750lux (DA750,T).

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

5.1 ESUT-Hall A Simulation analysis

The UDI simulation result was obtained for ESUT-HALL A as shown in Figure 7. It indicated the percentage of $UDI_{300-2000}$ in colors showing from blue (0.00 %) to red (100 %). The blue colour represents very low % (0 – 20), the green color (20 – 60), yellow colour (60-70), orange green (70-85) and red colour (85 -100). From the results, the reading space showed more of yellow and light red color at the reading space.

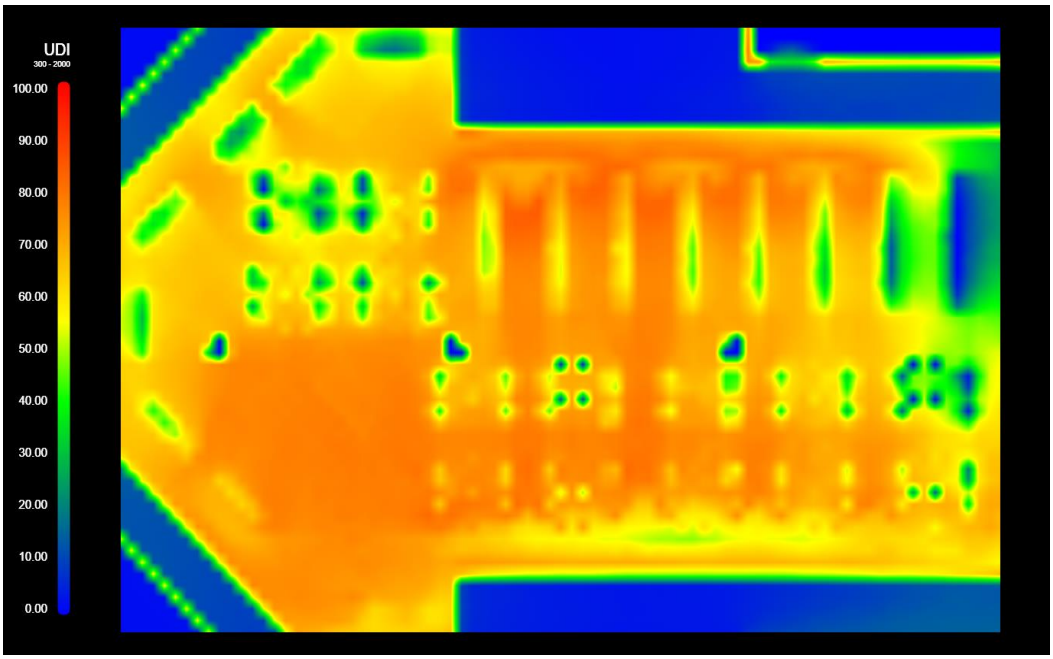

Fig. 7. Pictorial view of ESUT-HALL A UDI simulation

Table 3 shows the summary of the UDI, DA, and TAI results indicating their mean, median, minimum illuminance, maximum illuminance, uniformity 1, and uniformity 2. The reading space which needs the illuminance level of 300 lux to 500 lux was achieved for 90% and 64% of the working year, respectively (see Table 4), and the mean $UDI_{300-2000}$ (useful illuminance) was achieved for 52.50% of the working year with the TAI of 237122.90 kluxhrs (see Table 3).

Table 3. The mean UDI $_{300-2000}$ occupied % throughout the year for ESUT-HALL A

Mean	**$UDI_{300-2000}$**	**52.50%**	**23712.90 klux hrs**
Median	$UDI_{300-2000}$	64.06%	2895.71 klux hrs
Minimum	$UDI_{300-2000}$	0.00%	139.59 klux hrs
Maximum	$UDI_{300-2000}$	84.16%	173968.00 klux hrs
Uniformity 1	UDI_{min}/UDI_{avg}	0.0000	0.0059
Uniformity 2	UDI_{min}/UDI_{max}	0.0000	0.0008

Table 4. The EN17037 score for ESUT-HALL A

$F_{plane,\%} \geq DA_{100,TM}$	**99%**	**Pass (≥95%)**
$F_{plane,\%} \geq DA_{300,T}$	90%	Pass (≥50%)
$F_{plane,\%} \geq DA_{500,T}$	64%	Pass (≥50%)
$F_{plane,\%} \geq DA_{750,T}$	43%	Fail (<50%)

Table 4 is interpreted as follows:

a. For 99% of the working year, there were instances where one or more of the workplane were equal to or greater than 100 lux which is considered as pass by EN17037 standard.
b. For 90% of the working year, there were instances where one or more of the workplane were equal to or greater than 300 lux which is considered as pass by EN17037 standard.
c. For 64% of the working year, there were instances where one or more of the workplane were equal to or greater than 500 lux which is considered as pass by EN17037 standard.
d. For 43% of the working year, there were instances where one or more of the workplane were equal to or greater than 750 lux which is considered as fail by EN17037 standard

The daylight factor (DF) simulation was also carried out and as shown in Figure 8. The values of DF were indicated in colours showing from blue (0.00) to bright yellow (8.00 and above). From observation, the space has both blue and green colours of DF.

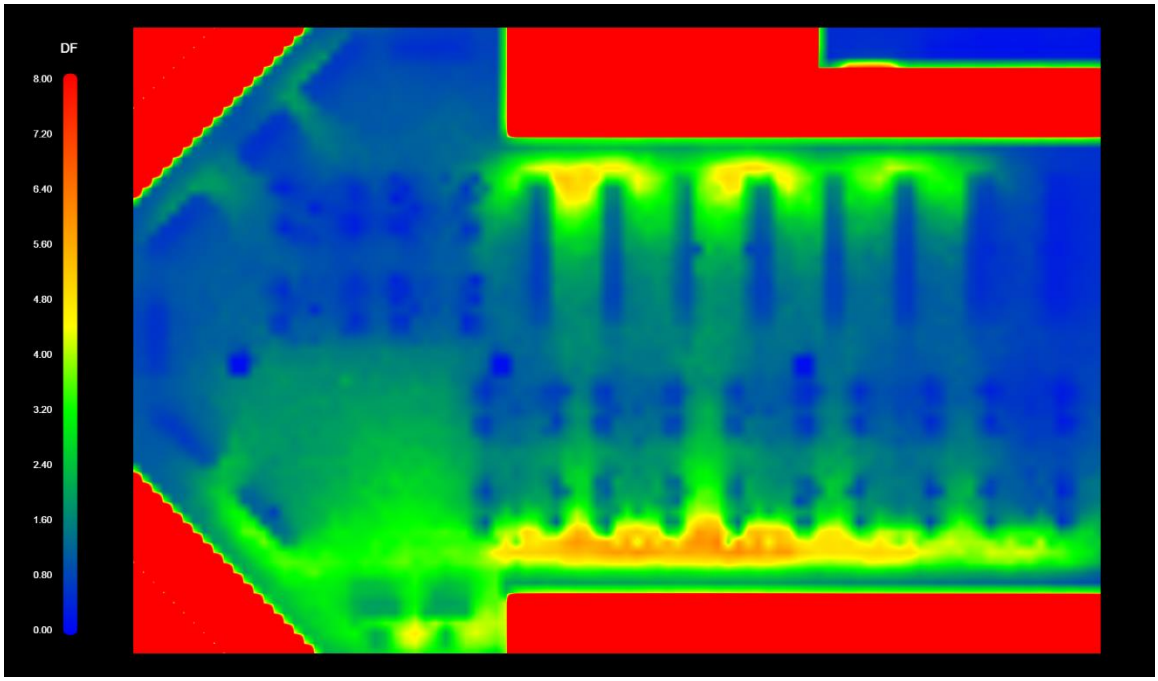

Fig. 8. Pictorial view of ESUT-HALL A DF simulation

Table 5 shows the summary of the DF results indicating their mean, median, minimum illuminance, maximum illuminance, uniformity 1and uniformity 2.

Table 5. The DF % throughout the year for ESUT-HALL A

Mean	**D**	**13.00%**
Median	D	1.83%
Minimum	D	0.15%
Maximum	D	86.78%
Uniformity 1	D_{min}/D_{avg}	0.0115
Uniformity 2	D_{min}/D_{max}	0.0017

Table 6 shows the EN17037 score of DF for ESUT-HALL A using related target daylight factor values of 2.1% (300 lux), 3.5% (500 lux) and 5.3% (750 lux). The minimum daylight factor target (D_{TM}) is 0.7% (100 lux).

Table 6. The EN17037 score for DF in ESUT-HALL A

$\mathbf{F_{plane,\%} \geq 0.7\%\ D_{TM}}$	**94%**	**Fail (<95%)**
$\mathbf{F_{plane,\%} \geq 2.1\%\ D_T}$	43%	Fail (<50%)
$\mathbf{F_{plane,\%} \geq 3.5\%\ D_T}$	28%	Fail (<50%)
$\mathbf{F_{plane,\%} \geq 5.3\%\ D_T}$	20%	Fail (<50%)

Table 6 is interpreted as follows:

a) For 94% of the working year, there were instances where one or more of the workplane were equal to or greater than 0.7% which is considered as fail by EN17037 standard.
b) For 43% of the working year, there were instances where one or more of the workplane were equal to or greater than 2.1% which is considered as fail by EN17037 standard.
c) For 28% of the working year, there were instances where one or more of the workplane were equal to or greater than 3.5% which is considered as fail by EN17037 standard.
d) For 20% of the working year, there were instances where one or more of the workplane were equal to or greater than 5.3% which is considered as fail by EN17037 standard.

For the evaluation of the daylight condition of ESUT-HALL A, the Useful Daylight Illuminance (UDI), Daylight Autonomy (DA), Total Annual Illuminance (TAI), and Daylight Factor (DF) were determined. The summary of the result is shown in Table 7.

Table 7. The summary of the daylight condition values of ESUT-HALL A

	Mean DA	**Mean DF**	**Mean TAI**
$UDI_{300\text{-}2000}$	52.50%	13%	23712.90 klus hrs

The values of the daylight condition using the global standard of required daylight level of 300 lux - 500 lux for library reading spaces are shown in Table 8

Table 8. The summary of the daylight condition values of ESUT-HALL A using the global standard for reading spaces

	Mean DA	**Mean TAI**
$UDI_{300\text{-}500}$	90% & 64%	28907.2 klus hrs
$DF_{3.5}$	28%	

$UDI_{300\text{-}500}$ was achieved in ESUT-HALL A for 64% of the working year with $DF_{3.5}$ achieved for only 28% of the working year. The total annual illumination (TAI) achievable for a working year is 28907.2 klus hrs.

5.2 ESUT-HALL C

The UDI simulation result was obtained for ESUT-HALL C as shown in Figure 9. It indicated the percentage of $UDI_{300\text{-}2000}$ in colors showing from blue (0.00 %) to bright yellow (100 %). The blue colour represents very low % (0 – 20), the red color (20 – 60), orange colour (60-70), mint green (70-85) and yellow colo (85 -100). From the results, the reading space showed more of blue color where most of the reading chairs/tables were placed.

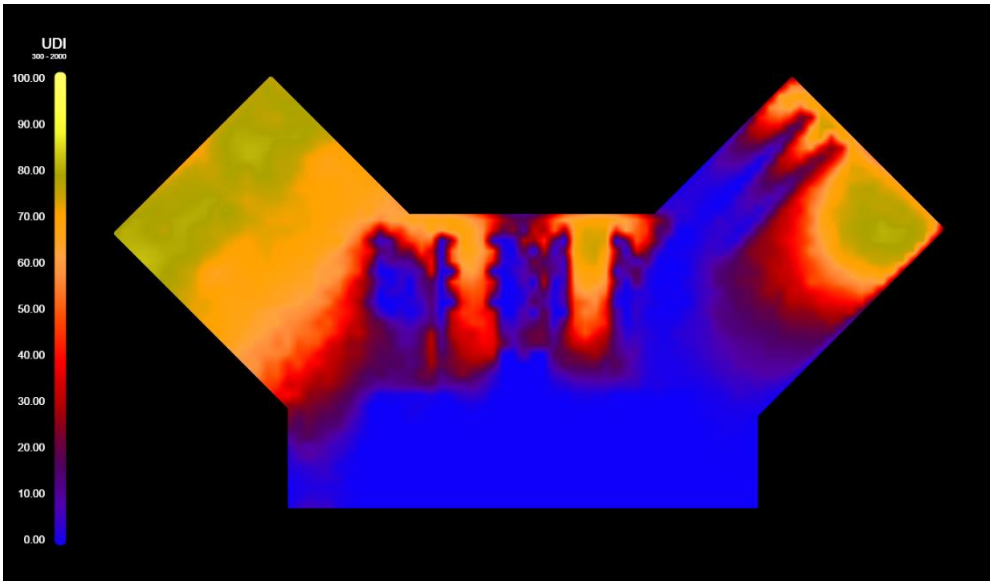

Fig. 9. Pictorial view of ESUT-HALL C UDI simulation

Table 9 shows the summary of the UDI, DA and TAI results indicating their mean, median, minimum illuminance, maximum illuminance, uniformity 1 and uniformity 2. For the reading space which needs the illuminance level of 300 lux to 500 lux was achieved for 33% and 8% of the working year respectively (see Table 10), and the mean $UDI_{300\text{-}2000}$ (useful illuminance) was achieved for 30.32% of the working year with the TAI of 968.80 klux hrs (see Table 9)

Table 9. The mean $UDI_{300-2000}$ occupied % throughout the year for ESUT-HALL C

Mean	**$UDI_{300-2000}$**	**30.32%**	**968.80 klux hrs**
Median	$UDI_{300-2000}$	19.62%	41.00 klux hrs
Minimum	$UDI_{300-2000}$	0.00%	5358.82 klux hrs
Maximum	$UDI_{300-2000}$	81.83%	0.0328
Uniformity 1	UDI_{min}/UDI_{avg}	0.0000	0.0077
Uniformity 2	UDI_{min}/UDI_{max}	0.0000	968.80 klux hrs

Table 10. The EN17037 score for ESUT-HALL C

$F_{plane,\%} \geq DA_{100,TM}$	90%	Fail (<95%)
$F_{plane,\%} \geq DA_{300,T}$	33%	Fail (<50%)
$F_{plane,\%} \geq DA_{500,T}$	8%	Fail (<50%)
$F_{plane,\%} \geq DA_{750,T}$	0%	Fail (<50%)

Table 10 is interpreted as follows:

a) For 90% of the working year, there were instances where one or more of the workplane were equal to or greater than 100 lux which is considered as pass by EN17037 standard.
b) For 33% of the working year, there were instances where one or more of the workplane were equal to or greater than 300 lux which is considered as pass by EN17037 standard.
c) For 8% of the working year, there were instances where one or more of the workplane were equal to or greater than 500 lux which is considered as pass by EN17037 standard.
d) For 0% of the working year, there were instances where one or more of the workplane were equal to or greater than 750 lux which is considered as fail by EN17037 standard

The daylight factor (DF) simulation was also carried out and the result shown in Figure. 2.0. The values of DF are indicated in colors showing from blue (0.00) to bright yellow (8.00 and above). From observation, the space has more low values of DF.

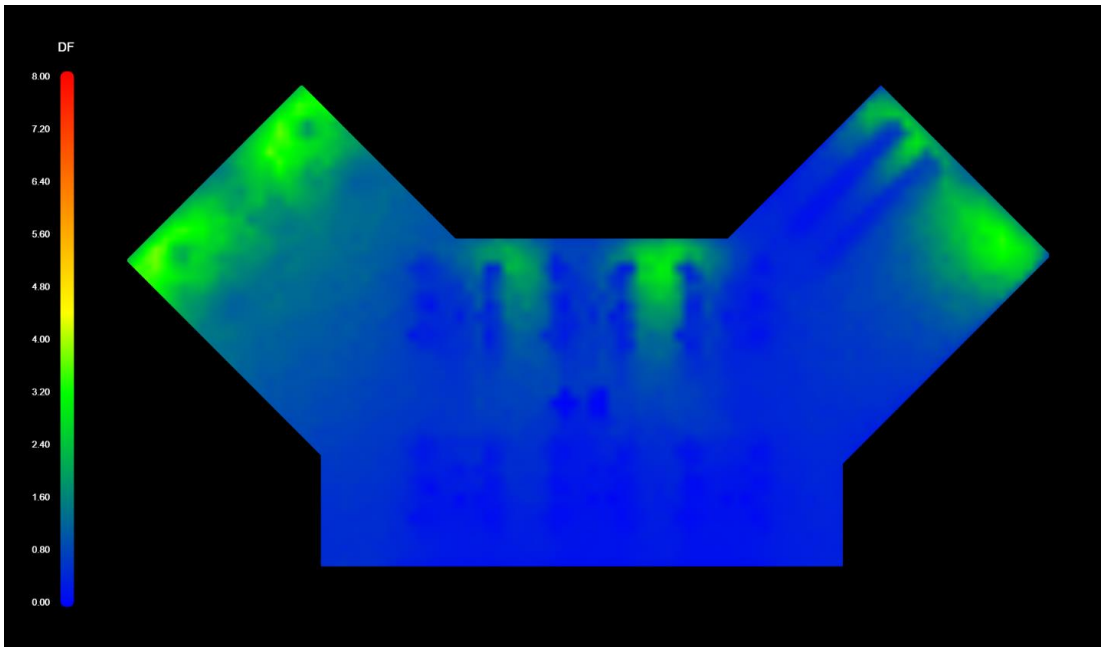

Fig. 10. Pictorial view of ESUT-HALL C DF simulation

Table 11 shows the summary of the DF results indicating their mean, median, minimum illuminance, maximum illuminance, uniformity 1and uniformity 2.

Table 11. The DF % throughout the year for ESUT-HALL C

Mean	**D**	**0.96%**
Median	D	0.72%
Minimum	D	0.05%
Maximum	D	3.76%
Uniformity 1	D_{min}/D_{avg}	0.0475
Uniformity 2	D_{min}/D_{max}	0.0122

Table 12 shows the EN17037 score of DF for ESUT-HALL C using related target daylight factor values of 2.1% (300 lux), 3.5% (500 lux) and 5.3% (750 lux). The minimum daylight factor target (D_{TM}) is 0.7% (100 lux).

Table 12. The EN17037 score for DF in ESUT-HALL C

$F_{plane,\%} \geq 0.7\%\ D_{TM}$	52%	Fail (<95%)
$F_{plane,\%} \geq 2.1\%\ D_T$	10%	Fail (<50%)
$F_{plane,\%} \geq 3.5\%\ D_T$	0%	Fail (<50%)
$F_{plane,\%} \geq 5.3\%\ D_T$	0%	Fail (<50%)

Table 12 is interpreted as follows:

a. For 52% of the working year, there were instances where one or more of the workplane were equal to or greater than 0.7% which is considered as fail by EN17037 standard.
b. For 10% of the working year, there were instances where one or more of the workplane were equal to or greater than 2.1% which is considered as fail by EN17037 standard.
c. For 0% of the working year, there were instances where one or more of the workplane were equal to or greater than 3.5% which is considered as fail by EN17037 standard.
d. For 0% of the working year, there were instances where one or more of the workplane were equal to or greater than 5.3% which is considered as fail by EN17037 standard.

For evaluation of daylight condition of ESUT-HALL C, the Useful Daylight Illuminance (UDI), Daylight Autonomy (DA), Total Annual Illuminance (TAI), and Daylight Factor (DF) were determined. The summary of the result is shown in Table 13.

Table 13. The summary of the daylight condition values of ESUT-HALL C

	Mean DA	Mean DF	Mean TAI
$UDI_{300\text{-}2000}$	30.32%	0.96%	968.8 klus hrs

The values of the daylight condition using the global standard of required daylight level of 300 lux - 500 lux for library reading spaces is shown in Table 14.

Table 14. The summary of the daylight condition values of ESUT-HALL C using global standard for reading spaces

	Mean DA	Mean TAI
$UDI_{300\text{-}500}$	33% & 8%	256 klus hrs
$DF_{3.5}$	0%	

$UDI_{300\text{-}500}$ was achieved in ESUT-HALL C for 33% and 8% of the working year with $DF_{3.5}$ achieved for only 0% of the working year. The total annual illumination (TAI) achievable for a working year is 256 klus hrs.

5.3 ESUT-HALL F

The UDI simulation result was obtained for ESUT-HALL F as shown in Figure 11. It indicated the percentage of $UDI_{300\text{-}2000}$ in colors showing from blue (0.00 %) to red (100 %). The blue colour represents very low % (0 – 20), the green color (20 – 60), yellow colour (60-70), orange green (70-85) and red colour (85 -100). From the result, the reading space showed more orange color but blue colour where the tables and chairs are placed.

Table 15 shows the summary of 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 300 lux to 500 lux was achieved for 76% and 33% of the working year respectively (see Table 16), and the mean $UDI_{300\text{-}2000}$ (useful illuminance) was achieved for 61.23% of the working year with the TAI of 2595.98 klux hrs (see Table 15)

Table 15. The mean $UDI_{300-2000}$ occupied % throughout the year for ESUT-HALL F

Mean	*$UDI_{300-2000}$*	*61.23%*	*2595.98 klux hrs*
Median	$UDI_{300-2000}$	73.32%	1869.98 klux hrs
Minimum	$UDI_{300-2000}$	0.00%	12.12 klux hrs
Maximum	$UDI_{300-2000}$	86.23%	171470.00 klux hrs
Uniformity 1	UDI_{min}/UDI_{avg}	0.0000	0.0047
Uniformity 2	UDI_{min}/UDI_{max}	0.0000	0.0001

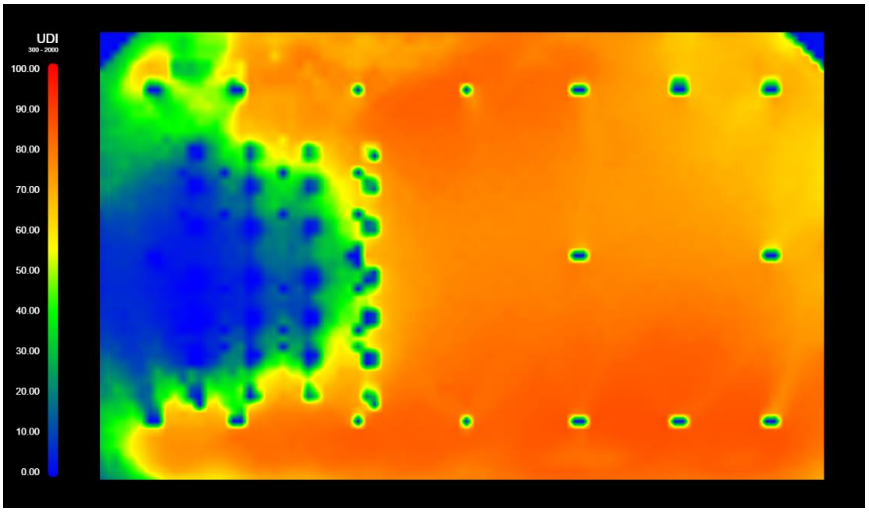

Fig. 11. Pictorial view of ESUT-HALL F UDI simulation

Table 16. The EN17037 score for ESUT-HALL F

$F_{plane,\%} \geq DA_{100,TM}$	*99%*	*Pass (≥95%)*
$F_{plane,\%} \geq DA_{300,T}$	76%	Pass (≥50%)
$F_{plane,\%} \geq DA_{500,T}$	33%	Fail (<50%)
$F_{plane,\%} \geq DA_{750,T}$	5%	Fail (<50%)

Table 16 is interpreted as follows:

a. For 99% of the working year, there were instances where one or more of the workplane were equal to or greater than 100 lux which is considered as pass by EN17037 standard.
b. For 76% of the working year, there were instances where one or more of the workplane were equal to or greater than 300 lux which is considered as pass by EN17037 standard.
c. For 33% of the working year, there were instances where one or more of the workplane were equal to or greater than 500 lux which is considered as pass by EN17037 standard.
d. For 5% of the working year, there were instances where one or more of the workplane were equal to or greater than 750 lux which is considered as fail by EN17037 standard

The daylight factor (DF) simulation was also carried out and was shown in Figure 12. The values of DF were indicated in colors showing from blue (0.00) to bright yellow (8.00 and above). From observation, the space has more low values of DF.

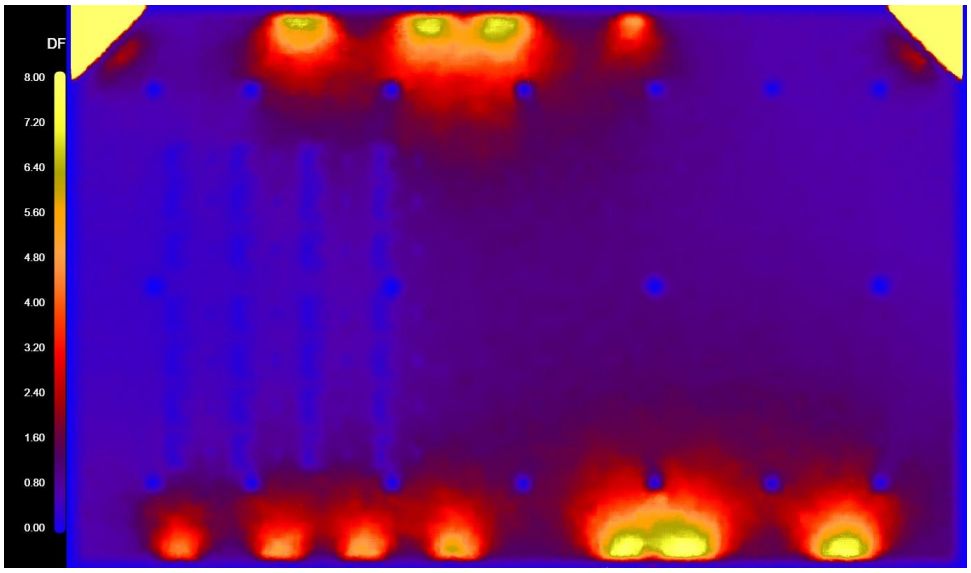

Fig. 12. Pictorial view of ESUT-HALL F DF simulation

Table 17 shows the summary of the DF results indicating their mean, median, minimum illuminance, maximum illuminance, uniformity 1and uniformity 2.

Table 17. The DF % throughout the year for ESUT-HALL F

Mean	*D*	*1.79%*
Median	D	1.36%
Minimum	D	0.01%
Maximum	D	81.34%
Uniformity 1	D_{min}/D_{avg}	0.0038
Uniformity 2	D_{min}/D_{max}	0.0001

Table 18 shows the EN17037 score of DF for ESUT-HALL F using related target daylight factor values of 2.1% (300 lux), 3.5% (500 lux) and 5.3% (750 lux). The minimum daylight factor target (D_{TM}) is 0.7% (100 lux).

Table 18. The EN17037 score for DF in ESUT-HALL F

$F_{plane,\%} \geq 0.7\% D_{TM}$	*85%*	*Fail (<95%)*
$F_{plane,\%} \geq 2.1\% D_T$	17%	Fail (<50%)
$F_{plane,\%} \geq 3.5\% D_T$	3%	Fail (<50%)
$F_{plane,\%} \geq 5.3\% D_T$	0%	Fail (<50%)

Table 18 is interpreted as follows:

a. For 85% of the working year, there were instances where one or more of the workplane were equal to or greater than 0.7% which is considered as fail by EN17037 standard.
b. For 17% of the working year, there were instances where one or more of the workplane were equal to or greater than 2.1% which is considered as fail by EN17037 standard.
c. For 3% of the working year, there were instances where one or more of the workplane were equal to or greater than 3.5% which is considered as fail by EN17037 standard.
d. For 0% of the working year, there were instances where one or more of the workplane were equal to or greater than 5.3% which is considered as fail by EN17037 standard.

For the evaluation of the daylight condition of ESUT-HALL F, the Useful Daylight Illuminance (UDI), Daylight Autonomy (DA), Total Annual Illuminance (TAI), and Daylight Factor (DF) were determined. The summary of the result is shown in Table 19.

Table 19. The summary of the daylight condition values of ESUT-HALL F

	Mean DA	**Mean DF**	**Mean TAI**
$UDI_{300\text{-}2000}$	61.23%	1.79%	2595.98 klus hrs

The values of the daylight condition using the global standard of required daylight level of 300 lux - 500 lux for library reading spaces are shown in Table 20.

Table 20. The summary of the daylight condition values of ESUT-HALL F using the global standard for reading spaces

	Mean DA	**Mean TAI**
$UDI_{300\text{-}500}$	76% & 33%	1399 klus hrs
$DF_{3.5}$	22%	

$UDI_{300\text{-}500}$ was achieved in ESUT-HALL F for 76% and 33% of the working year with $DF_{3.5}$ achieved for only 22% of the working year. The total annual illumination (TAI) achievable for a working year is 1399 klus hrs.

6. Findings and Discussion

After carrying out simulations on the three selected reading spaces, the results were shown in values, and colours were used to elaborate more on them. Table 21 below shows the summary of the values of the daylight conditions of the nine selected reading spaces.

Table 21. The summary of the values of the daylight conditions of the nine selected reading spaces.

READING SPACES	$UDI_{300lux\text{-}2000lux}$ DA (MEAN)	$UDI_{300lux\text{-}500\ lux}$ DA	DAYLIGHT FACTOR (DF) (MEAN)	TOTAL ANNUAL ILLUMINANCE (TAI) (MEAN)	SCORE
ESUT-HALL A	52.52%	90% & 64%	13%	23712.90 Kluxhrs	Pass
ESUT-HALL C	30.32%	33% & 8%	0.96%	968.80 Kluxhrs	Fail
ESUT-HALL F	61.23%	76% & 33%	1.79%	2595.98 Kluxhrs	Pass

The UDI threshold of 300 lux – 2000 lux was considered useful as analyzed by Nabil and Mardeljevic (2005), which should be achieved across a fraction of the reference plane within a space for at least half of the daylight hours (50% of the working year- DA) as stated by EN 17037 (2018). In this research, among the three selected reading spaces, only two of them were able to meet the threshold of illuminance that is considered useful for 50% of the working year. Those two reading spaces are ESUT-HALL A and ESUT-HALL F. This research also took note of light recommendation level of 300 lux – 500 lux for reading spaces as required by IESNA (2013) and EN 12464-1(2021), and these should be achieved for at least 50% of the working year. The same two (2) of the reading spaces met with the threshold. Although, ESUT-HALL F could not achieve up to 50% of the illuminance values of 500 lux, but 300 lux can enable a reader to read.

According to CIBSE (2002), a room will appear strongly daylit when the average DF is 5% or more, in which case electric lighting will most likely not be used during daytime. None of the nine selected was able to achieve a DF of 5%, which explains the reason for using artificial light to support daylight as was observed in most of the reading spaces.

TAI is the sum of all illuminance values during the occupied hours of the year, the annual exposure to illumination is a basic consideration for the preservation of items such as books, newspapers, etc. For example, the Scottish Museums Council recommends a maximum exposure of 450,000 lux hours per year (450 klux hrs) for “moderately sensitive items”, and 100,000 lux hours per year (100 klux hrs) for “very sensitive items”. All except CAR-HALL B exceeded the required TAI, therefore, there is a need to be cautious of where and how items such as books, newspapers, etc are kept in the reading spaces.

7. Conclusion

The two reading spaces that met the required UDI and DF thresholds are considered to be of good daylight quality. Looking at the unique nature of the individual building design features of these two reading spaces (Esut-Hall A and Esut Hall F), these features significantly influenced their daylight quality. The features that have no variance can still be maintained but the features that vary, the ones meant for these two reading spaces are to be considered. To achieve good daylight quality, the space geometry can either be rectangular or decagonal shape. The windows can be located on three sides of the walls, the doors should be opened from a lobby, the ceiling materials can either be a white slab or PVC, no serious obstructions, the windows can be as many as possible, window wall ratio should have a minimum of 13% and a maximum of 53%, and Window floor ratio should have a minimum of 8% and a maximum of 35%. For Esut Hall C, the WWR and WFR are within the range and most of its building design features are similar to the other two, but the two ineffective windows that were obstructed by a long internal corridor seem to be the cause of not meeting the 50% threshold for mean $UDI_{300lux\text{-}2000\ lux}$ DA, and $UDI_{300lux\text{-}500\ lux}$ DA. Therefore, the recommendation is that the area of the effective windows should be increased to compensate for the ineffective windows. In addition, since that space has no other floor on its top, top light windows should be introduced.

References

1. Ullah, Development of Fresnel-based CPV System with Uniform Illumination, *Journal of Daylighting* **1**, 1-6 (2014)
2. J. Gupta, Changing Roles of Academic and Research Libraries. Association of College & Research Libraries (ACRL) (2018)
3. D. Malman, Lighting for Libraries. U.S. Institute of Museum and Library Services (2005)
4. E.D. Edward, Daylighting Design in Libraries (2005)
5. A. Raihaneh, A. Halil Zafer, Investigation of the effects of daylight in a university Library. *Journal of Architectural and Planning Research* **35**(4), 343-356 (2018)
6. A.D. Galasiu, G.R. Newsham, C. Suvagau, D.M. Sander, Energy-saving lighting control systems for open-plan offices: a field study. *Leukos* **4**(1), 7–29 (2007)
7. J. Mardaljevic, M. Andersen, N. Roy, J. Christoffersen, Daylighting, Artificial Lighting and Non-Visual Effects. *Study for a Residential Building* (2012)
8. G.D. Ander, U.S. Department of Energy Federal Energy Management Program (FEMP) (2016)

9. J. A. Veitch, Principles of Healthy Lighting: Highlights of CIE TC 6-11, National Research Council, Canada, (2003)
10. Weather spark forecast report (2024)
11. M. Ayoosu, Y. Lim and P. Leng, Daylighting 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 (2020)
12. J.K. Darling, N. Hoyt, O.K. Murao, The energy Crises of Nigeria an overview and Implication for the future. *University of Chicago Publication* (2008)
13. IESNA LM-83-12: Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). The Illuminating Engineering Society of North America (IES) (2014)
14. EN 12464-1 European standard for Lighting requirements: Light and lighting (2021)
15. D. Abigail, C. Pool, A Comprehensive Evaluation of Perforated Façades for Daylighting and Solar Shading Performance: Effects of Matrix, Thickness and Separation Distance. *Journal of Daylighting* **6**(2), 97-111 (2019)
16. J.M. Monteoliva, A. Villalba, A. Pattini, Daylighting Metrics: An Approach to Dynamic Cubic Illuminance *Journal of Daylighting* **5**(2), 34-42 (2018)
17. R.P. Khidmat, H. Fukuda, B. Paramita, M.D. Koerniawan, The optimization of louvers shading devices and room orientation under three different sky conditions. *Journal of daylighting* **9**, 137–149 (2022)
18. J. Mardaljevic, The simulation of annual daylighting profiles for internal illuminance. *Lighting Research and Technology* **32**(3) (2000)
19. C.F. Reinhart, S. Herkel, The Simulation of Annual Illuminance Distributions - A State-of-the-art Comparison of Six RADIANCE-based Methods. *Energy and Buildings* **32**(2), 167-187 (2000)
20. C.F. Reinhart, O. Walkenhorst, Validation of dynamic RADIANCE- based daylight simulations for a test office with external blinds. *Energy & Buildings* **33**, 683–697 (2001)
21. R.G. Hopkins, Architectural Physics: Lighting. Her Majesty's Stationery Office, London (1963).
22. CIE 171:2006 Test Cases to Assess the Accuracy of Computer Lighting Programs (2006)
23. A. Nabil, J. Mardaljevic, Useful daylight illuminance: A new paradigm for assessing daylight in buildings. *Lighting Res. Technol.* **37,** 41–59 (2005)
24. EN 17037 European Standard for Daylight Requirements in Buildings (2018)