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ENHANCING DAYLIGHT IN DEEP-PLAN OFFICES FOR NIGERIA'S TROPICAL CLIMATE: A LIGHT PIPE APPROACH

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ABSTRACT

This research addresses the challenge of maximising daylight provision in deep-plan office buildings in Nigeria's tropical wet and dry climate. It investigates the effectiveness of horizontal light pipes at 5m, 10m, and 15m, employing a mixed-method approach that combines case studies and computer simulations.
The study utilises Climate Studio for Rhinoceros 3D as the simulation tool to assess light distribution uniformity and illuminance levels in deep-plan offices. Statistical analysis includes applying ANOVA tests to ascertain the significance of differences between various light pipe configurations. Findings reveal that the 10m light pipe configuration consistently outperforms the 5m and 15m options, providing superior uniformity of light distribution and higher illuminance levels, thereby maximising daylight provision.
The study recommends the 10m light pipe configuration as optimal for maximising daylight provision in deep-plan office buildings within Nigeria's tropical wet and dry climate.

Keywords: Daylighting, Light Pipes, Deep-Plan Office, Tropical Wet and Dry Climate, Uniformity, Illuminance, ANOVA.

1.0 INTRODUCTION

Modern businesses increasingly favour office layouts in middle and high-rise buildings that incorporate spacious floor plans. These designs, known for their considerable depth, provide flexibility and economic advantages, making them a preferred choice (Afroz, 2015). While this configuration is commonly favoured, particularly for daytime operations, it has a notable drawback. Daylight penetration naturally extends to about 5 meters from the perimeter opening (Garcia-Hansen & Edmonds, 2003). Nadal (2005) highlights that this results in an uneven illumination distribution, with higher levels near openings and significantly reduced lighting in the deeper core. Visual comfort plays a significant role in shaping the satisfaction and well-being of individuals within indoor settings (Frontczak & Wargocki, 2011).
Numerous studies have explored the relationship between daylight distribution, visual comfort, and productivity in office environments. Turan (2020) investigates the economic value of natural light in office spaces. The study finds that spaces with high amounts of daylight (55% spatial daylight autonomy) have a 5-6% value premium over spaces with less daylight. Despite the dense urban environment, tenants value high daylight, independent of other buildings, neighbourhood, and contract characteristics. The study concludes that

daylight is a key design driver and should be considered in design, policy, planning, and project financing. This suggests that the social benefits of daylight translate into economic value.

Wong (2017) comprehensively reviewed daylighting design in modern buildings. The study focused on the methods of predicting and measuring daylight levels and the various daylighting technologies available. Despite the wide range of developed and commercially available daylighting systems, their applications have been limited due to a lack of studies on their utilisations and high initial costs.

Carlucci et al. (2015) conducted a comprehensive review in Italy, emphasising the significance of balanced light distribution for occupant well-being. Loe et al. (1994) analysed 18 lighting conditions in The Bartlett, University College London, which is in the temperate maritime climate, identifying crucial visual interest and luminosity perception variables. Zhang et al.'s (2022) investigation into illuminance, uniformity, and colour temperature in China's humid continental climate highlighted the importance of optimal lighting design for comfort and energy efficiency.

Lu et al. (2020) delved into subjective evaluation, task performance, and physiological responses to different illuminance and colour temperature combinations in China's temperate monsoon climate. Their findings reinforced the profound impact of lighting conditions on visual comfort and mood. Kompier et al. (2021) explored the temporal dynamics of abrupt illuminance and colour temperature changes in the Netherlands' moderate maritime climate, indicating the immediacy of response to lighting conditions alterations.

1.1 Problem Statement

Office spaces with inadequate and uneven light distribution can have areas that are either too dim or excessively bright, affecting the workspace's overall visual comfort and functionality. This can aggravate eye strain, create discomfort, and make reading and monitoring screens difficult. Ultimately, this can result in less productivity, more mistakes, and a slower task completion rate. In many climate zones, the value of daylight in the workplace has been emphasised, and the problems associated with inadequate daylight have been extensively studied. Thus, methods for increasing daylight penetration are essential, particularly in spaces with little window light.

Nigeria has two distinct seasons: a wet season with lots of rainfall and a dry season with less precipitation. Understanding this climate pattern is essential for tailoring architectural solutions to harness and optimise available natural resources, such as daylight, in a manner that aligns with the unique challenges posed by the local climate (NIMET, 2023).

Nigeria has a large population of about 200 million, with about 51 million working at least 40 hours a week in the workforce (UNDESA, 2019). Nigeria stands to benefit significantly from improved daylighting in office buildings. However, there is a need for research on daylighting and using light pipes in office buildings within Nigeria's Tropical and Wet Dry climatic zone. This research aims to fill this gap with this study and give designers and the country important information on improving daylight utilisation in large office spaces.

1.2 Aim and Objectives

This research aims to maximise daylight provision using light pipes in the design of deep-plan office buildings for Nigeria's tropical wet and dry climate according to the Köppen Climate classification. The research tests the performance of horizontal light pipes with depths of 5m, 10m, and 15m. The specific objectives achieved by the study are:

i. Compare the uniformity of light distribution achieved by the horizontal light pipes with depths of 5m, 10m, and 15m throughout the deep-plan office space.
ii. Compare the illuminance levels (lux) achieved in different areas of the deep-plan office buildings using horizontal light pipes with depths of 5m, 10m, and 15m.

1.3 Research questions

i. How does the uniformity of light distribution vary among horizontal light pipes with depths of 5m, 10m, and 15m within deep-plan office spaces?
ii. Are there significant differences in illuminance levels (lux) achieved in different areas of the deep-plan office buildings when using horizontal light pipes set at depths of 5m, 10m, and 15m?

1.4 Hypotheses

i. Null Hypothesis (Ho): There are no significant differences in light distribution uniformity within the office space among horizontal light pipes set at 5m, 10m, and 15m depths. Alternative Hypothesis (H1): There are significant differences in light distribution uniformity within the office space among horizontal light pipes set at 5m, 10m, and 15m depths.
ii. Null Hypothesis (Ho): There are no significant differences in illuminance levels (lux) across different areas of the deep-plan office buildings when using horizontal light pipes set at 5m, 10m, and 15m depths. Alternative Hypothesis (H1): There are significant differences in illuminance levels (lux) across different areas of the deep-plan office buildings when using horizontal light pipes set at 5m,10 m and 15 m depths.

1.5 Research design

The research design for this study integrates exploratory and experimental approaches to maximise daylight utilisation in deep-plan office buildings within Nigeria's tropical wet and dry climate. In the exploratory phase, representative case studies, like the Centre of Excellence at Ahmadu Bello University and the Bank of Industry in Abuja, were selected to understand existing daylighting strategies and quantify daylight levels. The subsequent experimental phase employs computer simulations using Climate Studio for Rhinoceros 3D to assess the effectiveness of horizontal light pipes, with inferential statistical tests for hypothesis evaluation. Data collection procedures ensure accuracy, while quantitative metrics, including uniformity and illuminance levels, gauge the horizontal light pipes' performance. Multiple office models systematically explore the impact of light pipe configurations, allowing for a comprehensive investigation into daylight provision in these specific office environments.

2.0 LITERATURE REVIEW

A good indoor environment that encourages visual comfort is essential for employees to perform efficiently and maintain good health (Fisk, 2011).

2.1 Daylight and Light Pipes

Rosemann and Kaase (2005) found that efficient daylight utilisation in buildings can be achieved through hollow light guides, as examined in the European research project ARTHELIO. The use of these light guides to allow daylight into deeper parts of a building's interior was examined in this project carried out by the Lighting Research Institute at Technical University Berlin. The process consists of harvesting daylight by using heliostats to guide it through hollow light guides and releasing it into the building's interior. In this study, a goniophotometer was built to measure the distribution of the light intensity of these pipes. Demonstration sites have shown that this method effectively reduces the energy consumption of electricity lighting, indicating an efficient strategy.

Jenkins and Muneer (2003) examined the benefits of using sunlight to light homes and businesses, highlighting its advantages in terms of economy and environment as opposed to electrical lighting. The use of lighting pipes is a simple approach to maximising natural daylight. They proposed a model to predict the illumination level based on pipe dimensions to evaluate the effectiveness of lighting pipes. Their report described a method to predict the luminous flux produced by light pipes and offers approaches for calculating illuminance derived from overcast skies. This method is intended to help optimise the use of sunlight in buildings and demonstrate its potential for reducing reliance on traditional lighting resources. Shin et al., 2011 introduced a performance prediction method for the light pipe system that focused on daylight coverage and resulted in energy savings due to reduced reliance on electric light. A model of this type was assessed against an existing prediction model in Korea's climate conditions to assess its reliability and robustness. To determine the energy savings potential of using a light pipe system, the study considered various artificial lighting control methods, namely on/off control, two-step control, and dimming control. The results showed that, on average, installing light pipes could save up to 30% in energy consumption. Shin et al. have suggested that the findings from this study may encourage wider use of light conduit systems in Korea, especially in high-rise buildings where natural daylight might be limited. This approach would allow architects to be more flexible in their design and contribute to energy-efficient building practices.

Using the HOLIGILM tool, a study assessed the efficiency of straight lighting pipes and their illuminance distribution under ceilings. The researchers found that, except at low sun angles, the transmittance of light tubes increases with solar altitude. To measure photon redistribution at the base of the light pipe, they used an asymmetry parameter, "g." They noted that lower " g " values indicate a more uniform light distribution, especially at solar elevations between 10 and 30. By calculating the luminous intensity solid, the team determined the illuminance distribution at a working plane, with the bright ring's peak intensity and intensity gradient providing a way to evaluate the optical properties of various light pipes in different climates. This approach provides valuable insight into the design of light guide systems in various latitudes and sky luminance conditions (Tsang et al., 2018).

Heng et al. (2020) investigated how different light pipe transporter shapes affect daylighting in open-plan office spaces. The study used computer simulations with an Integrated Environment Solution Virtual Environment (IESVE) and validated results with a physical scale-model experiment, achieving high Pearson correlation coefficients (0.9170-0.9544). Testing under overcast and intermediate sky conditions showed that all light pipe configurations improved daylighting, with a semicircle transporter featuring two openings providing the best results. The semicircle design, which indicated possible savings in material costs and additional space for wire and ducts, had 14% less surface area than a standard round transport vehicle. The study also found that the shape of the light pipe transporter influences efficiency, although changes in the number of polygon shapes and side heights have little effect if the overall height has not been altered.

2.2 Daylight in Nigeria's Office Buildings

Haggai and Maina (2017) investigated user comfort within office spaces, juxtaposing comfort levels across the Architecture and Quantity Surveying Departments of Ahmadu Bello University, Zaria, Nigeria, and subjecting the buildings to comprehensive physical evaluations. Participants conveyed their perceptions of office environments by eliciting insights through questionnaires, highlighting factors influencing heightened comfort. Employing rigorous analytical tools, including IBM SPSS v. 21 and Microsoft Excel, the study emphasised users' control over indoor environmental quality in shaping comfort. While both departments excelled in acoustic comfort, a notable challenge arose from thermal comfort, impacting overall user satisfaction. The research emphasised the significance of creating private spaces, strategic building orientation, and thoughtful zoning in future office designs, specifically within academic contexts.

Research conducted within Nigeria by Joshua et al. (2012) highlights the inadequacy of natural lighting in many government office spaces, emphasising the need for innovative solutions to achieve energy efficiency. Similarly, Muhammad (2019) investigated the effects of building height on daylight distribution in mid-rise office buildings within the Nigerian climate, demonstrating the influence of various factors on daylight penetration. The study concluded that, for mid-rise office buildings in Nigeria's tropical wet and dry climate to meet the daylight requirements based on international standards, there is a need to look at their building forms, orientations, WWR, and building heights.

Ademola and Michael (2015) assessed the daylight intensity in office buildings. They concluded that the ratio of operable window area to total room volume of 0.0273 would be required for an acceptable indoor daylight intensity of 400 lux in East-Facing Office Buildings with 5mm clear glass windows in Jos, Nigeria.

3.0 METHODOLOGY

This section outlines the comprehensive methodology employed in this research, which encompasses a mixed-method approach combining exploratory and experimental elements. The overarching goal is to optimise daylight utilisation within deep-plan office buildings in Nigeria's tropical wet and dry climate by strategically applying horizontal light pipes.

3.1 Exploratory and Experimental Approach

i. Exploratory Phase: Case Study Selection: Multiple case studies were meticulously selected during the exploratory phase to represent a diverse range of deep-plan office buildings. Selected cases included the Centre of Excellence at Ahmadu Bello University, Zaria, and the Bank of Industry in Abuja, chosen to comprehensively understand daylighting strategies and quantify existing daylight levels within these structures.

ii. Experimental Phase: Simulation Using Climate Studio: The subsequent experimental phase involved computer simulations using Climate Studio for Rhinoceros 3D. This approach facilitated the assessment of the effectiveness of horizontal light pipes in enhancing visual comfort and maximising daylight utilisation.
iii. Inferential Statistical Tests for Hypotheses Testing: Experimental research involving hypotheses testing necessitated the application of inferential statistical tests. Specifically, the analysis of variance (ANOVA) test was employed to evaluate the significance of differences between multiple groups, such as the various configurations of horizontal light pipes.

3.2 Sampling

This study employed a purposive sampling approach to select participants strategically and case studies that align with the research objectives. Purposive sampling involves deliberately choosing individuals or cases with specific characteristics relevant to the study, ensuring a focused and targeted investigation. The selection criteria were designed to capture diverse perspectives within the chosen context, encompassing occupants from different roles and functions in the Centre of Excellence at Ahmadu Bello University and the Bank of Industry in Abuja. This method facilitated a nuanced exploration of daylighting effects on various occupant groups in distinct office settings. The purposive sampling strategy aimed to enhance the relevance and applicability of the study's findings to the specific context under investigation, contributing to a more comprehensive understanding of the relationship between daylighting and office environments.

3.3 Case Study Selection Criteria

To ensure the representativeness of the selected case studies, the criteria were meticulously established based on their relevance to Nigeria's tropical wet and dry climate and their potential to serve as prototypes for deep-plan office environments. Key considerations included architectural design, orientation, and daylighting strategies. A focus was placed on buildings that demonstrated innovative approaches to optimising daylight utilisation, aligning with the research objectives.

3.3.1 Criteria for Case Study Selection

i. Geographical Relevance: The Centre of Excellence at Ahmadu Bello University and the Bank of Industry are situated in Nigeria, providing a contextualised examination of daylighting strategies in a tropical wet and dry climate.
ii. Architectural Diversity: The selected case studies offer a range of architectural styles and design approaches, allowing for a nuanced analysis of daylighting applications in different office settings.
iii. Occupant Diversity: Each case study's varied functions and user groups, including students, faculty, and administrative staff at the Centre of Excellence and banking professionals at the Bank of Industry, provide insights into diverse occupant needs and preferences.
iv. Daylighting Installations: Both case study locations feature deliberate daylighting installations, facilitating an in-depth investigation into the effectiveness of these strategies in real-world office environments.

3.3.2 Selection of Representative Buildings

i. Centre of Excellence at Ahmadu Bello University: This educational institution represents a dynamic and active environment with diverse occupancy patterns. The study aims to extrapolate findings from this case to broader educational contexts.
ii. Bank of Industry in Abuja: As a financial institution, the Bank of Industry operates in a high-demand, professional setting. Exploring the impact of daylighting in such a context contributes valuable insights for office designs that prioritise functionality and occupant well-being.

The primary function of the case studies is to assess existing daylighting strategies within deep-plan office buildings and to evaluate the potential improvement from implementing light pipes.

3.4 Data Collection and Analysis

i. Data Collection Procedures: Extensive data collection procedures were implemented to ensure the accuracy and reliability of the gathered information. Architectural and daylighting data for the selected case studies were obtained through on-site measurements, surveys, and detailed analysis of building plans. Special attention was given to capturing variations in daylight availability at different times and seasons to account for dynamic lighting conditions.
ii. Simulation Parameters: During the simulation phase, consistent input parameters were rigorously applied to ensure the reliability and validity of the software performance. These parameters included geographical location data, building orientation, window configurations, and internal reflective surfaces. By maintaining consistency in simulation parameters across different case studies, the research aimed to establish a robust basis for comparative analysis and draw meaningful conclusions regarding the effectiveness of various daylighting strategies.

3.5 Quantitative Metrics for Evaluation

i. Uniformity: The evaluation of uniformity employed quantitative metrics, comparing values such as the ratio of minimum illuminance (Emin) to average illuminance (Eavg) or maximum illuminance (Emax) to average illuminance (Eavg) on the work plane. This comprehensive analysis extended to assessing how daylight was evenly distributed across specified heights of the work plane within the deep-plan office spaces under investigation.
ii. Illuminance Levels: Besides uniformity, another critical aspect of the investigation involved assessing illuminance levels (lux) achieved in different areas of the deep-plan office buildings. This assessment allowed for a nuanced understanding of how well horizontal light pipes with depths of 5m, 10m, and 15m provided adequate lighting for various office spaces, addressing the specific challenges posed by the deep-plan configuration.
iii. Light Pipe Configurations: To systematically explore the impact of varying light pipe lengths (5m, 10m, and 15m), diffuser sizes, and orientations on daylight distribution and resultant visual comfort, a structured approach was devised. Each light pipe was meticulously simulated in four office models, with sizes systematically increasing by 2.5m in depth. These models were constructed to represent the following configurations:

- 5m light pipe (5m x 5m, 5m x 7.5m, 5m x 10m, 5m x 12.5m).
- 10m light pipe (10m x 10m, 10m x 12.5m, 10m x 15m, 10m x 17.5m).
- 15m light pipe (15m x 15m, 15m x 17.5m, 15m x 20m, 15m x 22.5m).

3.6 Office Models and Configurations

A core research component systematically explored the impact of varying light pipe lengths, diffuser sizes, and orientations on daylight distribution and resultant visual comfort. Multiple office models were designed and evaluated, each characterised by specific dimensions and light pipe configurations. Fig 1 shows the components of the light pipe from Solatube used in this study, including a light collector, light tubes (which are flexible and can be bent up to 30 degrees), and a diffuser. Fig 2 presents a visual representation of the 5m x 5m office model, showcasing sensor points and the placement of the 5m light pipe. Sensor points were situated at 2m intervals, forming nine sensor points. The southern orientation was selected for light pipe placement.

Fig. 1: Light pipe components.
(Source: Solatube)

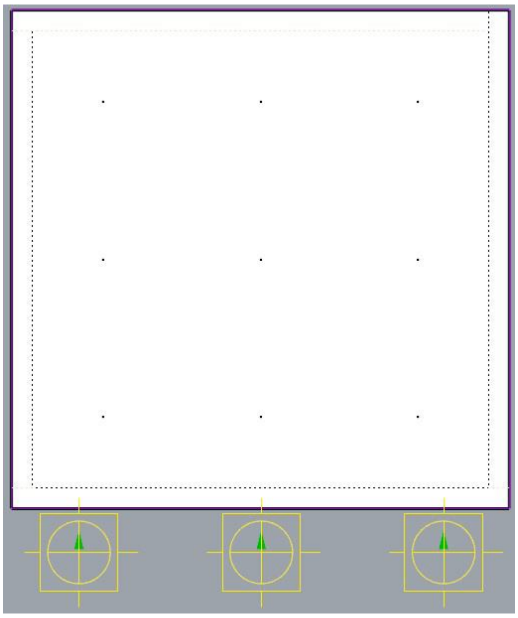

Fig. 2: Light pipe placement and sensors on a 5m x 5m model.
(Source: Climate Studio)

4.0 RESULTS

The findings of this research offer crucial perspectives on the influence of various horizontal light pipe configurations on the uniformity of light distribution and illuminance levels within deep-plan office buildings, with a particular focus on Nigeria's tropical wet and dry climate. Fig 3 shows the section view in Rhinoceros 3D, showing the light pipe placement of a model.

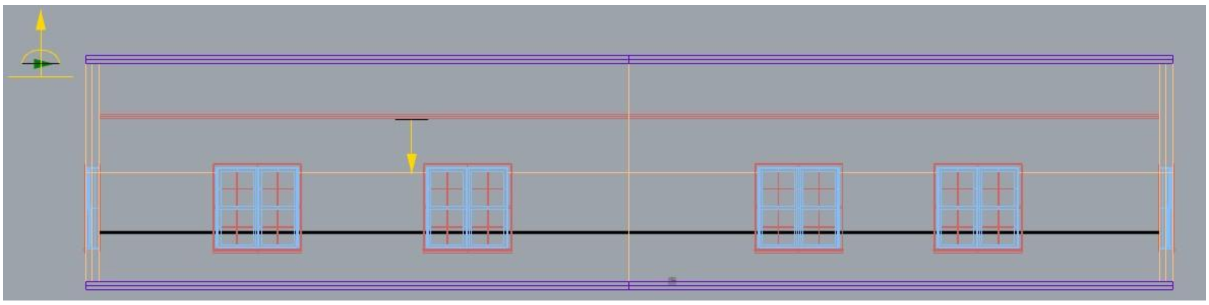

Fig. 3: Light pipe placement.
(Source: Climate Studio)

4.1 Impact of Light Pipe Configurations

The research explored the effects of light pipes with depths of 5m, 10m, and 15m on daylighting performance in office models of varying sizes. Fig 4 presents the simulation results for a 5m light pipe, serving as a benchmark for subsequent comparisons.

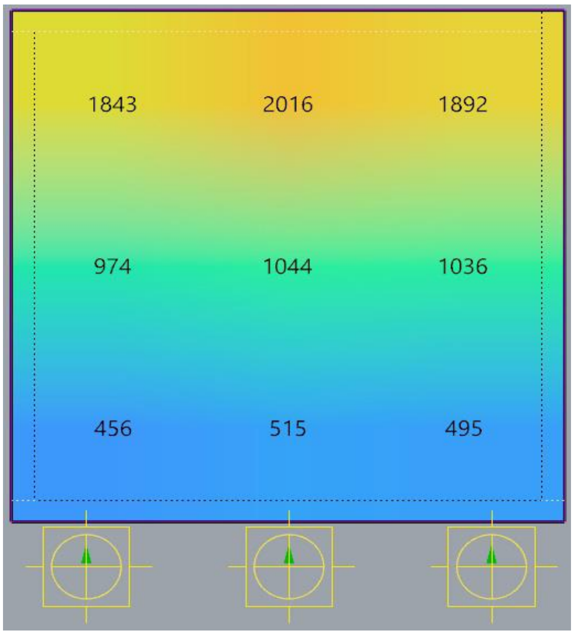

Fig. 4: Simulation result for light pipe with a length of 5 meters.
(Source: Climate Studio)

Moving to Fig 5, the outcomes of simulations involving a 10m light pipe were examined. Notably, this configuration significantly enhances illumination levels throughout the office space, particularly in areas previously characterised by insufficient lighting.

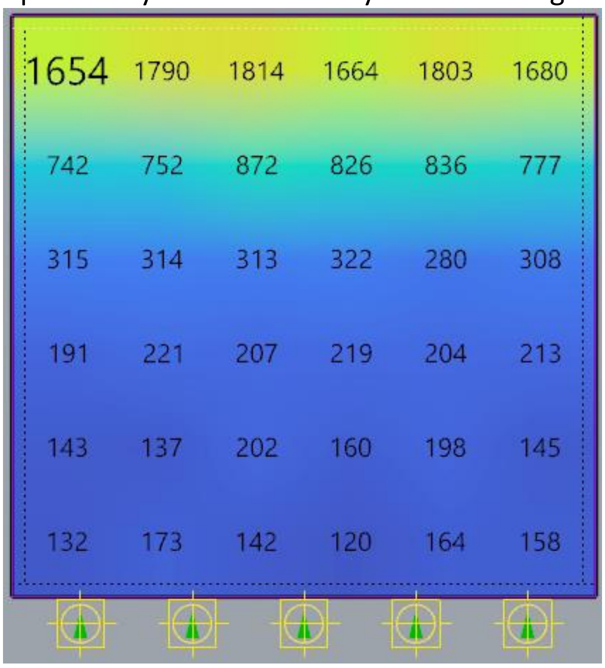

Fig. 5: Simulation result for light pipe with a length of 10 meters.
(Source: Climate Studio)

Fig 6 broadens the scope of the investigation to a 15m light pipe. While there is a noticeable enhancement in illumination, it is crucial to highlight that the performance of the 15m light pipe seems to be eclipsed by the 10m configuration when it comes to achieving a balanced and desirable lighting level.

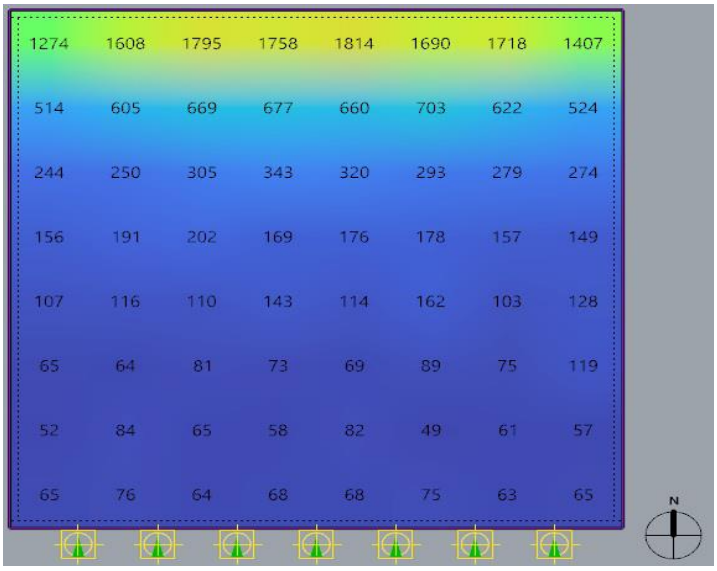

Fig. 6: Simulation result for light pipe with a length of 15 meters.
(Source: Climate Studio)

These visual representations provide an in-depth understanding of how different light pipe lengths affect light distribution and illuminance levels within deep-plan office spaces, specifically in Nigeria's unique climatic conditions.

4.2 Quantitative Metrics for Evaluation

Numerous quantitative metrics were evaluated to develop a more comprehensive understanding of the impact of different light pipe depths. These included minimum illuminance, average illuminance, mean illuminance, and uniformity ratio (UR) for different light pipe configurations (5m, 10m, and 15m) and office models of varying sizes. The results are presented in Table 1.

Table 1: Illuminance Levels and Uniformity Ratio for Different Light Pipe Configurations

Light Pipe Depth (m)	Office Model Size	Minimum Illuminance (Lux)	Average Illuminance (Lux)	Mean Illuminance (Lux)	Uniformity Ratio (UR)
5	5 x 5	456	1141	799	0.4
	5 x 7.5	345	817	581	0.4
	5 x 10	165	632	399	0.26
	5 x 12.5	79	508	294	0.15
10	10 x 10	120	561	341	0.21
	10 x 12.5	79	485	282	0.16
	10 x 15	58	407	233	0.14
	10 x 17.5	73	366	220	0.20
15	15 x 15	49	381	215	0.12
	15 x 17.5	27	346	187	0.07
	15 x 20	25	319	172	0.07
	15 x 22.5	24	279	152	0.08

4.3 ANOVA Test

An Analysis of Variance (ANOVA) test was conducted to ascertain whether significant differences exist among the means of different light pipe lengths for various performance indicators. The test was performed using Microsoft Excel; the results are summarised in Tables 2 and 3.

Table 2: Illuminance Levels and Uniformity Ratio for Different Light Pipe Configurations

SUMMARY						
Groups	Count	Sum	Average	Variance		
Light Pipe Depth (m)	12	120	10	18.18182		
Uniformity Ratio (UR)	12	2.26	0.188333	0.013124		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	577.6128	1	577.6128	63.49158	6.31E-08	4.30095
Within Groups	200.1444	22	9.097471			
Total	777.7572	23				

Table 3: ANOVA Test Results for Average Illuminance

SUMMARY						
Groups	Count	Sum	Average	Variance		
Light Pipe Depth (m)	12	120	10	18.18182		
Mean Illuminance (Lux)	12	3875	322.9167	36606.63		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	587501	1	587501	32.08213	1.07E-05	4.30095
Within Groups	402872.9	22	18312.41			
Total	990374	23				

4.3.1 Interpretation of ANOVA Results for Uniformity Ratio (UR)

The ANOVA test results for uniformity ratio (UR) reveal significant differences among the means of different light pipe depths (5m, 10m, and 15m). The p-value ($p < 0.001$) indicates these differences are statistically significant. Moreover, the F-value (63.49) exceeds the critical F-critical value, leading to the rejection of the null hypothesis (Ho). Thus, it can be inferred that significant differences exist in uniformity between the 5m, 10m, and 15m light pipe depths.

4.3.2 Interpretation of ANOVA Results for Mean Illuminance

The ANOVA test results for mean illuminance also demonstrate significant differences among the means of different light pipe depths (5m, 10m, and 15m). The low p-value ($p < 0.001$) suggests these differences are statistically significant. In addition, the F-value (32.08) surpasses the critical F-critical value, leading to the rejection of the null hypothesis (Ho). As a result, it is concluded that there are significant differences in mean illuminance levels between the 5m, 10m, and 15m light pipe depths.

5.0 DISCUSSIONS

The investigation aimed to uncover the influence of varying light pipe depths on the uniformity of light distribution and mean illuminance levels within office spaces. The ANOVA test results for uniformity ratio (UR) indicated significant disparities among the 5m, 10m, and 15m light pipe configurations. The 10m light pipe configuration emerged as the most efficient in achieving uniform lighting distribution, outperforming the 5m and 15m configurations. This holds significant importance in office design, as uniform lighting contributes to reduced glare and shadows, ultimately enhancing visual comfort for occupants. While the 15m light pipe was considered, it did not exhibit statistically significant differences in uniformity compared to the 5m and 10m configurations. However, it may have advantages in specific contexts.

Furthermore, the results of the ANOVA tests revealed significant differences between light pipes at depths of 5m, 10m, and 15m. Consistently, the 10m light pipe configuration delivered higher mean illuminance levels across the office space when compared to the 5m and 15m configurations. The 10m light pipe excelled in uniformity and proved effective in providing sufficient lighting conditions within deep-plan office environments. Adequate mean illuminance levels are pivotal for cultivating productive and comfortable work environments, further highlighting the significance of the 10m configuration.

The study provides a comprehensive understanding of the impact of different light pipe configurations on the uniformity of light distribution and illuminance levels within deep-plan office buildings. The findings suggest that the 10m light pipe configuration is the most efficient in achieving uniform lighting distribution and delivering higher mean illuminance levels. These insights hold significant implications for office design, particularly in Nigeria's unique climatic context, and pave the way for future research. The study also emphasises the importance of considering local climate conditions when designing lighting systems for office buildings. Future studies could explore the impact of other factors, such as window size and orientation, shading devices, and light-reflecting materials, on daylighting performance.

This research contributes to the growing knowledge of daylighting in office buildings and provides valuable insights for architects, designers, and building professionals. It highlights the potential of light pipes as a sustainable solution for enhancing daylighting performance in deep-plan office buildings, particularly in tropical climates like Nigeria. The findings of this study could inform the design of more sustainable, energy-efficient, and comfortable office environments. Ultimately, this research underscores the importance of sustainable design practices in mitigating the impacts of climate change and promoting the well-being of building occupants.

5.1 Implications and Limitations

In light of the research findings, the implications for Nigeria's design and construction industry are substantial. The study underscores the importance of prioritising dynamic daylighting strategies in office buildings to enhance occupant well-being, visual comfort, and overall productivity. Architects and designers can leverage these insights to inform design decisions, emphasising the integration of adaptive lighting systems that respond to real-time environmental factors and user preferences. This approach aligns with global trends emphasising sustainable and human-centric design and caters to the specific climatic conditions of Nigeria's tropical wet and dry climate.

However, implementing these strategies may need to be improved within the Nigerian context. Limited awareness and understanding of the benefits of dynamic daylighting among stakeholders in the design and construction industry could pose a barrier to widespread adoption. Additionally, the upfront costs associated with integrating smart building technologies and adaptive lighting systems may be perceived as a financial hurdle.

6.0 CONCLUSION

The study investigated how light pipes could improve daylighting in deep-plan office buildings in Nigeria's tropical wet and dry climate. This study tested 5m, 10m or 15m light pipes using case studies and simulations to determine which configuration would provide the best visual comfort and lighting performance. The results demonstrated that the 10m light pipe configuration provided the most consistent and uniform lighting, reducing glare and shadow. It also consistently provided adequate illuminance, enhancing visual comfort, and supporting productivity in office spaces. The 10m configuration has been validated by statistical analysis and ANOVA as performing better than the 5m and 15m configurations. The 15 m light pipe offered flexibility for specific contexts but did not provide significant performance advantages.

The study concluded that the 10m configuration is the most effective choice for deep-plan office buildings in Nigeria. It offers a balanced approach to daylighting that supports occupant well-being and energy efficiency.

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