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MAPPING DAYLIGHTING ZONES IN NIGERIA USING EMPIRICAL DATA AND CLIMATE MODELLING

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ABSTRACT

This study investigates the relationship between the widely used Koppen-Trewatha-Horn (KTH) climate classification system of Nigeria and daylighting performance. It assesses the suitability of existing climate zones for assessing daylighting effectiveness through Climate-Based Daylight Modelling (CBDM) in test classrooms at 24 locations across the country. Data analysis using both supervised (Chi-square goodness-of-fit) and unsupervised (hierarchical clustering) statistical tests reveals a marked difference between the traditional climate zones and the empirically derived daylighting zones. The research provides new, evidence-based daytime zone maps for Nigeria using daylighting metrics such as Daylight Autonomy (DA), Useful Daylight Illuminance (UDI), and Daylight Uniformity Index (DAUI). The results indicate that the best-fit daylighting zones do not align with the conventional climate zone limits, suggesting that expert daylighting classification schemes should be employed in architectural design practices. The research forms the basis for the design of Nigerian and other tropical region-specific daylighting design guidelines.

Keywords: Daylighting zones, Koppen-Trewatha-Horn classification, Climate-based daylight modelling, Nigeria, Fenestration design

1.0 INTRODUCTION

Daylighting is the intentional introduction of natural light into buildings to provide functional and aesthetic advantages. Daylighting enhances people's health and productivity, improves energy efficiency, and supports sustainability, making it worthwhile to maximise the utilisation of natural light in buildings (Boubekri, 2008; Shishegar & Boubekri, 2016; Heschong, 2002; Kousalyadevi & Lavanya, 2019; Guzowski, 1999). This aspect is highly crucial in tropical regions like Nigeria, where unmanaged excessive sunlight exposure can cause overheating and glare.

Contemporary daylighting encompasses several key parameters, including available daylight, sky conditions, interior daylighting computations, glare analysis, user preferences, and window technology (Phillips, 2012; Tregenza & Mardaljevic, 2018). The two primary factors at the outset, daylight availability and sky type, depend largely on regional climate, suggesting a possible relationship between climate classification and the effectiveness of daylighting.

Effective daylighting prediction is now a computationally intensive area that requires computational capacity, facilities, time, and funding. Sadly, most architectural professionals cannot perform effective daylighting analyses, particularly in the early design phases. The classical "daylight factor" specification (a minimum of 2%) has been found wanting, especially in the tropics, as it was designed for overcast-sky conditions that prevail in northern latitudes. In response to this, more advanced methods, such as Climate-Based Daylight Modelling (CBDM), have evolved to deliver climate-specific, more precise daylight predictions. However, these methods are generally too sophisticated for most practising architects (Mardaljevic, 2015; Dubois et al., 2025).

In response to this challenge, the lighting and building design community has increasingly accepted the need for simple-to-use, regionally oriented daylighting guidance (Ander, 1995). Certain countries have encouraged the creation of regionally based daylighting zones aligned with their climatic conditions, which will be addressed in the literature review section. The initiatives suggest that regionally adapted daylighting zones could offer architects simple-to-use design parameters that take into consideration local conditions.

Nigeria, with its diverse geography that encompasses various climates, presents a strong case study for determining whether traditional climate classification schemes can reliably predict daylighting performance. The Koppen-Trewatha-Horn (KTH) climatic classification, chosen on the basis that it is the widest system employed for the description of Nigeria's climate (Ayoade, 1993), has three distinct climate types: hot semi-arid in the northern region, tropical wet and dry in the central zone, and tropical wet in the southern part of the country. Given the diversity of these climate categories, this research seeks to establish whether these classifications can effectively predict daylighting performance in Nigeria.

Despite the extensive worldwide literature on daylighting zones, the gap in research on the classification of comparable categories is enormous in the Nigerian context. The foundation of this study is the authors' previous work, conducted in Zaria, Nigeria, to optimise fenestration for daylight, which assisted in the development of prototype models for this research (Salisu, 2015).

Statistical tools of supervised and unsupervised learning are applied in this paper. Supervised learning methods are predictive inferential statistical methods, such as regression, correlation, and hypothesis tests. Unsupervised learning methods focus on discovering meaningful patterns and subgroups in data, with prediction not a goal. The method provides exploratory research with a valuable tool (James et al., 2013), allowing the detection of subgroups with similar characteristics and providing opportunities for data interpretation and theory construction.

1.1 Aim and Objectives

This research aims to generate daylight zones with equivalent daylight availability under the Koppen-Trewatha and Horn climate classifications using computer simulation and daylighting evaluation indicators. The objectives are as follows:

i. To determine whether the Koppen-Trewatha and Horn climate classifications for Nigeria can be used as a daylighting zone map.
ii. To establish empirically based daylighting zones for Nigeria by utilising Climate-Based Daylight Modelling (CBDM) simulation data through hierarchical cluster analysis.

1.2 Research Hypotheses

The null hypothesis (H_0) states that the distribution of towns across the KTH climate zones does not differ significantly from their distribution within the empirically established daylighting zones.

H_0: ρA (Towns in KTH Climate zones) = ρB (Towns in Daylighting zones)
The alternative hypothesis (H_1) is that the two are not similar in locations:
H_1: ρA (Towns in KTH Climate zones) ≠ ρB (Towns in Daylighting zones)

2.0 LITERATURE REVIEW

2.1 Daylighting Zones Internationally

Daylighting researchers and designers have been busy predicting and examining the quantity and quality of daylighting in relation to climate characteristics and climate zones internationally. The use of climate zones has been inextricably linked with climate files as a point of departure for daylighting design concepts.

i. **United States:** The American Architectural Manufacturers Association Skylight Handbook – Design Guidelines (SHDB-1) has divided the US into six daylight-availability zones, with a representative trial skylight design for each city, varied by climate for cooling (Ander, 1995).
ii. **Europe:** A European daylight standard has been proposed based on eight European climates, from the south of Europe (Madrid, Spain) to the northernmost part of North (Ostersund, Sweden) (Mardaljevic et al., 2013).

iii. **ASHRAE Standards:** In examining the daylighting requirements in ASHRAE Standard 90.1, six climate locations were selected to represent a combination of ASHRAE climate zones and three sky types to study. These three sky types were categorised into sky-type A with a mean annual sunshine percentage greater than 75%, sky-type B between 45%-75%, and sky-type C, less than 45% (Athalye et al., 2013).
iv. **North America:** Five daylight zones in North America were proposed in 2014 by Reinhart, based on similarities between daylight autonomy distributions in offices derived from simulations conducted using a climate-based daylight modelling methodology (Reinhart, 2014). This was corroborated by subjective occupant perceptions for students in 11 schools of architecture.
v. **China:** Five light-climate zones according to the 'Standard for Daylighting Design of Buildings' published by the Ministry of Housing and Urban-Rural Development of the People's Republic of China (Guan & Yan, 2016)

Given that daylighting zones are the unifying element of these global proposals, design professionals will likely develop fewer complex methods to derive daylighting design parameters from climate for different building types, such as schools, offices, and factories. Inappropriateness of prevalent climate classification systems for daylighting may have led to the creation of daylight-specific daylighting regions.

2.2 Climate Classification Systems

Climate is a process comprising climatic and non-climatic factors (topography, soil cover, human activities, etc.), with temperature and precipitation most commonly used to define it (Ayoade, 1993). Different climate classification systems are available, depending on specific needs, yet the Köppen-Geiger and Trewartha climate classification systems are the most widely accepted (Ayoade, 1993). This plan in effect connects the vegetation of a region to its climate and temperature, as well as its seasonal characteristics.

2.3 Climate Context of Nigeria

Nigeria is a 36-state country with a combined area of 910,770 km² and a population of more than 235 million as of 2024 (Obokoh & Obokoh, 2024). Nigeria has three climate types based on the Köppen-Geiger and Trewartha classification, as shown in Fig. 1.

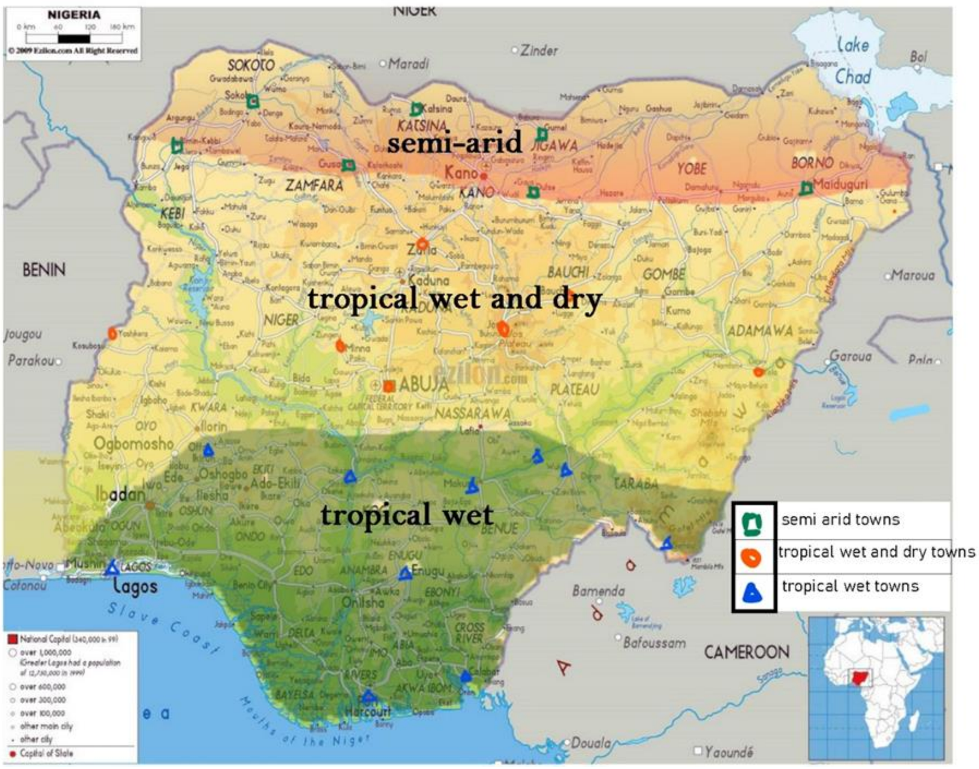

Fig. 1: Map of Nigeria showing the Three Climate Zones according to the Koppen-Trewatha-Horn classification scheme. (Source: Salisu, 2015).

i. **Hot** Semi-Arid: This region experiences clear skies and dryness for most of the year, receiving 250 to 750 mm of rainfall annually. The temperature fluctuates significantly between day (reaching as much as 44°C) and night (dropping to as little as 12°C).
ii. **Tropical Wet and Dry:** Annual rainfall in this zone is 1000-1500 mm for six months with a well-defined dry season. Monthly mean temperatures can reach as high as 40°C during the dry season.
iii. **Tropical Wet:** Southern Nigeria has an area that receives heavy rainfalls totalling 2000-4000 mm per year, along with high cloud cover and many overcast days from the middle areas to the coast.

2.4 Daylighting Assessment Metrics

Climate-Based Daylight Modelling (CBDM) has been established as the benchmark for daylighting assessment, using climate- and location-based parameters. Research scientists have suggested a multifaceted assessment on a climate- and location-based basis, incorporating climate change variables. This, along with user assessments, has aided in fulfilling various assessment metrics for Daylight Autonomy (DA), Useful Daylight Illuminances (UDIs), and Spatial Daylight Autonomy (sDA) over the last one and a half decades (Reinhart et al., 2006).

These assessment metrics have helped researchers but have not been particularly 'useful' to design professionals due to their complexity (Dubois, 2020; Tregenza & Mardaljevic, 2018). Additionally, some people's assumptions have been questioned (Brembilla & Mardaljevic, 2019), especially regarding different locations on Earth and users' adjustments to daylight illuminance and glare limits. In some locations, absolute illuminance cut-off levels might be more crucial than daylight distribution. In contrast, in other locations, daylight distribution (bearing on contrast and thus visibility) might be more important.

Consequently, rather than applying the most recently suggested sDA measures of the IESNA (Illuminating Engineering Society of North America), four measures are applied in this paper. The first DA of 500 lux was suggested by Zack Rogers of Architectural Energy Corporation in 2006 (Reinhart et al., 2006), and the $UDI_{100-2000}$ suggested by Nabil and Mardaljevic (2005) for daylight quantities. For daylight quality, UDI illuminance greater than 2000 lux and DA Uniformity distribution index (introduced due to the bilateral opposite or corner-wall windows characteristic of the tropics, especially classrooms). These performance requirements are discussed below:

i. **Daylight Autonomy (DA):** For a specified work plane (in this case, 750mm above floor level), it is the percentage of the year for which a minimum target is met by daylight alone. Typically, a DA of 60% of the work plane illuminance (500 lux) is acceptable daylighting, especially for classrooms.
ii. **Useful Daylight Illuminance of 100 to 2000 lux ($UDI_{100-2000}$):** At a specified work plane as described earlier, means useful daylight, and according to the British Society of Light and Lighting, a room that reaches a criterion value of 80% in this measure can be said to be successfully lighted (Society of Light and Lighting, 2011).
iii. **Excessive Daylight Illuminance in excess of 2000 lux ($UDI_{>2000}$):** At a specific work plane, as discussed earlier, is an excess of daylight that may produce visual distraction, solar gains, and thermal discomfort (Nabil & Mardaljevic, 2005).
iv. **Daylight Uniformity Index (DAUI):** For a specified work plane, it is the ratio of the maximum Daylight Autonomy to the average Daylight Autonomy of an area, which is unitless. The closer this value is to '1', the more uniform the daylight is distributed in the area. It is used for comparative tests with no cut-off point.

From the analysis above, there is a natural correlation between daylighting and climate zones; however, the link between traditional climate classifications and the amount of daylight available is complex, as highlighted by the varied zone-specific methodologies implemented globally. Importantly, the studies examined share a common drawback: they presuppose, rather than test empirically, the appropriateness of using climate classification systems as indicators for daylighting zone delineation. None has used CBDM to directly assess whether a country's existing climate zones can predict daylighting performance across its region. This deficiency is particularly prominent in sub-Saharan Africa, where there is currently no daylighting zone mapping based on CBDM. The current study tackles this deficiency by empirically examining the relationship between Nigeria's KTH climate zones and daylighting performance data derived from simulations.

2.5 Prototype Classroom Designs

Two virtual classroom designs were created from common configurations present in public secondary schools in Nigeria. These forms were also optimised for orientation, sun shading, and light redirection, suggesting their shared use within a tropical setting (Salisu, 2015). The models in Fig. 2 and Fig. 3 feature both glazed and unglazed window forms and measure 10,500 mm in length, 7,200 mm in width, and 3,000 mm in floor-to-ceiling height. They are to be utilised where there is no artificial light and operate between 8 a.m. and 6 p.m. on weekdays for students aged 6 to 14. Daylight readings were conducted at the floor height of 750 mm, and material photometric reflectance values were: 0.502 for walls, 0.302 for floors, 0.8 for ceilings, and 0.70 for desks and chairs.

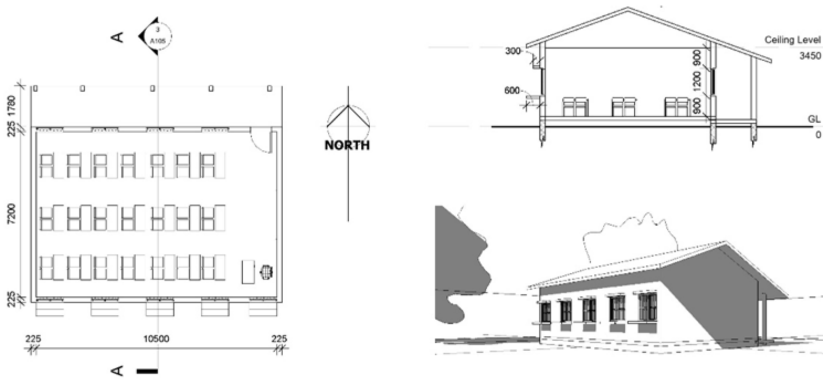

Fig. 2: Prototype Classroom Design 1 (glazed variant)
(Source: Salisu, 2015).

The prototype classroom features 3 mm single-glazed casement windows with a transmittance rate of 0.722. The Window-to-Wall Ratios (WWRs) were modified from a non-veranda window area of 7.80 m² (WWR of 24.76%) to a veranda window area of 6.24 m² (WWR of 19.81%), which is typical for public schools in Nigeria. On the non-veranda side, this design includes daylighting components such as a horizontal concrete sunshade measuring 300 mm × 1200 mm × 100 mm and a light shelf that extends 6000 mm, located beneath the windows, while a sloped roof over the veranda provides shade on that side.

The unglazed prototype classroom, on the other hand, features tropical steel casement windows with 2 mm thick panels and a surface reflectance of 0.755. The window areas have been slightly reduced, with a non-veranda window area measuring 7.20 m² (WWR of 22.86%) and a veranda window area measuring 5.76 m² (WWR of 18.29%). On the side without the veranda, a horizontal concrete sunshade (300 mm × 1200 mm × 100 mm) provides shading. Both room configurations share a consistent sill height of 900 mm and include burglar-proofing.

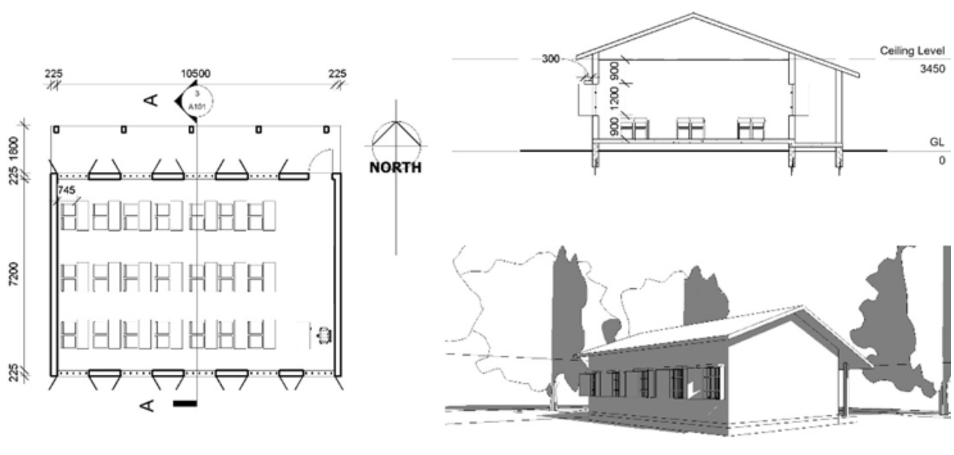

Fig. 3: Prototype Classroom Design 2 (unglazed variant)
(Source: Salisu, 2015).

3.0 METHODOLOGY

A post-positivist worldview was employed (Creswell & Creswell, 2018), with the assumption that location and climate significantly influence daylight provision. Data are collected to test the hypothesis that the Koppen-Trewatha-Horn climate classification schemes determine daylighting zones, and, where necessary, revisions and further testing would be performed. Quantitative research was used to follow the daylighting parameters of DA, UDIs, and DAUI to twenty-four (24) locations in the nation's three climate zones. Hierarchical clustering within clusters was used to establish the similarity and best fit of clusters in the sample locations.

3.1 Study Population and Sampling

The population under study comprises Nigerian towns lying between latitudes 4° and 14°N and longitudes 2° and 15°E across the three climate zones of the Koppen-Trewatha-Horn classification. Stratified sampling across the zones, as well as longitudinal factors, were applied in the choice of locations as follows:

i. Hot Semi-Arid zone (7 locations): Birnin-Kebbi, Sokoto, Gusau, Katsina, Gumel, Dutse, Maiduguri
ii. Tropical Wet and Dry (7 sites): Yashikera, Minna, Abuja, Zaria, Jos, Bauchi, Yola
iii. Tropical Wet (10 sites): Lagos, Offa, Lokoja, Port-Harcourt, Enugu, Makurdi, Calabar, Tunga, Wukari, Gembu

Ten locations were selected for the Tropical Wet zone, taking into account the hill country of Taraba and Plateau States. They were to provide a satisfactory stratified sample for testing glazed and unglazed fenestrations in the zones.

3.2 Research Design

The research adopted a quantitative design with an exploratory sequential approach. Phase one determined whether a "goodness of fit" existed between the Koppen-Trewatha and Horn climate classifications and daylighting zones derived from K-Means clustering of similarities based on the CBDM metrics for Nigeria's twenty-four selected sites.

The analysis was performed using climate-based daylight modelling (CBDM), a computer simulation technique that accounts for the year-round dynamic behaviour and variability of the tropical skies. The research equipment and techniques employed are given in Table 1.

Table 1: Research Method Schedule

Study	Instruments	Issues for Investigation	Statistical Analysis
Assessment of prototype Glazed and Unglazed classrooms in the three climate zones of Nigeria (24 samples)	Climate files Autodesk Ecotect Analysis 2011 IBM SPSS Statistics 21	Daylight Autonomy (DA). Useful Daylight Illuminances ($UDI_{100\text{-}2000}$ &$UDI_{>2000}$). Daylight Uniformity Index (DA_{UI})	*K*-Means clustering for both Glazed and Unglazed sample similarities within groups for *K*=3 based on the three climate zones as shown in Fig. 6. Descriptive maps based on clustering for both Glazed and Unglazed samples.
Comparison of Koppen-Trewatha and Horn Climate classification to both Glazed and Unglazed Daylighting zones from maps developed from Hierarchical clustering.	MS Excel Maps based on *K*=3 cluster sampling Tests	Hypothesis Ho – ρA (Towns in KTH Climate zones) = ρB (Towns in Daylighting zones). Hypothesis Ha –ρA ≠ ρB	Chi Square Test X^2 for test of goodness fit.

4.0 RESULTS

The primary data for CBDM indicators were developed through computer simulation using Autodesk Ecotect Analysis of the two secondary classroom building glazing prototypes at 24 locations across Nigeria, spread across the three climate zones. A K-Means clustering with K = 3, chosen a priori to correlate directly with Nigeria's three KTH climate zones, was analysed using IBM SPSS Statistics 21. This enabled a direct goodness-of-fit comparison between simulation-derived clusters and the traditional climate categorisation. The agglomerative approach and the default SPSS setting of squared Euclidean distance were used for this.

The similarities among the location clusters and their spatial locations are shown in Tables 2 and 3 and Figs. 4 and 5. Even though the recommendations for the glazed and unglazed options are closer together, it is evident that the ranges of locations across the two sets of climate zones and the three daylighting zones (obtained from the cluster analysis) vary. This is illustrated in Table 4.

Table 2: Glazed Illuminance Data and 3-Cluster Classification for the assessed 24 Locations across Nigeria

Town	DA	$UDI_{100-2000}$	$UDI_{>2000}$	DAUI	Cluster
Birnin-Kebbi	34.71	93.30	1.64	2.53	1
Sokoto	37.71	93.18	2.89	2.39	2
Gusau	35.41	95.72	1.61	2.46	2
Katsina	36.70	96.58	1.90	2.42	2
Gumel	38.26	97.05	2.01	2.45	2
Dutse	37.23	96.99	1.75	2.46	2
Maiduguri	38.51	96.74	2.24	2.48	2
Yashikera	33.55	91.04	2.26	2.57	1
Minna	34.22	94.81	1.61	2.64	1
Abuja	35.58	96.03	1.70	2.49	2
Zaria	35.94	97.31	1.57	2.51	2
Jos	32.59	94.67	2.11	2.63	1
Bauchi	37.58	96.67	1.80	2.41	2
Yola	37.72	96.59	2.02	2.52	2
Lagos	29.21	88.70	1.23	2.82	3
Lokoja	30.76	93.53	1.30	2.82	1
Port-Harcourt	27.14	90.52	0.97	3.04	3
Enugu	32.32	89.54	1.14	2.53	1
Makurdi	32.45	95.32	1.26	2.72	1
Calabar	27.92	90.62	1.38	2.92	3
Offa	34.17	96.32	1.41	2.66	1
Wukari	32.82	94.79	1.40	2.72	1
Tunga	35.98	95.96	1.99	2.58	2
Gembu	30.60	93.71	1.35	2.84	1

Table 3: Unglazed Illuminance Data and 3-Cluster Classification for the assessed 24 Locations across Nigeria

Town	DA	$UDI_{100-2000}$	$UDI_{>2000}$	DAUI	Cluster
Birnin-Kebbi	84.94	89.17	7.37	1.13	1
Sokoto	86.65	87.98	9.08	1.11	1
Gusau	87.61	91.10	7.41	1.12	1
Katsina	88.72	91.19	8.03	1.11	1
Gumel	91.59	90.84	8.64	1.08	1
Dutse	90.22	91.14	8.22	1.10	1
Maiduguri	91.61	90.39	8.99	1.08	1
Yashikera	82.03	87.35	8.39	1.15	1
Minna	82.79	91.43	7.45	1.18	2
Abuja	87.12	91.15	7.99	1.13	1

Town	DA	$UDI_{100-2000}$	$UDI_{>2000}$	DAUI	Cluster
Zaria	89.83	91.70	7.52	1.10	1
Jos	85.32	91.17	8.18	1.16	1
Bauchi	90.91	90.89	8.39	1.09	1
Yola	91.65	90.53	8.68	1.08	1
Lagos	73.28	87.76	6.87	1.24	3
Lokoja	79.59	91.38	6.88	1.21	2
Port-Harcourt	71.12	91.32	5.96	1.30	3
Enugu	75.40	89.86	6.31	1.23	3
Makurdi	83.01	91.91	7.17	1.18	2
Calabar	72.20	90.99	6.80	1.32	3
Offa	87.31	91.19	7.99	1.13	1
Wukari	82.69	91.50	7.38	1.18	2
Tunga	88.36	90.93	8.27	1.11	1
Gembu	80.54	91.88	6.81	1.18	2

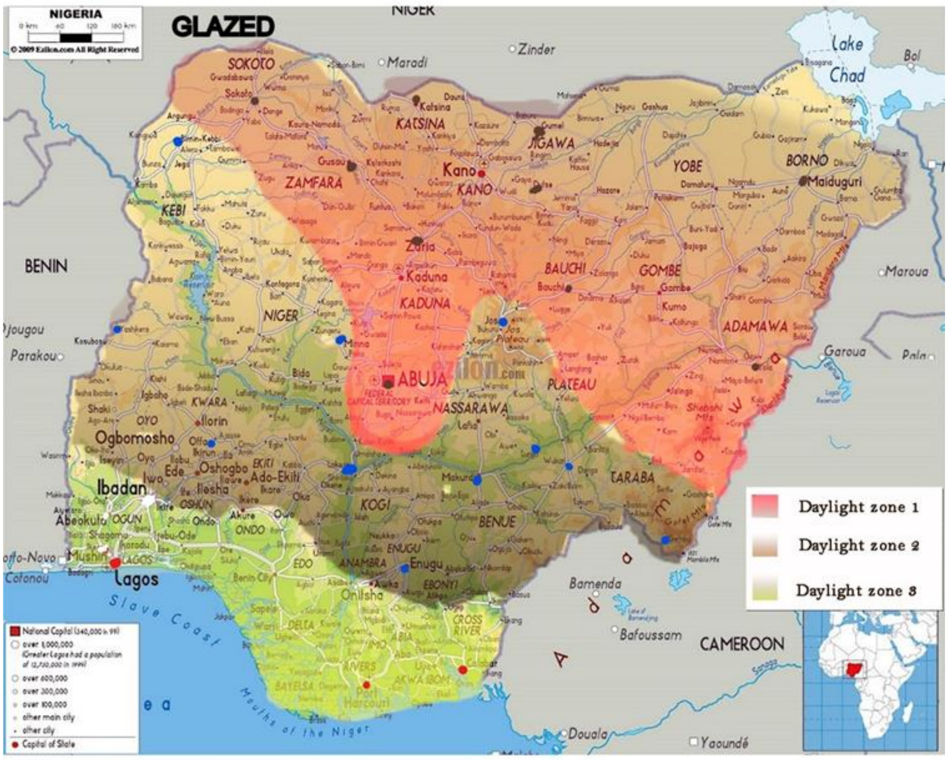

Fig. 4: Map of Nigeria showing the Three Daylighting Zones for Glazed classrooms according to the 3 Cluster classification schemes
(Source: Salisu, 2015).

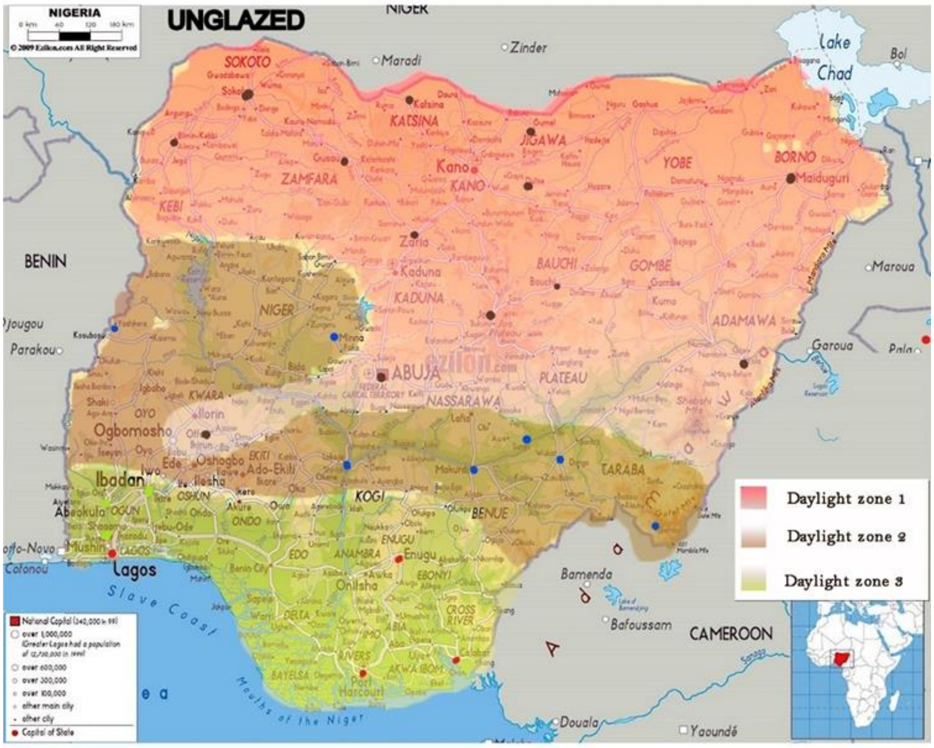

Fig. 5: Map of Nigeria showing the Three Daylighting Zones for Unglazed classrooms according to the 3 Cluster classification schemes

(Source: Salisu, 2015).

Table 4: Distribution of Locations for KTH Climate Zones and Proposed Daylighting Zones (Glazed & Unglazed) based on CBDM for the 24 Locations across Nigeria

Koppen-Trewatha-Horn Climate Zone			Proposed Daylighting Zone from K-Means Clustering, K=3 Analysis	
	Locations	Zone	Glazed: Locations	Unglazed: Locations
1.	7 no. Birnin-Kebbi, Sokoto, Gusau, Katsina, Gumel, Dutse & Maiduguri.	Semi-Arid	Zone 1: 10 no. Sokoto, Gusau, Katsina, Zaria, Abuja, Gumel, Dutse, Bauchi, Maiduguri & Yola.	Zone 1: 14 no. Birnin-Kebbi, Sokoto, Gusau, Katsina, Gumel, Dutse, Maiduguri, Yola, Abuja, Offa, Jos, Bauchi, Zaria & Tunga.
2.	7 no. Yashikera, Minna, Zaria, Abuja, Jos, Bauchi & Yola.	Tropical Wet & Dry	Zone 2: 11 no. Birnin-Kebbi, Yashikera, Offa, Minna, Lokoja, Enugu, Makurdi, Jos, Tunga, Wukari & Gembu.	Zone 2: 6 no. Yashikera, Minna, Lokoja, Makurdi, Wukari & Gembu.
3.	10 no. Lagos, Offa, Lokoja, Port-Harcourt, Enugu, Makurdi, Calabar, Tunga, Wukari & Gembu.	Tropical Wet	Zone 3: 3 no. Lagos, Port-Harcourt & Calabar.	Zone 3: 4 no. Lagos, Port-Harcourt, Enugu & Calabar.

Looking at Figs. 4 and 5 compared with Fig. 1, no visual compatibility is observed within the coastal regions, with 70% of the sites being outside the Tropical Wet zone, and over half of the sites in the semi-arid and tropical wet and dry are not in the relative Daylighting zones 1 and 2.

A Chi-Square Test of Goodness of Fit was applied after verifying its assumptions (the sample was drawn from a stratified selection across the three climate zones and there were more than five observations in each category) to determine if the observed and expected locations of the Climate map of Koppen-Trewatha-Horn and the Daylighting zones map from the 3-cluster analysis, are the same for both Unglazed and Glazed fenestrations groups. A p-value of less than 0.05 indicates grounds to reject the null hypothesis. The null hypothesis of the two types of fenestrations stated that the observed and expected locations are equal, as presented below:

i. H_0 - ρA (Towns in KTH Climate zones) = ρB (Towns in Daylighting zones)
ii. Ha - ρA (Towns in KTH Climate zones) ≠ ρB (Towns in Daylighting zones)

The outcome of the Chi-Square test showed a significant difference between the two cases:

i. For glazed fenestrations: $\chi^2 = 19.93$; (df = 2; n = 24) p = .000
ii. For unglazed fenestrations: $\chi^2 = 14.02$; (df = 2; n = 24) p = .001

In both instances, the p-values were below 0.05, and therefore the null hypotheses were rejected. This implies that the KTH climate zones do not adequately represent daylighting zones in Nigeria.

4.1 Hierarchical Clustering Results

After the null hypothesis was rejected, the findings were again fine-tuned to achieve the goal of developing the "Daylighting Zones" map for the country based on CBDM. Hierarchical clustering was used to determine the optimal number of clusters for comparable cases. This was preceded by the agglomerative process, z-scores for normalising the data, and Ward's clustering method to create equal-sized clusters. The findings were as follows:

4.1.1 Glazed System

Based on the agglomeration schedule shown in Table 5, the largest relative distance covered is between stages 22 and 23, and the coefficient of variation is approximately 50%. This indicates that a two-cluster solution is the most stable and interpretable for the glazed classroom data. This is also supported by the dendrogram shown in Fig. 6, where the two dominant clusters are readily distinguishable.

Table 5: Agglomeration Schedule for Glazed Classrooms

Agglomeration Schedule						
Stage	**Cluster Combined**		**Coefficients**	**Stage Cluster First Appears**		**Next Stage**
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	16	24	.007	0	0	18
2	3	10	.061	0	0	8
3	6	13	.121	0	0	5
4	19	22	.200	0	0	11
5	4	6	.297	0	3	13
6	5	14	.406	0	0	7
7	5	7	.601	6	0	12
8	3	11	.869	2	0	13
9	9	21	1.150	0	0	11
10	15	20	1.723	0	0	15
11	9	19	2.317	9	4	18
12	5	23	2.994	7	0	17
13	3	4	3.795	8	5	17
14	1	12	4.886	0	0	16
15	15	17	6.102	10	0	22
16	1	8	7.483	14	0	19
17	3	5	9.486	13	12	21

Agglomeration Schedule						
Stage	**Cluster Combined**		**Coefficients**	**Stage Cluster First Appears**		**Next Stage**
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
18	9	16	11.952	11	1	20
19	1	18	16.396	16	0	20
20	1	9	23.175	19	18	22
21	2	3	30.083	0	17	23
22	1	15	46.335	20	15	23
23	1	2	92.000	22	21	0

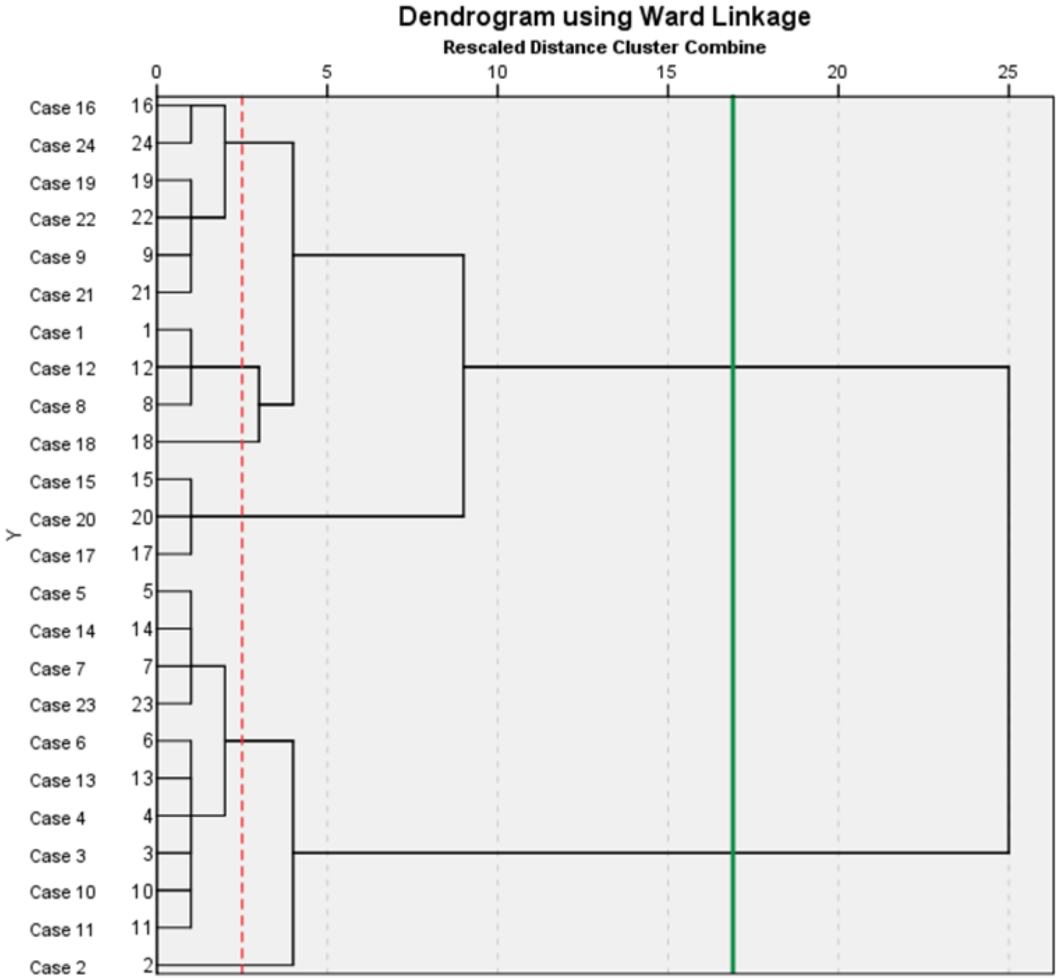

Fig. 6: Dendrogram Plot of Glazed Illuminance Data for 24 Locations showing Cluster relationships. (Source: Salisu, 2015).

4.1.2 Unglazed System

Similarly, the agglomeration schedule in Table 6 of the unglazed system shows the largest relative coefficient difference between stages 22 and 23, once again indicating a two-cluster solution as the most robust and stable. This is further supported by the dendrogram shown in Fig. 7 for the unglazed data.

Table 6: Agglomeration Schedule for Unglazed Classrooms

Agglomeration Schedule						
Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	10	21	.001	0	0	8
2	9	22	.006	0	0	6
3	5	14	.037	0	0	7
4	6	13	.094	0	0	13
5	4	23	.157	0	0	8
6	9	19	.297	2	0	14
7	5	7	.436	3	0	13
8	4	10	.614	5	1	11
9	16	24	.806	0	0	14
10	3	11	1.031	0	0	16
11	4	12	1.465	8	0	16
12	17	20	2.063	0	0	20
13	5	6	2.663	7	4	19
14	9	16	3.365	6	9	21
15	2	8	4.276	0	0	18
16	3	4	5.316	10	11	19
17	15	18	6.957	0	0	20
18	1	2	9.666	0	15	22
19	3	5	13.662	16	13	22
20	15	17	18.528	17	12	21
21	9	15	31.521	14	20	23
22	1	3	45.072	18	19	23
23	1	9	92.000	22	21	0

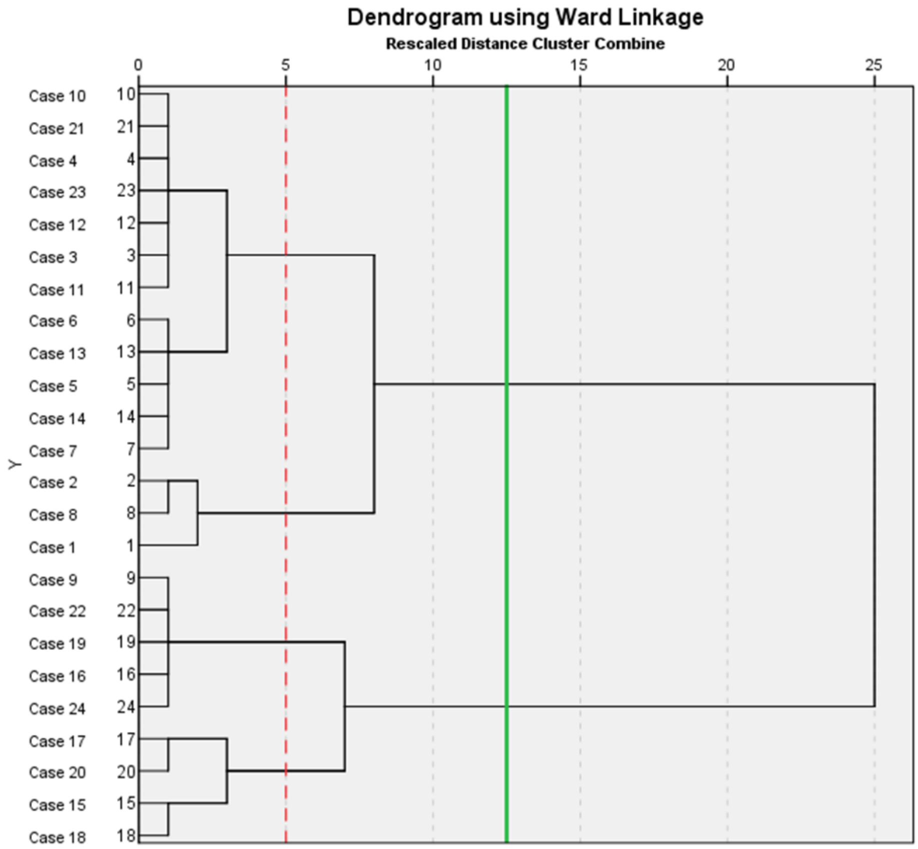

Fig. 7: Dendrogram Plot of Unglazed Illuminance Data for 24 Locations showing Cluster relationships. (Source: Salisu, 2015).

4.2 Proposed Two-Cluster Daylighting Zone Maps

Based on the two-cluster solution for both fenestrations, we recommend the daylighting maps given in Figures 8 and 9 for glazed and unglazed classrooms.

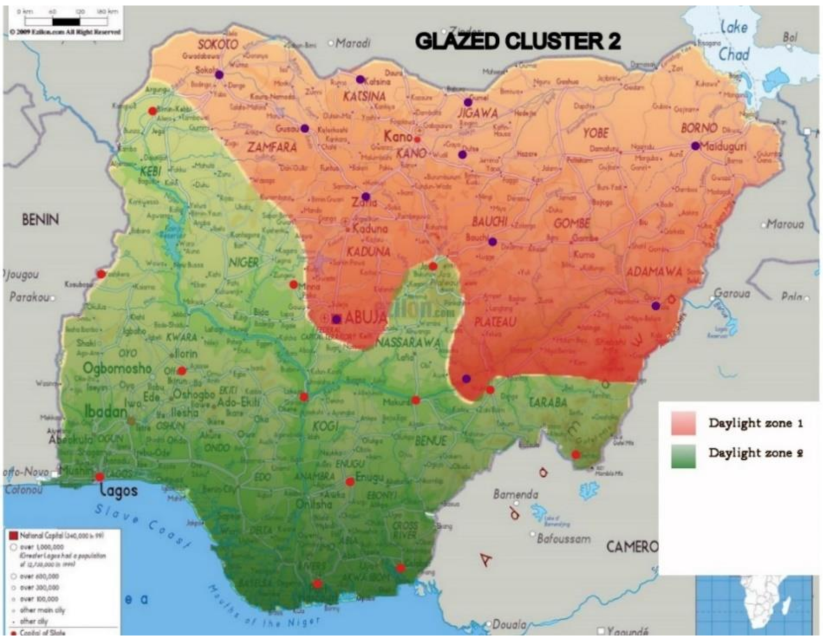

Fig. 8: Proposed Daylighting Zones for Glazed classrooms according to 2 Cluster Hierarchical classification schemes.
(Source: Salisu, 2015).

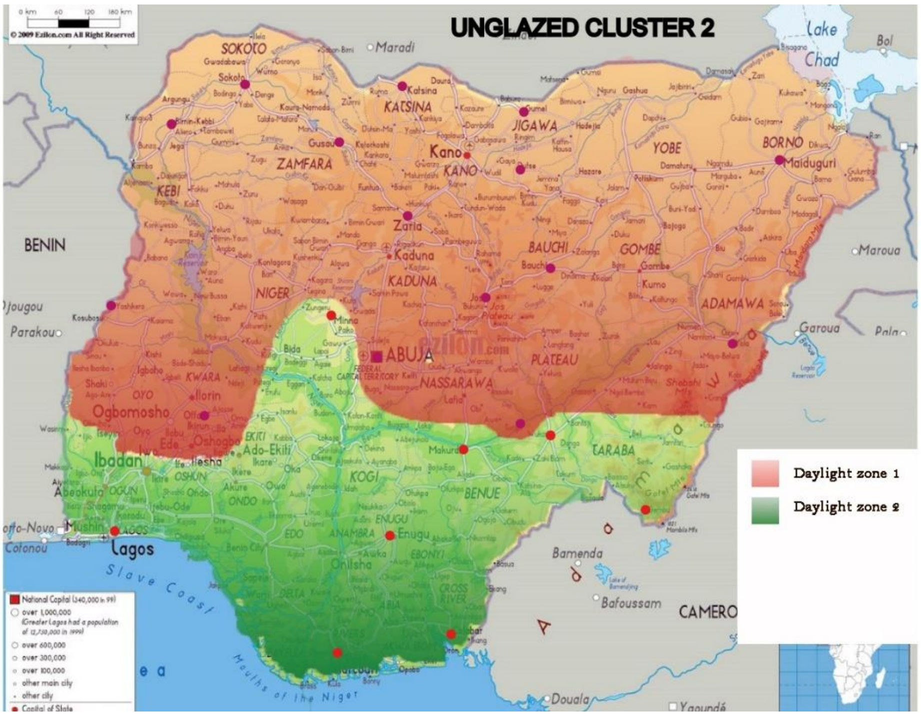

Fig. 9: Proposed Daylighting Zones for Unglazed Classrooms according to 2 Cluster Hierarchical classification schemes.

(Source: Salisu, 2015).

5.0 DISCUSSION AND SUMMARY OF FINDINGS

5.1 Principal Findings

Daylighting provision in Nigeria does not align with the Koppen-Trewatha-Horn climate zones, and the local environmental conditions have a more significant influence than latitude. Two daylighting zones were established based on the analysis. Zone 1, comprising coastal and highland areas, has less Daylight Autonomy (DA) but greater uniformity (DAUI) for glazed classrooms due to widespread cloud cover, which diffuses sunlight. In contrast, Zone 2, covering northern Nigeria, provides abundant daylight throughout the year with increased DA and lower uniformity, implying a higher glare potential. These performance trends are reversed in unglazed classrooms.

5.2 Implications for Architectural Practice

Given Nigeria's unpredictable electricity, these evidence-based daylighting zones allow architects to implement optimised design templates without resorting to location-specific simulations. This calls for a paradigm shift from generic solutions to region-specific strategies. In low-DA regions, such as the south, structures must have larger glazed areas to attain maximum light gain. In contrast, high-DA locations in the north must have effective shading and glare control to prevent visual discomfort. This empirical data forms a vital foundation for revising the Nigerian Building Code, which currently has inadequate daylighting recommendations, and can facilitate the development of simpler, zone-based design tools for practitioners.

5.3 Comparison with International Daylighting Zone Systems

Nigeria's two-zone system is simpler than the five or six zones used in the US and China. The simplicity reflects the more consistent tropical climate of Nigeria and the dominant effect of cloud cover patterns on the latitude differences. The distinction points out that daylighting zones must be separately established for specific geographic areas because the correlation between climate factors and daylighting performance is more complex than traditional climate classifications suggest.

6.0 SCOPE AND LIMITATIONS

The study is based on Autodesk Ecotect Analysis 2011 models of common classroom structures. The CBDM engine of this program has been used and cross-validated in peer-reviewed daylighting studies, and it remains technically suitable for the illuminance measures used in this work, even though it is no longer financially maintained (Mardaljevic, 2015; Brembilla & Mardaljevic, 2019). The EnergyPlus Typical Meteorological Year (TMY) datasets, which depict long-term average conditions but do not account for year-to-year fluctuation or anticipated climate change effects, provided the climate files utilised in the simulations. Therefore, without additional research, the conclusions are limited to classroom building typologies and cannot be applied to other building types, such as offices or residential buildings. The study also requires physical validation through field measurements and does not incorporate significant real-world variables such as occupant behaviour, cultural preferences, interior finishes, or future climate change impacts. Despite these limitations, the study provides a foundational and necessary step towards evidence-based daylighting design in Nigeria.

7.0 CONCLUSION

The study shows that the Koppen-Trewatha-Horn climate classification is not a reliable predictor of daylighting performance in Nigeria for the prototype secondary classroom typology modelled across 24 sampled locations. The results show that the 24 locations can be grouped into two simulation-based daylighting patterns, providing the first empirically derived daylighting zone maps for Nigeria and suggesting that local conditions more strongly shape daylighting provision than broad climate zone boundaries. These findings provide a foundation for architectural practice reform and building code updates, subject to further validation. The methodology employed in this study, which uses CBDM simulation data and cluster analysis to establish daylighting zones systematically, can be applied to other tropical countries where conventional climate classifications may struggle to predict daylighting effectiveness accurately.

7.1 Future Research Directions

Future research should focus on four priority areas. Firstly, to check modelled performance trends against real-world data by carrying out measurements on the ground at several representative locations within the two zones. Secondly, to test whether the two-zone approach applies to all building types, such as offices, dwellings, and health-care buildings, or whether sector-specific zoning is required. Thirdly, occupant behaviour patterns, user preferences for shading and ventilation, and interior finishing may be introduced in subsequent simulations to reduce the performance discrepancy between the prototype model and the actual building. Fourthly, as climate change is predicted to significantly alter patterns of cloud cover, solar radiation, and seasons in West Africa, longitudinal investigations are required to assess the long-term reliability of the modelled daylighting zones and formulate sustainable design guidelines for Nigerian architects.

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All authors contributed to the conception and design of the study. Abubakar Sadiq Salisu formulated the research idea and created the comprehensive design framework. Andrew Okotete Oghenekevwe was responsible for performing the daylighting simulations and analysing the data. Faruk Ibrahim Mukhtar prepared, formatted, and organised the manuscript for submission and publication. The initial draft of the manuscript was written by Abubakar Sadiq Salisu, with all authors reviewing and giving feedback on earlier drafts. All authors have read and approved the final version of the manuscript.

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