MAXIMISING VISUAL COMFORT AND NATURAL LIGHTING IN LECTURE ROOMS FOR THE PROPOSED FACULTY OF ARCHITECTURE, AHMADU BELLO UNIVERSITY, ZARIA, KADUNA.

BY

OKOTETE ANDREW OGHENEKEVWE

DEPARTMENT OF ARCHITECTURE,

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

SEPTEMBER 2018

MAXIMISING VISUAL COMFORT AND NATURAL LIGHTING

IN LECTURE ROOMS FOR THE

PROPOSED FACULTY OF ARCHITECTURE, AHMADU BELLO UNIVERSITY,

ZARIA, KADUNA.

BY

OKOTETE ANDREW OGHENEKEVWE B.Sc. Arch (A.B.U) 2014

P14EVAT8153

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILMENT FOR THE AWARD OF A MASTER DEGREE IN ARCHITECTURE.

DEPARTMENT OF ARCHITECTURE,

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

SEPTEMBER 2018

DECLARATION

I declare that the work in this Thesis entitled 'MAXIMISING VISUAL COMFORT AND NATURAL LIGHTINGIN LECTURE ROOMS FOR THEPROPOSED FACULTY OF ARCHITECTURE, AHMADU BELLO UNIVERSITY, ZARIA, KADUNA STATE.' has been carried out by me in the Department of Architecture under the supervision of Dr A. S. Salisu. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this Thesis was previously presented for another degree or diploma at this or any other institution.

ANDREW O. Okotete ____________________ SEPTEMBER 2018

CERTIFICATION

This Thesis entitled MAXIMISING VISUAL COMFORT AND NATURAL LIGHTING IN LECTURE ROOMS FOR THE PROPOSED FACULTY OF ARCHITECTURE, AHMADU BELLO UNIVERSITY, ZARIA, KADUNA STATE.' by Andrew Oghenekevwe Okotete meets the regulations governing the award of the degree of Master of Science Architecture of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Dr. A. S. Salisu ______________ ______________ ______________
Chairman, Supervisory Committee Signature Date

Dr. Amina Batagarawa ______________ ______________ ______________
Member, Supervisory Committee Signature Date

Dr. A. S. Salisu ______________ ______________ ______________
Head of Department Signature Date

Prof. S. Z Abubakar ______________ ______________ ______________
Dean, School of Postgraduate Studies Signature Date

DEDICATION

I dedicate this research work to my parents, Sir Philip Okotete and lady Blessing Okotete, for their love, support and encouragements, and to my late grandfather, Mr. Abel Oshemughen. May his soul rest in perfect peace, amen!

ACKNOWLEDGEMENT

I give thanks to God almighty for grace to see this day, for the strength to finish this research. I would like to express my sincere gratitude and appreciation to my supervisor Dr A.S. Salisu for his knowledge, inspiration, guidance and supervision throughout my research and seeing my research to a successful completion. Thank you sir and may God bless you.

I will like to thank my wonderful parents, Sir Philip Okotete and lady Blessing Okotete for your prayers and support that has enabled me finish my research. God bless you, provide for you and continually keep you in good health. To my sibling Emmanuel Okotete, Ejiro Okotete, Emmanuella Okotete and David Okotete, I love you all and thank you for being there for me.

My thanks go to my friends Theophilus Solomon, Abraham Othniel, Ekele Victor, Oluwatosin Iselowo, Toyeeb Arowono,Femi Michael, Ayodeji John, Halima Obansa, Gabriel, AhmadSuleiman, Niimah Inuwa, Stella Inabo and Irene Okpanachi, Thank you all for your support and encouragement.

ABSTRACT

In the last decade, the world has begun making a shift to sustainable and environmentally friendly alternatives of power one of which is daylighting. The most common method of harnessing daylighting is through windows openings. Daylighting was observed in several studies to improve student performance and health in lecture rooms.With increasing cost of electricity and epileptic state of electricity in Nigeria, it has become a necessity to harness daylighting in lecture rooms but with the advantages of daylight follows the problems of inadequate placements of apertures, which brings about overheating, underlighting, overlighting and glare. This is due to varying intensity of daylighting from place to place, that is most evident at openings to the east and west side of a building suffer from drastic changes of light quality through the day, heat gains and require versatile solutions to harness which makes openings to the north and south as the best choices for harnessing daylighting.However, there are no researches under adequate methodologies that identify the optimum head height of openingsalong the north and south orientation, without shading devices for lecture rooms in the Tropical Wet and Dry Climate of Nigeria.The aim of this research is to determine the optimum head height of openingsalong the north and south orientation without shading devices, based on the quality and quantity of daylight in alecture room while minimizing the probability for glare and therefore develop models which can be employed in the design of lecture rooms in the Tropical Wet and Dry Climate of Nigeria. The methodology for this research climate based daylight modelling due to its prediction of various radiant or luminous quantities (e.g. irradiance, illuminance, radiance and luminance) using sun and sky conditions that are derived from standard meteorological datasets. Case studies were selected from the Faculty of environmental design, Ahmadu Bello University Zaria, which consists of; the Department of Architecture, Department of Building, Department of Urban and Regional Planning, Department of Quantity Surveying and the Department of Geomatics. They were used for validation studies and evaluation of current daylighting design practices in University lecture rooms. Prototype lectures rooms were created and simulated using ecotect, radiance and Daysim. Results showed that the quantity and quality of daylighting for both north and south orientations were affected by a change in head height of openings. The study concludes that for maximized daylighting of lecture rooms in the wet and dry tropic region of Nigeria, window openings to the south should have a window head height of 2400mm and window openings to the north should have a window head height of 2700mm. For areas of further research, evaluation for the impact of window head height of thermal comfort can be performed. In addition, this research was conducted for lecture rooms in tropical wet and dry region of Nigeria only so further research can conducted on the other climate regions such as the tropical wet region and the semi-arid regions of Nigeria.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

1.0 INTRODUCTION

1.1 Background of the Study

Experts agree with the importance of lighting in lecture rooms and its influence on students' performance. They argued that lighting quality has direct influence on students learning performance (Samani & Sanaz, 2012). Recent studies show that day lighting in schools may significantly increase students' test scores and promote better health and physical development and can be attained without an increase in school construction or maintenance costs. (Plympton, Susan, & Kyra, 2000), Daylight in lecture rooms has an essential effect on the learning environment. The careful introduction of daylight into educational buildings reduces operating costs, improves students' vision and perception, and contributes to improved students' health, comfort, and productivity (Dahlan & Mahmoud, 2015).

Lighting has a very powerful and essential role on students learning performance in places of learning. Lighting control to avoid discomfort and glare in all different types of lighting is very important. Also students feel and act well in a place with a good lighting quality (Erwine & Heschong, 2002). The best school environments give an impression of liveliness, attractive spaces and a general feeling of satisfaction which it is difficult to define. There can be no doubt that in these cases the surroundings contribute to the happiness and well-being of teachers and pupils, and that lighting plays a significant if not the leading role (Architects & Building Branch, 1999).

Aperture placement, area and orientation are important aspects of daylighting because strategic use of windows and skylights can help you achieve thermal and visual comfort passively, saving both energy and money. Bigger apertures are not necessarily better. They can cause too much heat loss or heat gain, or too much brightness and glare. Choosing just the right sizes for apertures ("right-sizing") is the key (Autodesk Sustainabilty Workshop, 2015).

In Nigeria even with its efforts to increase its quantity of power generated through the privatization of the Power Holding Company of Nigeria (PHCN) the country still experiences epileptic power supply with about 75 percent of the Nigerian population still live without access to regular electricity supply. (Femi, 2015), Economists, NAEE, despite statistics indicating that 45 percent of the country's population is currently connected to the national grid, regular supply is still restricted to just about 25 percent of the population (Femi, 2015).

An architect's duty in the design of an educational facility is to understand clearly and sensibly the requirements and parameters for the proper day to day functioning and completion of activities within the facility. To do so all necessary factors or aspects of design must be considered to ensure a healthy and mentally stimulating environment for learning is designed and created, among these factors is lighting. Studies have shown a coalition between adequate lighting and the physical as well as mental health of the users of facilities, "A school with insufficient light can reduce a student's ability to learn due to the effect lighting has on physiology. Poor spectral light can create eyestrain, leading to decreased information processing and learning ability and causing higher stress level"(Liberman, 1991).

However, with the numerous benefits of daylighting in buildings also follows the problems caused by improper placements of openings, whereas large openings can cause increased temperatures due to thermal radiation through glass members or surfaces a well-balanced amount of openings has to be stressed. Unlike north and south windows, which have roughly the same properties all day long, windows to the east and west side of a building suffer from drastic changes of light quality through the day, heat gains and require versatile solutions to harness (Gabe Cross, 2010).

This research considers the relationship between head height of openings along the north and south axis to the quality and quantity of daylight within a classroomthrough the use of energy efficient natural lighting and fenestration in multi-storey lecture roomsto make best useof this inexpensive natural resource for visual comfort and as a mentally and physically healthy replacement to artificial lighting.

1.2 Problem Statement

The head height of window openings in lecture rooms are determined most of the time by the head height of a door or in other cases based on the height the architect feels is required which brings about varying daylighting performance. This is because there are no existing studies conducted under modernmethodology, which stipulates the relationship between head height of openings to the quality and quantity of daylight based on the depth of a classroom located in the Tropical Wet and Dry Climate of Nigeria.Design of classroom openings over a period have been standardized to proportioned openings as well as “use of particular window typologies in an effort to reduce cost and protect against vandalism” (Salisu, 2015). This in turn leads to conditions such as underlighting, overlighting, inadequate distribution of light and possibility of glare, this causes discomfort of the users, results in reduced academic and physical performance but also results in increased dependence and use of artificial lighting source. This is difficult due to the ever increasing cost of energy and the epileptic state of power generation and supply in the country with about 75 percent of the Nigerian population still living without access to regular electricity supply, bringing about the high reliance of fossil fuel and other environmentally unfriendly sources of power generation which should not be allowed in a world moving towards energy efficient and ecofriendly sources of power. This makes the need for improved classroom designs urgent.

The provision of adequate daylighting in buildings depends greatly on its climate (Mardaljevic, 2006).The daylighting of a locale varies from minute to minute especially in the tropics and varies from one climate zone to another even in the samecountry. These variations are a result of different climate conditions (Salisu, 2015). Previous researches into daylighting in the tropic wet and dry climate of Nigeria have been using methodologies that are based on static metrics such as daylight factor, which does not consider direct sunlight or single point inline, as well as the dynamic nature of the tropic climate(Salisu, 2015).

This brings about a need for a methodology that takes into consideration the factors of a dynamic climate, daylight quality as well as quantity, fenestration types and sizes. For this purpose, climate based daylighting performance indicators are assessed to provide models using strategies to maximize daylighting and ensure comfort in lecture rooms located in tropical climate of Nigeria.

1.3 Aim and Objectives of Research

The aim of this research is to determine the optimum head height of openingsalong the north and south orientation without shading devices, based on the quality and quantity of daylight in alecture room while minimizing the probability for glare. Therefore, develop models which can be employed in the design of lecture rooms in the Tropical Wet and Dry Climate of Nigeria.

The objectives of the study are;

I. Evaluate current daylighting design practices in Universitylecture rooms in Tropical Wet and Dry Climate of Nigeria.

II. Determine the influence of head height of openings on the provision of daylighting in Universitylecture rooms in the Tropical Wet and Dry Climate of Nigeria.

Identifythe optimum head height of openings for adequate lighting of lecture rooms along the north and south axis ina Tropical Wet and Dry Climate.

III. Execute findings from the study in the design.

1.4 Research Questions

I. What are thecurrent daylighting design practices in University lecture rooms in Tropical Wet and Dry Climate of Nigeria.?

II. What is the influence of head height of openings on the provision of daylighting in University lecture rooms in the Tropical Wet and Dry Climate of Nigeria

III. What is the optimum head height of openings for adequate lighting of lecture rooms along the north and south axis in a Tropical Wet and Dry Climate of Nigeria?

1.5 Scope and Delimitation of Research

This research encompasses the use of energy efficient natural lighting strategies in multistory lecture rooms in Nigeria. Application of day lighting involves the use of design methods, concept in form composition, spatial organization, and use of materials (light), with the aim of applying them to achieve a suitable design, which meets a stable solution

The scope of the research involves a study of basic requirements for appreciation and smooth functioning of a Faculty of Architecture. Emphasis was focused on applying day lighting, whichwill be limited to:

I. An overview of day lighting in lecture rooms in tropic wet and dry climate of Nigeria.

II. The contribution of day lighting to interior luminance through clear casement windows.

III. Daylighting along the north and south axis

IV. The advantages of climate based daylight modeling.

V. Application in the design.

1.6 JUSTIFICATION

The study provides specialist knowledge in developing day lighting design guides for government, architects and school administrators for the development of Universitylecture rooms in the tropic wet and dry climate of Nigeria. This will encompass the following

I. Identification and documentation on the existing situation

II. Provision of models to optimize the existing situation

III. Provision of models for new class designs

The incorporation of optimized fenestration decisions with reference to day lighting early in the design stage based on specific site and climatic conditions, which bring about more efficient lecture rooms design with reduced demands for energy.

2.0 LITERATURE REVIEW

2.1 What Is Daylighting

The history of architecture is synonymous with the history of the window and of day lighting from the initial crude openings. From the earliest caves, daylight informed the lives of the inhabitants, initially about the variation between night and day but dwellings became more sophisticated, by means of openings or windows letting in light and air, heat and cold, the window was the vehicle for the introduction of daylight (Philip, 2004).

Although light can be described as invisible, its effects are tangible and an inseparable component of architecture. As Meier (1987) clearly acknowledged in an interview, 'For me light is the best and most versatile building material'. How light is reflected and what we read into the qualities of that reflected light affects our perception of the solids, of the black lines we draw; immaterial light changes the materials of building (Brawne, 2003).For Many years the study of the illumination of a building was limited to solving functional and safety problems. The main aim was to guarantee sufficient levels of light to carry out any given activity without really taking other factors such as psychological comfort and visual fatigue into account (Verges, 2008).

Daylight is the total illumination provided by the direct sunlight, skylight and the diffusely reflected sunlight, which is absorbed and reflected over surfaces, both externally and internally. The technical term of delivering this natural light into an enclosed space is what is generally referred to as day lighting (Salisu, 2015). Day lighting is the use of natural light to provide illumination in buildings during the day, daylight is an essential resource that is readily available and unlikely to run out for the near future, it has the very special characteristic of having the ability to transform an internal space from uninspiring uniformity into a psychologically uplifting experience. This ability to both illuminate an area and to make it more interesting, is one of the main reasons that architects try to make provision for daylight to come into a building wherever practical(Kjeld & Richard, 2010).

Roaf, Horsley, & Gupta, (2004)stated that lighting cannot just be measured in the amount alone but that indicators of good lighting should include:

i. Average illuminance in the working plane.
ii. Uniformity of illuminance in the working plane.
iii. Luminance ratios within the space.
iv. Glare levels in the space.
v. Direction of light and the effect of shadows.
vi. Color temperature of light.
vii. Color rendering of light.

2.1.1 Difference between Daylight and Sunlight

The sun releases a power flux of 63 MW, equivalent to six thousand million lumens, for every square meter of its surface area. Of this around 134 kilolux reaches the earth's outer atmosphere (Thermie Programme Action). People often assume that "sunlight" and "daylight" can be used synonymously. In reality, they have very different physical properties and different effects on sky lighting design. The most important differences are their intensity, their color, and the extent to which their light is scattered, or diffused (Energydesignresourse, 2014).

Sunlight on the other hand refers to direct sunshine and is very much brighter than ambient daylight (East Renfrewshire Council Planning Service, 2012). Direct sunlight as seen in fig 2.1 requires control and shading devices to be useful.

Ambient daylight is the volume of natural light that enters a building to provide satisfactory illumination of internal accommodation between dawn and dusk, Daylight from an overcast sky as seen in fig 2.2 is generally the same no matter how the building is orientated.

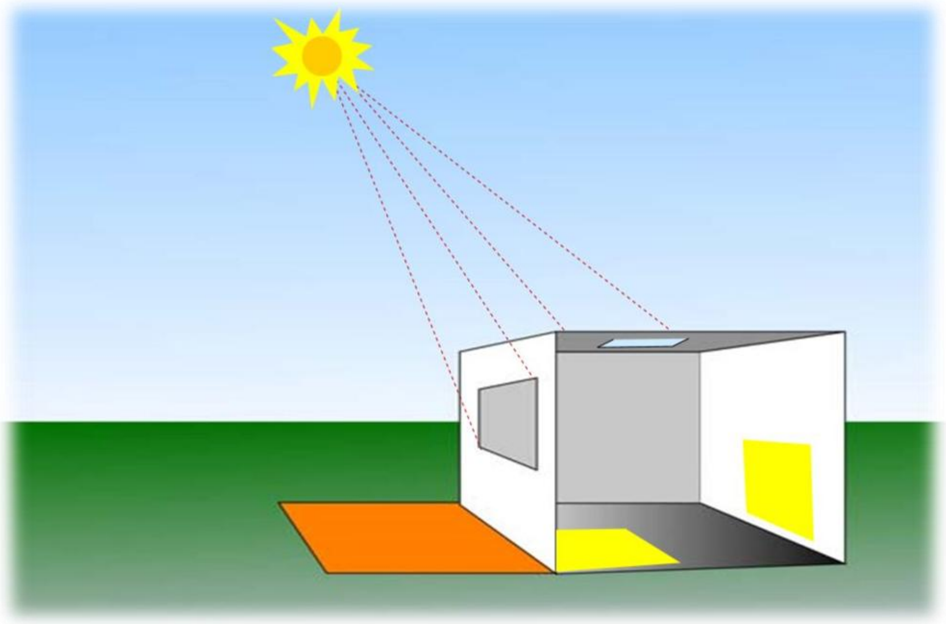


Figure 2.1Sunlight: an illustration of the directional beam emitted by the sun. Source:Lighting Research Center, 2006.

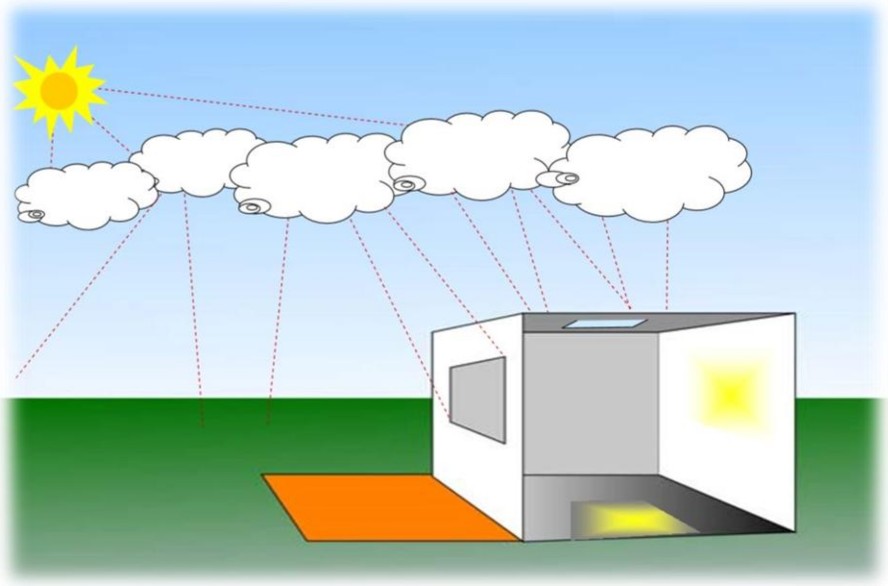


Figure 2.2 Daylight: an illustration showing diffused beams of light emitted by the sun. source:Lighting Research Center, 2006.

2.2 Daylighting and Human Comfort

According to Magnus & Magnus (2012) daily performance of tasks is also very dependent on the lighting conditions, and the visual performance. The visual performance is measured by the accuracy and speed at which a visual task is done.

According to thermie programme action, optimal illuminances for different activities has been defined by various researches and study. These are generally based on uniform and constant levels of artificial light falling on the work plane.as seen in table 2.1:

Table 2.1Some typical recommended illuminances

ACTIVITY	**ILLUMINANCE RANGE (LUX)**
Corridors/Toilets	100-150
Restaurant/Canteen	200
Library/Classroom	500
General office	500
Workbench	500
Drawing office	500-750
High-precision tasks	1500

Source: Thermie Programme Action, 2016.

2.2.1 Glare

Glare is reflected or uncontrolled light that shines directly into your eyes. Although it is very bright, the light produced by glare does not usually help you see more clearly; instead, it can interfere with your visual comfort, physical safety, and independent performance of everyday activities (Gerritsen, 2016). Glare produced by lighting has been classified into two types—as “discomfort glare” and as (more severe) “disability glare”. Both of these have consequences in terms of task performance, Both types of glare are caused by a source being much brighter than the background against which it is viewed, and are affected by the size, shape and position of the source, as well as by its brightness (Advanced Lighting Guidelines, 2016).

2.3 Daylighting in Lecture Rooms

Over the last decade, many of the world's biggest businesses have made day lighting in the workplace a priority. From improved productivity to better sales, turning off artificial lights and opening the curtains has been a huge help for businesses, Now, a growing number of schools and colleges are taking the initiative and making natural light a key architectural focus. Natural light offers a wide variety of benefits in an educational environment, from improved focus to better student health (Bristolite Team, 2014).

A school with insufficient light can reduce a student's ability to learn due to the effect lighting has on physiology. Poor spectral light can create eyestrain, leading to decreased information processing and learning ability and causing higher stress levels (Samani & Sanaz, 2012). The aim of lighting design is to supply appropriate illuminance, color temperature, and lighting to meet the requirement of the users‟ vision form physical to psychological (Samani & Sanaz, 2012).

2.3.1 Benefits of Adequate Daylighting on Students Performance

"Using natural light or daylight for illumination is one of the hallmarks of a high-performance building. In addition to the benefits of supplying substantial light for free, natural light provides great physical and psychological benefits to the building's occupants" (Dahlan & Mahmoud, 2015).

(Bristolite Team, 2014) Stated that the benefits of adequate lighting on students include:

i. Natural light improves standardized test scores.

Studies indicate that well-designed daylighting is associated with enhanced student performance, evidenced by 13% to 26% higher scores on standardized tests, while poor daylighting design has been shown to correlate with reduced student performance. It makes sense that students and teachers perform better in stimulating, well-lit environments. Daylighting can provide high quality light, stimulating views, and an importantcommunication link between the classroom and adjacent spaces(Heschong Mahone Group, 1999).

ii. Natural light eliminates common distractions.

During the 1970s, windows were scaled down in school in an effort to remove any visual distractions. The idea was simple, albeit completely wrong – big windows can cause students to look out into the environment instead of focusing on their work. Decades later, many of the same architects are taking the opposite approach, with a far better result. Far from making students more distracted, natural lighting actually makes students significantly more focused and less distracted from their work(Bristolite Team, 2014).

Experts are not sure why daylight reduces time spent on distractions, although one theory claims that since students are free to look around, they're less likely to find distractions within the classroom(Bristolite Team, 2014).

iii. Natural light is completely free of charge.

Depending on artificial light has more costs associated with it than poor academic performance and a higher number of student sick days. In addition to its negative effects on school performance, artificial light costs a huge amount every month.

With the price of energy on the rise, being able to inexpensively light your school or college is a massive financial advantage. By reducing your utility bills using natural light, you will have a larger budget to spend on important educational activities(Bristolite Team, 2014).

Schools and colleges, particularly those in sunny states like California, can enjoy an extensive range of benefits from natural lighting. Consider daylighting today for a more productive, healthy, cost effective and motivated learning environment(Bristolite Team, 2014).

2.4 Harnessing Daylighting

Daylight is superior to electric light sources in the measure of light source efficiency. Beyond the simple conclusion that well-designed daylighting can reduce electric energy use in buildings, there are two additional traits of daylighting that make its use compelling (Dean, 2004).

In any day lighting system, the light source (directly or indirectly), and the fenestration systems in addition to the building surfaces, determine the quantity and quality of daylight present in the building. The influence on visual comfort can be in terms of the adequacy or inadequacy of lighting, possibility of glare and thermal loads, together with good or poor uniformity within the space (Salisu, 2015).

2.4.1 Daylighting strategies

Evenly distributed light is critical to good daylighting, so apertures that are evenly distributed are useful. Continuous-strip apertures are even better, and apertures on multiple sides are often best otherwise rooms can have "hotspots", both in terms of temperature and brightness, Often this is accomplished with horizontal bands of windows that are placed high in a space (to avoid glare and reflect light off the ceiling), or with evenly spaced vertically oriented windows that reach the full height of the room (Autodesk Sustainabilty Workshop, 2015).

2.4.2 Types of Daylighting Aperture

2.4.2.1 Side light

Light coming from side apertures like windows seen in fig 2.3 can only penetrate so far into a building, this is the reason why shallow floor plans are recommended for daylighting multi-story buildings. A simple rule of thumb for most latitudes is that daylight penetrates into a room roughly 2.5 times the height of the top of the window seen in fig 2.4 (Autodesk Sustainabilty Workshop, 2015).

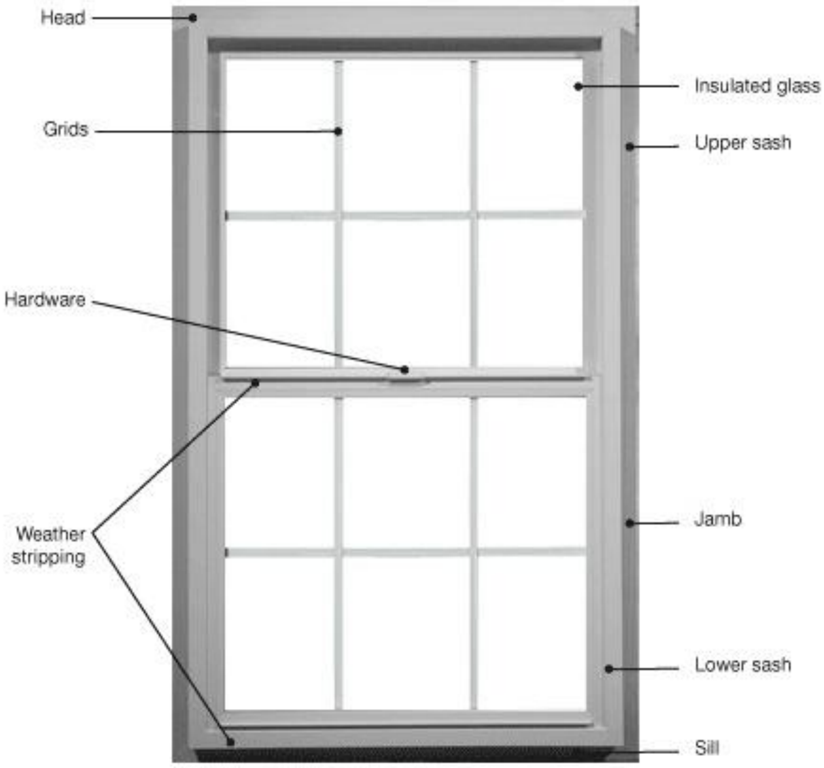


Figure 2.3 main components of a window.

Source:Mandinfinity, (2017)

Clear glass is preferred for daylighting, but this in turn requires carefully designed exterior sun control devices to provide adequate shading. Although internally mounted shades and blinds reduce the high intensity and heat content of direct sunlight, the most effective sun control device is the exterior sunshade. An internal shade, even a light-colored fabric or blind, reduces solar heat gain by about one-third to one-half of the incident solar energy. An exterior shade will create a reduction of 80% of the incident solar energy (Dean, 2004).

According to Skylight Council (2011), Side-lighting from windows and doors provides daylight and solar energy along the perimeter of a building. Good day lighting design should consider this side -lighting characteristics:

1. Most daylight is provided through ambient lighting from the sky. The amount of daylight available will vary throughout the day depending on the direction the fenestration is facing. External obstructions are likely to reduce the available daylight.
2. Orientation (north, east, south, west) with respect to the sun's path is a critical factor
3. The need for shading to avoid glare is essential when the sun is low in the sky

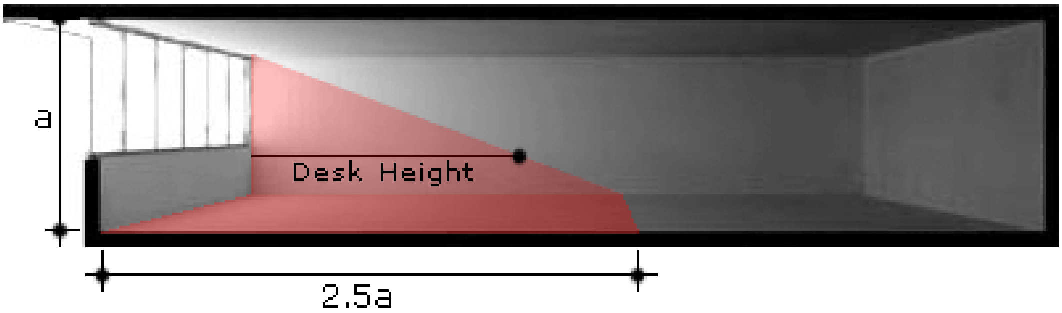


Figure 2.4 Side lighting only reaching into room.

Source: autodesk sustainabilty workshop, 2015

Side lighting also have the ability of providing a view of the outside. Notwithstanding these advantages, this fenestration system has some disadvantages. They may cause glare due to high contrast between the aperture and surrounding wall surfaces (Ander, 1995).

Many modern commercial windows employ low-e glazing. Low-e glazing employs two or more panes of glass, one of which is coated with a relatively clear material that reflects infrared energy while passing visible portions of the sun‘s energy. In any building with a cooling season, low-e glass is essential in minimizing solar heat gain. Reflective coatings can also be used; these make the building look mirrored while further decreasing solar penetration. Tinted glass can also reduce solar penetration and glare. Glazing selection is always a compromise between clarity and energy efficiency (Oluwatosin, 2014).

1. Glazing

Glazing is derives from the Middle English for 'glass', is a part of a wall or window seen in fig 2.3, made of glass (Dahlin, 2016). Several types of glazing used architecturally includes Translucent Glazing, Tinted Glazing, Metallic Coatings, Multi-Paned Glazing, tempered glass, laminated glass and insulated glazing.

The choice of glazing is critical in ensuring good daylighting. A wide range of glazing is available offering both good admission of daylight and low heat gain (Cole, Connery, Rousseau, & Threaker, 1999). A conventional window, single-glazed with clear float glass will transmit approximately 85% of the light that falls upon it. Double or triple glazing will reduce light transmission to 70% and 60% respectively as shown in table 2.2.

Table 2.2 glazing types showing corresponding solar transmission levels and u-value..

GLAZING TYPE	SOLAR TRANSMISSION	EQUIVALENT U-VALUE
CLEAR ,SINGLE	75% -89%	1.11
CLEAR DOUBLE	68% - 75%	0.49
LOW-E CLEAR DOUBLE	45% - 55%	0.38
LOW-E TINTED, GREY	30% - 45%	0.38
LOW-E, ARGON	45% -55%	0.30

Source: innovative design, 2004

Where lighting requirements demand larger areas of glass than would be thermally satisfactory, specially treated glass can be used to control heat losses or gains (Thermie

Programme Action). In all cases where windows are used specifically for daylighting, clear glass has an advantage over glazing with Low-E coating because the 10% - 30% reduction in visible light transmission of most Low-E coatings would be required to produce the same daylight benefits (innovative design, 2004).

To increase the amount of daylighting window area and glazing visible transmissivity on north- and northeast-facing walls should be increased and the amount of glazing on west and southwest orientations where sun is difficult to shade effectively with fixed fins or overhangs should be reduced (Cole, Connery, Rousseau, & Threaker, 1999).

Studies on window to wall ratio (WWR) by Bokel , (2007)and Mahdavi, Rao, & Inangda, (2013) for Suitable Area Zone with appropriate daylight have stated that 30% - 35% is the appropriate range for adequate daylighting.

2. Laser Cut Panels (LCP)

This is an innovative daylighting system used to redirect high angle light upwards towards ceilings by total interior reflections and redirecting low angle light or diffusing light downwards by internal refractions, thus it is used to reflect light into deep rooms. (Tukur, 2013). These laser cuts seen in fig 2.5, work by deflecting a fraction of the incoming light through total internal reflection at the surface of the cuts, whilst the remaining light passes through the panel undeflected. LCP's perform better in climates with clear sky conditions, deflecting direct sunlight into the ceiling avoiding direct sunlight on the work plane (Hirning, 2010).

Figure 2.5 Typical Laser Cut Panel System.

Source: Urban design system, (2016)

3. Transparent Concrete

Translucent concrete is a concrete based material with light-transmissive properties, obtained due to embedded light optical elements like Optical fibers in it as seen in fig 2.6. Light is conducted through the stone from one end to the other. This results into a certain light pattern on the other surface, depending on the fibre structure. (Padma, Johnson, Afzal , & Prasanthi, 2013).Its transmits light without the accompanying effects of heat,It is more durable than other precast panels and is resistant to aging caused by UV radiation. (Italcementi, 2015)

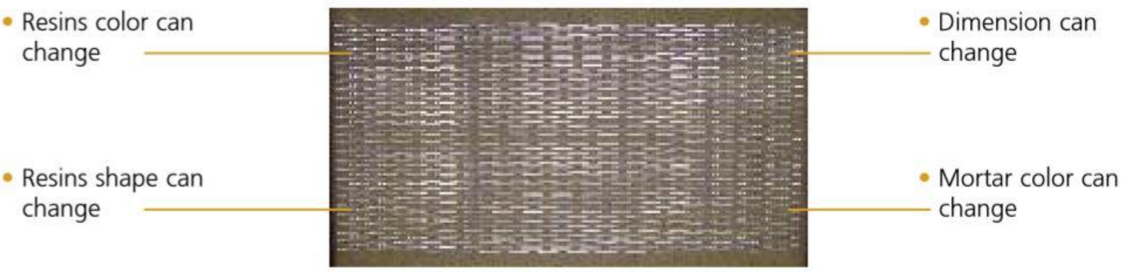


Figure 2.6 illustration of a typical transparent concrete panel.

Source: Italcementi, 2015.

2.4.2.2 Top Light

This is the name given to a fenestration system situated in the ceiling/roof plane seen in fig 2.7. It has the attributes of providing uniform and high illumination over the horizontal work plane since it receives light from the brightest regions of the sky (IEA TASK 21, 2000)

Higher apertures are more effective at bringing light deep into the building. This often means glazing in roofs. Skylights are not the only kind of aperture to bring light in through roofs. Other "top lighting" strategies include clerestories, monitors, and saw-tooth or other scoop-shapes. Each has their own advantages and disadvantages in construction cost and how they bring the sun into the space at different times of day and year. (Autodesk Sustainabilty Workshop, 2015).

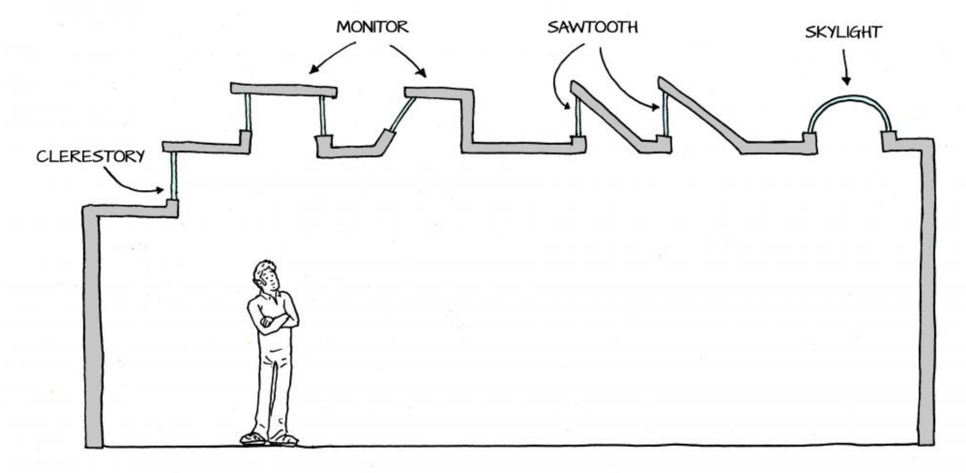


Figure 2.7 Different types of top lighting devices.

Source: autodesk sustainabilty workshop, 2015.

There are basically three different types of top lights - skylights (horizontal or near horizontal aperture to the sky), monitor roof lights and clerestories (which are vertical or nearly vertical projecting glazed apertures) (Salisu, 2015).

Top lighting can provide greater freedom of source placement to achieve more uniform illumination, takes advantage of high wall surfaces and other architectural elements to distribute light where needed, and increases security and privacy. (Kroelinger, 2005)

1) skylights:

A skylight on a sloped roof cannot see the full sky hemisphere, but only a partial view determined by the slope of the roof. Furthermore, depending upon the angle and orientation of the sloped roof, the sun may not reach the skylight during certain times of the day or year. For example, a skylight on an east-facing roof with a 45° slope will only receive direct sun during the morning and midday hours. In the afternoon it will receive skylight, but only from three-fourths of the sky. As a result, in the afternoon it will deliver substantially less light to the space below than an identical skylight located on a flat roof (Energydesignresourse, 2014).

Skylights can be successful daylighting roof apertures provided the direct sun is prevented from coming within view by washing down walls or striking floor or table surfaces. In addition, because of the heat content of direct sunlight, the skylights should be relatively small in area and should be accompanied by large adjacent diffusing surfaces as seen in fig 2.8 (Dean, 2004)

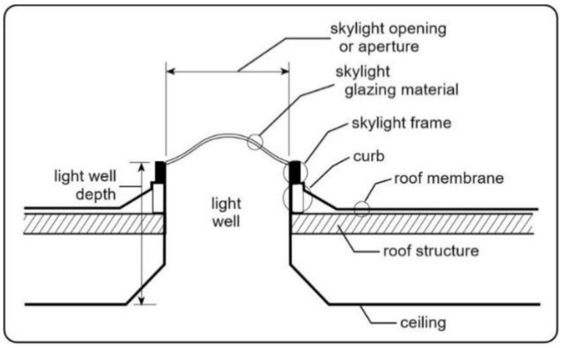


Figure 2.8 Components of a Typical Skylight

source: Dean, (2004)

2) Monitor roof lights

The monitor roof light has vertical glazing in two opposite directions. In this study, north and south orientation is preferred because the south-facing glazing can easily be shaded and the north-facing glazing only admits diffuse daylight to the space. (Ladan, Wayne, & Soolyeon, 2012)

Monitor roof permits abundant daylight, especially in buildings where solar orientation or weather does not permit the saw tooth or other more unusual designs. With proper choice of glazing and overhang, a monitor can produce exceptionally balanced and comfortable daylight. (Mark, James, & Christina, 2012)

Roof monitors are popped-up extensions of the roof, with vertical glass areas. Large roof monitors often appear to be forms of vertical extensions of the ceiling, and can provide dramatic high internal spaces in special areas seen in fig 2.9 (Dean, 2004)

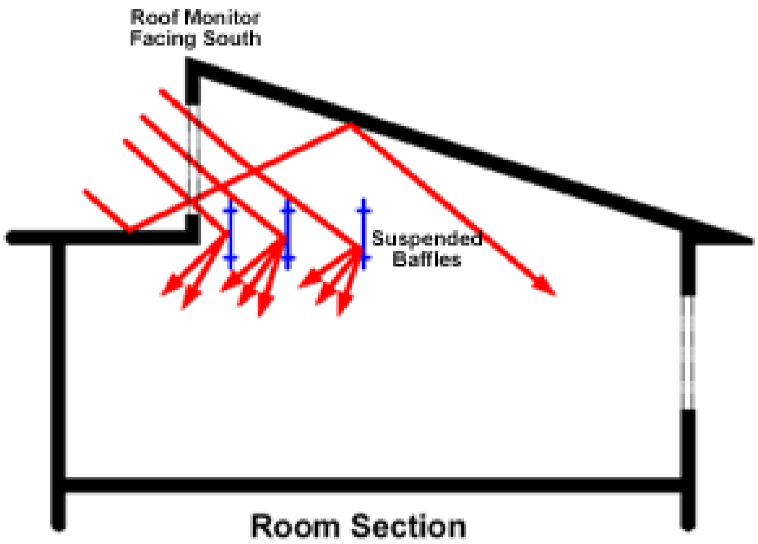


Figure 2.9 monitor roof.

Source: Tao, (2010)

3) Clerestories

A clerestory is a series of windows high up in a space. These can be a formal row, like in a cathedral, or a single, simple opening in the wall. Clerestories are often confused with transoms. Transoms are smaller windows stacked on top of other windows or doors. In traditional buildings, transoms were operable allowing air to move around a building while still keeping the safety and privacy of closed lower doors and windows. (Architects, 2015)

The single clerestory produces both direct and indirect lighting by introducing light through a vertical clerestory window. Depending on the adjacent roof, some of the light may be reflected downward by the ceiling into the space seen in fig 2.10. However, depending on site orientation, the relatively high percentage of direct light can be glaring. (Oluwatosin, 2014)

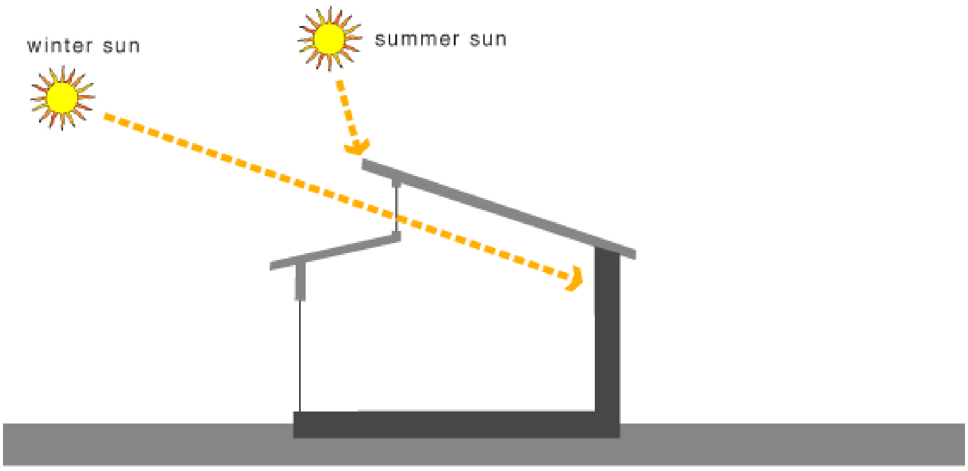


Figure 2.10illustrations of clerestories taking in light.

Source: m.gerwing architects, 2015.

4) Saw tooth roof

A saw-tooth roof is a roof comprising a series of ridges with dual pitches either side. The steeper surfaces are glazed and face away from the equator to shield workers and machinery from direct sunlight. This sort of roof admits natural light into a deep plan building or factory. (Babylon, 2015)

Saw tooth are apertures with vertical or angled glazing installed in a slopped roof plane seen in fig 2.11. Saw tooth are most effective when used in series of three and were historically used in industrial and manufacturing buildings as the primary light source. Saw tooth slope is generally at a 45-degree angle. (Kroelinger, 2005)

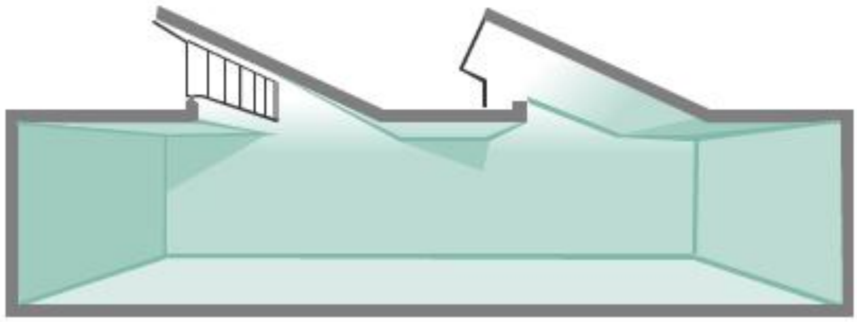


Figure 2.11 illustration of a saw tooth roof .

source: build2016.

saw-tooth roof produces both direct and indirect lighting but, by bouncing a high percentage off the adjacent slanted ceiling, increases the amount of downward light and can minimize the amount of direct light. If the saw tooth glazing faces north, it can be an excellent source of natural light for a large interior area. (Oluwatosin, 2014)

2.4.3 Light pipes

Light tubes or light pipes are physical structures used for transporting or distributing natural or artificial light for the purpose of illumination, and are examples of optical waveguides. In their application to daylighting, they are also often called tubular daylighting devices, sun pipes, sun scopes, or daylight pipes. Light pipes may be divided into two broad categories: hollow structures that contain the light with a reflective lining, and transparent solids that contain the light by total internal reflection. The principles governing the flow of light through these devices are those of non-imaging optics (Bernfart, 2014).

In applications for daylighting, they are also often called sun pipes, solar pipes, solar light pipes, daylight pipes, tubular skylight, sun scoop or simply tubular daylighting device seen in fig 2.12. In comparison to conventional skylights and windows, a light pipe offers better heat insulation properties and more flexibility for use within buildings, however with little visual contact with external environment (Jeong & Gon, 2010).

Sun tube lights are highly effective at transferring daylight into parts of buildings that have little or no natural lighting. They can be used to replace artificial lighting and will therefore substantially reduce the annual energy consumption of a home. In many cases, sun tube lights will be used to provide all the light for an internal space but they can also be used to compliment an artificial lighting scheme. (Low Energy House, 2016).

Light pipes perform the same function as other skylight strategies, the only different is the way daylight is transported into internal spaces by using highly reflective tube. This system is also known as solar pipe, tubular daylight guidance system or mirror pipe. Compared to conventional skylights and windows, a light pipe offers better heat insulation properties and are more flexible (Jeong & Gon, 2010).

The challenges of light pipe system utilization includes high initial cost, maintenance and user awareness (Aslila, Lokman, & Narimah, 2015)

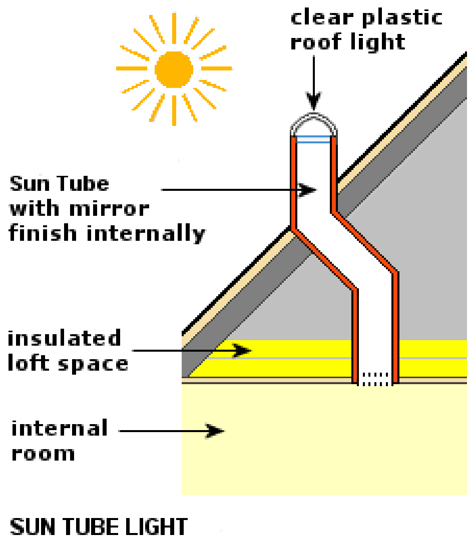


Figure 2.12 illustration of a typical light pipe

source: Low Energy House, (2016)

2.4.4 Fenestration materials

The fenestration consists of frame components and a daylight aperture. The frames are made from either timber, steel, aluminum, alloys or some form of plastics. To complement them, daylight apertures may have a void, a transparent or a translucent glazing layer between the source of natural illumination and the interior space (Salisu, 2015).

2.5 Conceptual Framework for Day Lighting Calculation

According to Abubakar, (2015) Research into day lighting has undergone various concepts since 1895 and these concepts are

1. The Daylight Factor Concept
2. The 'Design Sky' Concept
3. The 'Total Flux' or Lumen Concept of Day lighting
4. The 'Split Flux' Concept of Day lighting
5. The PSALI (Permanent Supplementary Artificial Lighting of the Interior)
6. The Static Point Illuminance and Luminance Measurement Concept
7. Climate-Based-Daylight-Modelling (CBDM)

2.5.1 The daylight factor concept

The daylight factor (DF) is a very common and easy to use measure for the subjective daylight quality in a room. It describes the ratio of outside illuminance over inside illuminance, expressed in percent. The higher the DF, the more natural light is available in the room (Clear Comfortable Low Energy Architecture, 2016). It is expressed as such:

DF = SC + ERC + IRC

SC is the sky component

ERC is the externally reflected component

IRC is the internally reflected component

It is usually expressed as a percentage of internal illuminance to unobstructed outdoor horizontal illuminance under a standard CIE overcast sky condition and is assumed to be a worst case scenario which does not consider any form of direct sunlight. This concept, irrespective of climate and location, has been elevated to a 'performance metric' whereby design guidelines worldwide currently recommend provisions in terms of daylight factors (DF) (Mardaljevic, Heschong, && Lee, Daylight metrics and energy savings, 2009).

According to Grant, (2015) The Daylight Factor and the light inside a room are made up of three separate components:

1. The sky component – light arriving at a point in a room coming directly from the sky
2. The externally reflected component – light arriving at a point in a room reflecting into it from an external obstruction
3. The internally reflected component – light arriving at a point in a room having been reflected from an internal surface.

These three components can be recorded and added to give the overall daylight factor.

Modification of the daylight factor method has been proposed by some researchers to allow for the effect of a clear sky and direct sunlight (Khalid, 1996).

2.5.2 'Design sky' concept

This concept is applied together with an established daylight factor for a given space. This method ensures that the required illumination will be reached or exceeded 85 per cent of the time, but it does not show the distribution pattern or quality. The major shortcoming of this concept is that it is based on the 'daylight factor' concept with all its shortcomings (Salisu, 2015).

2.5.3 'Total Flux' Concept or Lumen Concept

The lumen method is recommended by the Illuminating Engineering Society of North America. In this method, natural light received inside a room is a function of lightincidence on the window plane (Khalid, 1996).

This method allows for the estimation of absolute illuminance values at three stations inside a room. The first point is located at 5 feet from the window wall, the second is in the center of the room and the third is 5 feet from the back wall of the room. All these points are on a center line perpendicular to the window wall and at 0.75 meters above the floor level.

According to Khalid, (1996) the illuminance at any of the three station points can be found as follows:

$$E \quad = E5\ Ag\ Tg\ Cs\ Ks + Eg\ Ag\ Tg\ Cg\ Kg$$

Where:

Ep = absolute illuminance value at the station point

Es = exterior illuminance from the sun and the sky incident on the window

Ag = area of glazing

Tg = transmission of glazing

Eg = exterior illuminance reflected from the ground to the window

C5, Cg = coefficients representing the relationship between the light reachingthe window and the room length, room width and the reflectance of the interior walls of the room

Ks, Kg = coefficients representing the relationship between the light reaching the window and the ceiling height, room width and the reflectance of the interior walls of the room

2.5.4 'Split-flux' concept

Split-flux method, which is an empirical formula for calculating the IRC, based on the formula proposed by Arndt. The split-flux method proposes that one treat the flux entering the room in two parts. In this method, the window is divided into two parts by a horizontal imaginary plane passing through the center of the room. The first part is the flux coming from the sky and any external obstruction above the imaginary plane. The second part is the flux coming from the ground and any external obstruction falling below the imaginary plane. The first flux summations are then multiplied times the average reflectance of the lower surfaces of the room; the second with the reflectance of the upper surfaces of the room. Then the unit sphere method is applied for the inter-reflection of light. In this way the split-flux formula treats external obstructions in the form of horizontal band of infinite length (Kota , 2007).

2.5.5 PSALI (Permanent Supplementary Artificial Lighting of the Interior Concept)

PSALI is a system of combined artificial lighting and daylighting, where the two are blended together to provide an even illumination. Parts of the room are permanently lit by artificial light (Grant, 2015).

PSALI retains most of the psychological advantages of artificial lighting, but can illuminate deeper plan rooms than could be lit with daylight alone. The principle of PSALI is to provide illumination that appears to be of good daylight character even though most of the working illumination may be from artificial light (Grant, 2015).

1. Large variation of light during workday does not adversely affect visual performance.
    - I. Lightness Constance
    - II. Variations in daylight occur slowly over a period of time
    - III. Contrast ratios remain constant
2. Daylight and artificial light are easily combined
3. Supplemental systems must be coordinated so lighting levels do not change abruptly.

PSALI is also used to control the switching of lights on and off as daylight levels go up and down. In bright light, all illumination may be provided by daylight. At night, all lighting is artificial. Light-level switching of luminaires is known as photoelectric switching(Grant, 2015).

This concept involved the use of artificial illumination to aid the provision of lighting within deep lecture rooms. With this concept came smaller windows and the insufficient daylight became permanently supplemented by artificial means. This may not be an appropriate solution for the tropics, which has abundant daylight and certainly not for Nigeria where epileptic power supply is common(Salisu, 2015).

2.5.6 Static Point Illuminance and Luminance Measurement Concept

This concept is based on simulations or measurements under either real or artificial skies, or using computer tools (digital models and lighting software). This concept considers not only the diffused daylight entering a room, but also direct sunlight and its internal lighting effects (Salisu, 2015).

2.6 Climate-Based-Daylight-Modelling (CBDM)

Climate-based daylight modelling is the prediction of various radiant or luminous quantities (e.g. irradiance, illuminance, radiance and luminance) using sun and sky conditions that are derived from standard meteorological datasets. Whilst it hardly needs remarking that daylight is inherently climate-dependent and time varying, the accepted evaluation method, called the daylight factor, makes no account of this everyday reality. The principles of climate-based daylight modelling have been described in various publications since the first reports around the turn of the millennium (Mardaljevic, 2000). However, it is fair to say that acceptance has been slow amongst significant sections of the daylighting community, both practitioners and researchers (Mardaljevic, 2006).

The ability to undertake a year round assessment of day lighting using site-specific climatic datasets and orientation of the building into consideration makes this the methodology of choice for this research. It takes into consideration direct sunlight, diffused daylight and the inter-reflected daylight within a space into consideration when simulating. With access to computer hardware and software at affordable costs, this methodology will counter the limitations of the daylight factor and the single point in time methods (Salisu, 2015).

Using CBDM in place of daylight factors provides far greater detail about light distribution and intensity which allows the building design to be adjusted to maximize the use of sunlight and daylight. Annual weather data are used to calculate lux levels and targets can be set which are relative to user needs (Cundall Johnston and partners, 2015).

With CBDM the direct sun and diffuse components will be dynamic in their intensity and altitude for each façade: north, south, east and west. Therefore while orientation has allows been understood,the analysis and result will now detail the impact of the sunlight and daylight and inform the designer on the quantity and quality of the light within the space (Antonutto, 2013). The EFA Output Specification has a very different approach to daylight design compared with previous building programs and school design guides. In the past, design for daylight within the learning environment has been a numerical process based on a static overcast sky. The ambition was to deliver a certain percentage of diffuse light into the space (daylight factors) and achieve a degree of uniformity (Cundall Johnston and partners, 2015).

Derived from CBDM concept, a set of daylight specific performance indicators have been put forward by the proponents of this concept. These indicators have the ability to quantify and qualify day lighting in climate region, taking into consideration the location of the building and orientation inclusive of most climate peculiarities (Salisu, 2015).Theyincludes:

1. Performance Indicators for Quantity

a) Daylight Autonomy (DA) at a specified work plane location is defined as the percentage of the year when a minimum target illuminance for the day lit space is met by daylight alone. In mathematical terms, daylight autonomy is the percentage of annual work hours during which all or part of a building's lighting needs can be met through daylighting alone (lutron, 2013). In general, a Daylight Autonomy threshold of 60% of the work plane illuminance (500 lux) that meets the recommended illuminance requirement is considered good day lighting, especially for lecture rooms(Architectural Energy Corporation, 2006). For values below the prescribed minimum illuminance, a modified version of the above metric known as continuous Daylight Autonomy (DAcon) allocates credit for partial daylight that does not meet the target illuminance (Reinhart et al.,2006, Architectural Energy Corporation, 2006). DA is based on extensive research on lecture rooms and shows how well daylight penetrates into a space with appropriate display of the distribution pattern. In the absence of an upper limit on the allowed illuminance levels (until it meets the DAmax, which is ten times the benchmarked space illuminance level), poorly performing spaces with direct sunlight which is below the DAmax could do quite well with this metric. The DAmax of a factor of ten times the recommended illuminance is not backed by actual research, but is intuitive (Architectural Energy Corporation, 2006 and Reinhart et al., 2006).

b) Useful Daylight Illuminance (UDI)

UDI is defined as the annual occurrence of illuminance across the work-plane that is within a range considered "useful" by occupants – 100 to 2000 lux (Cundall Johnston and partners, 2015). A. They decided to base the criteria on the useful daylight illuminance (UDI) metric. The useful daylight illuminance approach is founded on occupant responses to daylight levels, as reported in several studies (Mardeljevic, Brembilla, & Drosou, 2016).It calculates the percentage of total number of occupied hours that 'useful' daylight enters a space at a selected point on the work plane (Salisu, 2015). It is the provision of ambient light at the work plane at illuminance levels is subdivided into:

- UDI<100 represents illumination less than 100 lux.
- UDI 100-2000 represents useful daylight
- UDI>2000 represents an excess supply of daylight

Thus, only three metrics are used to characterize the hourly-varying daylight illuminances for an entire year at each of the calculation points.

c) Simplified daylight glare probability (DGPs)

A major departure of DGP relative to other metrics summarized in this paper is that glare sources are determined by comparing areas of bright luminance against the total vertical eye illuminance for a viewing hemisphere of 2π sr. Therefore, DGP can evaluate direct sunlight falling on a workplane as a glare source while at the same time a dim visible sky might not be perceived as such. Specular reflections can also be seen as glare sources A glare probability >.45 corresponds to intolerable glare – an estimated 45 percent of people would feel discomfort in such a lighting situation, while a value <.3 is considered imperceptible(Jakubiec & Reinhart, 2012).

d) Spatial Daylight Autonomy (sDA)

It is a single quantitative value for a space unlike the multiple values obtained in the Daylight Autonomy (DA) scheme. It has been put forward quite recently in the IESNA publication IES LM-83 (IES Daylight Metrics Committee, 2012).. It identified two levels for acceptability of performance: ‘Preferred’ and ‘Nominally Accepted’. The ‘Preferred’ level is defined as a space with sufficiency of ambient daylight to meet or exceed 75% of sDA300, 50%, being the analysis points on the horizontal surface that meet or exceed 300 lux for 50% of the analysis period from 8am to 6pm. The ‘Nominally Accepted’ is defined as a space with sufficiency of ambient daylight for at least 55% of sDA300, 50%, being the analysis points on the horizontal surface that meet or exceed 300 lux for 50% of the analysis period from 8am to 6pm. This concept provides a single number for a space, more like the daylight factor (DF). It has already been experimentally verified to predict occupant satisfaction using a study of 61 different spaces by the authors (IES Daylight Metrics Committee, 2012). On the other hand, the performance metric for all types of spaces are the same- be it a classroom or an office, which may highly be unlikely due to peculiarities of the different working environments. Being a relatively new concept, preconfigured tools for calculations are not available at present. Simplified daylight glare probability DGPs

2. Performance Indicators for Quality

    a. Proposed Daylight Autonomy Uniformity Index (DAui). Uniformity has often been expressed in terms of a ratio of two quantities - maximum to minimum, maximum to average and average to minimum illuminance over a work plane (IESNA, 2000). Uniformity in day lighting could also be taken to be the distribution of daylight across the work plane at an assumed height. Salisu, (2015) to assess uniformity in the spaces that have fenestrations on opposite facades, proposed a daylight autonomy uniformity index (DAui).

       This will be calculated as a ratio of maximum measured daylight autonomy to the average daylight autonomy of the assessed space and the closer this value is to '1'; the more the daylight is uniformly distributed in the space.

    b. Useful Daylight Illuminance greater than 2000 lux (UDI>2000). Using this indicator, which is one of the three bins of the Useful Daylight Illuminance concept of CBDM, an assessment of the probability of solar gains and glare can be undertaken. Using a threshold of 2000 lux, these two qualities of daylighting in a space can be assessed using simpler and less complicated methods of ‘flagging’ of potential areas of thermal and visual discomfort. This threshold was arrived at after extensive survey on occupants in day lit office environments under a wide range of illumination conditions(Nabil & Mardaljevic, 2005).Though it will be ideal to achieve a 5% value or less for this performance indicator, the SLL (Society of Light and Lighting, SLL, 2011) has come up with the following criteria:

i. For new buildings, the combined value of the UDI<100 and UDI>2000 on a horizontal work plane should not exceed 20% of the assessed time of the activity period.

ii. For refurbished buildings, the UDI>2000 should not exceed 20% of the assessed time.

c. The Annual Sunlight Exposure (ASE) is a relatively new performance indicator put forward recently by the IESNA. This is a metric that describes the potential for visual discomfort by calculating the number of hours in a year that direct sun is incident on a surface. A threshold of 1000 lux for 250 hours in a year was selected based on user surveys as an indicator for tolerance level that can be used to compare spaces (IES Daylight Metrics Committee, 2012). This metric can flag potential issues of thermal discomfort and glare caused by direct sunlight from the sky, but does not provide for glare from specular reflections or veiling glare. Being a relatively new metric, preconfigured tools for calculations are not available at present (Salisu, 2015).

2.7 Climate and Daylighting

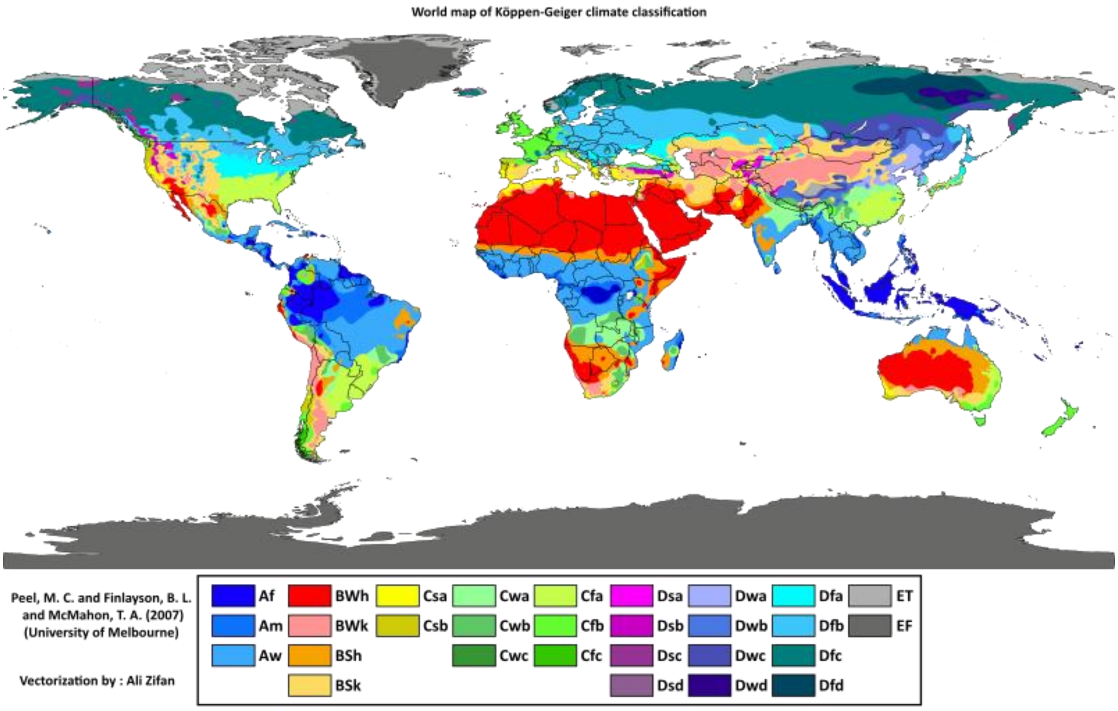
Climate is the long-term expression of weather; in the modern world, climate is most noticeably expressed in vegetation and soil types and characteristics of the land surface (Egeh & Okoloye, 2010). The climate of a region is characterized by its fundamental properties of air temperature, the rate and form of precipitation, the rate of evaporation, humidity, cloudiness (including the amount and type of clouds), solar and long wave radiation rates, wind speed and direction, and air pressure (Salisu, 2015).

The climatic characteristics of a site can dictate the significance of the use of overcast illumination as a design influence and the use of the mirror box artificial sky as a prediction tool. Projects with sites that experience predominantly overcast conditions can be well served by mirror box artificial sky testing. Primarily sunny climates require different daylighting strategies and might only use the mirror box to check performance for the occasional overcast day. Knowing a project's regional climate and lighting characteristics and understanding the percent of daylight hours each month that the sky is clear versus overcast gives important weight to the hierarchy of decisions about the kinds of daylighting techniques to be used in a design for a given locale (Ball State University, 2016).

The quality of day lighting design depends heavily on solar altitude, weather, and other time-dependent environmental factors. Yet very few existing tools provide the user with some understanding of the annual performance of a day lighting design, and similarly few lighting metrics focus on this temporal aspect of light measurement (Siân, Magali, & Marilyne, 2007).

2.7.1 Climatic zones

The Köppen climate classification is one of the most widely used climate classification systems. Russian German climatologist Wladimir Köppen first published it in 1884, with several later modifications by Köppen himself, notably in 1918 and 1936. Later, German climatologist Rudolf Geiger collaborated with Köppen on changes to the classification system, which is sometimes referred to as the Köppen–Geiger climate classification system. The system is based on the concept that native vegetation is the best expression of climate. Thus, climate zone boundaries have been selected with vegetation distribution in mind. It combines average annual and monthly temperatures and precipitation, and the seasonality of precipitation (Liquidsearch, 2016).



PlateiThe Köppen climate classification.

Source:Peel, Finlayson, & McMahon, 2007.

The Köppen climate classification scheme divides climates into five main groups (A, B, C, D, and E), each having several types and subtypes. Each particular climate type is represented by a two- to four-letter symbol.

Group A: Tropical/megathermal climates:

- Tropical rainforest climate (*Af*)
- Tropical monsoon climate (*Am*)
- Tropical wet and dry or savanna climate (*Aw*)

Group B: Dry (arid and semiarid) climates:

- Desert climate BW: Hot desert (*BWh*), Cold desert (*BWk*)
- Steppe climate (Semi-arid) BS: Hot steppe (*BSh*), Cold steppe (*BSk*)

Group C: Temperate/mesothermal climates:

- Dry-summer or Mediterranean climates (*Csa*, *Csb*, *Csc*)
- Temperate or subtropical hot-summer climates (*Cwa*, *Cfa*)
- Maritime temperate climates or Oceanic climates (*Cwb*, *Cwc*, *Cfb*, *Cfc*)
- Maritime subarctic climates or subpolar oceanic climate (*Cfc*)
- Temperate highland climates with dry winters (*Cwb*, *Cwc*)

Group D: Continental/microthermal climates

- Hot summer continental climates (*Dsa*, *Dwa*, *Dfa*)
- Warm summer continental or hemiboreal climates (*Dsb*, *Dwb*, *Dfb*)
- Continental subarctic or boreal (taiga) climates (*Dsc*, *Dwc*, *Dfc*)
- Continental subarctic climates with extremely severe winters (*Dsd*, *Dwd*, *Dfd*)

Group E: Polar and alpine climates:

- Tundra climate (*ET*)
- Ice cap climate (*EF*)

2.7.2 Climatic Zones in Nigeria

Nigeria is located along the West African coast in between latitudes 3°-15°E and longitudes 4°-14°N with a distinctly tropical climate that varies from the damp and very humid in the south to the hot and semi-arid climate in the north. Divisions of the country into southern and northern regions are obviously simplistic and lacking in scientific conviction. The country has three distinct climate types according to the Köppen system as modified by Trewartha and Horn, 1980. This is noticeable as one moves from the southern region through the middle belt and up to the northern states (Salisu, 2015).

In line with its close proximity to the equatorial belt and the Atlantic Ocean, Temperatures are generally high and consistent, and seasons are more aptly characterized by the difference in rainfall than a change in the mercury. For example, in Lagos, the average high in January is 31°C and 23°C, and in June it's 28°C and 23°C; though June is the season with peak rains and in January one would be lucky to see the smallest drop of water squeezed from the sky. In the south of the country, a coastal region that includes Lagos and the oil-rich area of Port Harcourt, it's incredibly humid, but it rarely gets hotter than 32°C. This area is defined by two rainy periods, one short period and one long period (Expatarrivals, 2016).

a. The Tropical Wet Climate

The Tropical Wet Climate is found in the southern part of the Nigeria and extends to the confluence of the two main rivers in the middle belt region of the country. The weather is constantly warm and humid with a lot of rainfall as the major characteristic of this climate, averaging over 2000mm which goes up to 4000mm in the coastal regions. The cloud cover can be quite substantial with the position of the sun remaining high throughout much of the day resulting in cloudy days. The prevalent ecology is the rainforest which is characterized by a huge variety of plants which grow all year round, insects and animals(Salisu, 2015).

b. Tropical Wet and Dry Climate or Tropical Savanna Climate

The tropical wet-and-dry climate regions are located adjacent or around tropical wet climates, but in more elevated regions, occurring in uplands at altitudes of 500m or higher. The first major characteristic of this climate is that it has a distinct dry season during when hardly any rainfall occurs. This season occurs for periods of between three to six months. Annual total rainfall for this climatic type usually range from 1000mm to 1500mm. Cloud cover patterns follow the rainfall during the wet season and clear skies during the dry. The dry season is distinguished by high monthly mean temperatures of up to 40°C with a correspondingly monthly mean minimum temperatures as low as 13°C. After the wet season, a dry, harsh, cold and dusty period of two to three months known as the 'harmattan' precedes the dry season. During this period the skies are mostly overcast. The major ecology of this climate is the savannah, which consists of flat grassland with occasional groups of trees or individual trees(Salisu, 2015).

c. The Hot-Semiarid Climate or Steppe Climate

Semi-arid climates have little rainfall and are usually located in-between the tropical wet-and – dry climates and the desert climates. The predominant feature of this climate is that it is dry with hot weather for significant periods of the year. It has the characteristics of dryness (both in rainfall and relative humidity). The hot dry season comes with clear skies and hot winds, while at the end of the year, a cold and dusty harmattan for about three months becomes the dominant feature. The amount of rainfall in this region varies between 250 to 750mm per year and occurs for a period of three or four months starting from May or June and is normally brief and intense. However, despite when the rainfall occurs, the sky is generally clear and the annual precipitation rate is less than the sum of the potential rate of evaporation of groundwater and the water lost by transpiration of plants (Heerwagen, 2004).The major ecology of this climate type is the Sahel savannah made up of shrubs and grassland with occasional trees. (Salisu, 2015)

Similar to most of West Africa, Nigeria's climate is characterized by strong latitudinal zones, which become progressively drier moving from the north from the coast. Rainfall is the key climatic variable, there are timed alternation between the wet and dry seasons in most areas. Two air masses control rainfall--moist northward-moving maritime air coming from the Atlantic Ocean and dry continental air coming south from the African landmass(U.S. Library of Congress, 2015).

Temperatures throughout Nigeria are generally high; temperature variations during the day are more pronounced than seasonal ones withhighest temperatures occur during the dry season; rains moderate afternoon highs during the wet season. Average highs and lows for Lagos are 31° C and 23° C in January and 28° C and 23° C in June. Although average temperatures vary little from coastal to inland areas, inland areas, especially in the northeast, have greater extremes. There, temperatures reach as high as 44° C before the onset of the rains or drop as low as 6° C during an intrusion of cool air from the north from December to February. Topographic relief plays a significant role in local climate only around the Jos Plateau and along the eastern border highlands (U.S. Library of Congress, 2015).

2.7.3 Technology for Climate-Based-Daylight-Modelling

Several software can be used in implementing a Climate-Based-Daylight-Modelling study. These tools include Radiance, a lighting software (a UNIX based software), Ecotect Analysis (a Windows based building simulation software) and Daysim (a Windows - based annual daylight analysis tool).

1) Autodesk Ecotect Analysis

Autodesk Ecotect Analysis is a stand-alone tool for climate-responsive, pre-design analysis of weather and solar site data, Ecotect is a standalone program that can read model files from other programs such as AutoCAD, Max, Maya Sketchup, etc. for analysis (Marchese, 2006).It was developed as a Windows-based environmental analysis and building simulation software by Dr Andrew Marsh, The software has the ability to export models/drawings with all the embedded building data and import results of analysis and visualizations in various formats. It provides a logical 3-D interface for parametric modelling with plug-ins to more specialized software like Radiance, EnergyPlus and Daysim for analysis (Salisu, 2015).

One of the functions of the software is that it can analyze simple natural lighting performances of buildings with illuminance at points based on the daylight factor concept It executes this using the British Research Establishment (BRE) split-flux method for determining the natural light levels at points within a model. For more accurate and comprehensive lighting analysis, it can output Radiance scene files for direct input into Radiance Lighting Simulation System (Salisu, 2015).

2) Radiance Lighting Simulation and Rendering System

Radiance lighting simulation and rendering system is a physically-based rendering system tailored to the demands of lighting design and architecture developed by author at Lawrence Berkeley Laboratory (LBL) and Ecole Polytechnique Federale de Lausanne (EPFL) in Switzerland. The simulation uses a light-backwards ray-tracing method with extensions to efficiently solve the rendering equation under most conditions (Ward , 1994).

According to Ward , (1994) the principal design goals of Radiance were to:

i. Ensure accurate calculation of luminance.
ii. Model both electric light and daylight.
iii. Support a variety of reflectance models.
iv. Support complicated geometry.
v. Take unmodified input from CAD systems.

These goals reflect many years of experience in architectural lighting simulation; some of them are physically-motivated, others are user-motivated. All of them must be met before a lighting simulation tool can be of significant value to a designer (Ward , 1994). It has been found to be more accurate in predicting illumination levels than most of the lighting softwares used in determining illumination in a space, though with the disadvantage of being slow and non-user friendly (Ubbelohde & Humann, 1998).

2.8 Findings from Literature Review

This chapter was devoted to reviewing relevant literature that pertains to this study with the aim of identifying gaps, which exists in the study of daylighting. The review identified different strategies of harnessing daylighting and identified side windows as the easiest and most commonly used for multi-storey buildings. The review revealed a systematic development of daylight assessment methods and concepts of daylighting developed through the years. A new concept known as CBDM came into being to assess the dynamic quantities and qualities of daylighting. A new quality assessment index, known as Daylight Autonomy Index (DAui), was put forward along with the useful daylight index (UDI)

3.0 RESEARCH METHODOLOGY

Much research has been carried out on the advantages of daylighting in lecture rooms over artificial lighting along with incorporation of daylighting into lecture rooms, these includes guidelines and strategies for adequate utilization of daylighting (Samani & Sanaz, 2012) (Architects & Building Branch, 1999) (Dahlan & Mahmoud, 2015) (Heschong Mahone Group, 1999). However to ensure adequate assessment of daylighting ,factors that affect the levels of luminance must be considered in relations to the location, orientation, variable sky conditions including relevant and accurate meteorological data of the location (Salisu, 2015).

From the literature review,which considered the existing methods of daylight analysis, the conclusion is climate based daylight modelling (CBDM).CBDM is the best methodology due to its ability to handle or cope with the constantly changing nature of the Tropical Wet and Dry Climate of Nigeria.The use of climate based daylight modelling (CBDM) architecturally could provide data about the ability of a designed space to reach an optimal level of illuminance, uniformity of distribution of illuminance and a reduction in the probability of glare or thermal discomfort.The CBDM was therefore adapted for the research.

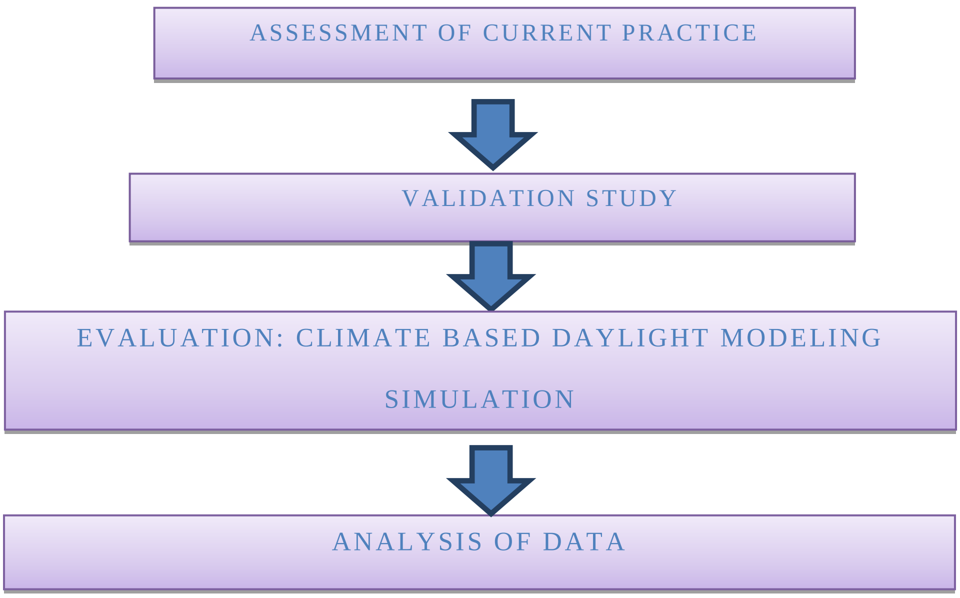
This chapter provides information on how the research was conducted in order to achieve the aim and objectives of this research. It covers the research design, sampling selection, research strategy, and method adopted for this thesis thereby contextualizing the methodology and justifying its use.

3.1 Design Strategy

The aim of this research is to determine the optimum head height of openings along the north and south orientation without shading devices, based on the quality and quantity of daylight in a lecture room while minimizing the probability for glare, For developing models which can be employed in the design of lecture rooms in the Tropical Wet and Dry Climate of Nigeria.

A quantitative research strategy is used. The research strategy adopted for this research was selected due to the basis and design of the research. The basis of the research is exploratory and the design research is experimental. The basis of the research is a data collecting and exploratory one, therefore a quantitative research strategy is used.

The process of evaluating daylighting in classroom quantitatively is illustrated



Source: author, 2016

1) Assessment of current practice

   At this stage, primary data for illumination of Universitylecture rooms within wet and dry tropical region of Kaduna State are determined. These are obtained from actual measurements of existing buildings.

2) Validation study

At this stage predicted building performance against actual measurements in the real building under normal occupation. This is analyzed to test the research instruments validity and reliability. Illuminances predicted using the Radiance system within ±10% of measured values could be deemed adequate (Mardeljevic, Brembilla, & Drosou, 2016).

3) Evaluation: Climate based daylight modeling simulation

   At this stage, simulation are carried out to determine the effects of climate, orientation and the influence of fenestration type on the provision of daylighting in lecture rooms located in the wet and dry tropics of Nigeria.

4) Analysis of data

   Based on the results of evaluation stage models are developed maximize the different configurations of fenestrations observed to ensure adequate daylighting and reduction in clear

The procedure and analysis adopted in this research is based fromAbubakar, (2015)andmardeljevic, brembilla, & drosou, (2016).

3.2 Research Design

This research is an exploratory type.First, primary data for illumination of Universitylecture rooms in wet and dry tropic climate of Kaduna State, Nigeria are obtained and research is done to determine the ability of these spaces to fulfil the functional needs of adequate lighting conditions and the visual performance. It then goes further to refine the fenestration variables to maximize the present methods based on climate based daylight modeling simulation research.

3.2.1 Research method

The research methods for this study are shown below in table 3.1

Table 3.1 Research Methodology

S/NO	STUDY	INVESTIGATED ISSUE	RESEARCH AND STRATERGIC ANALYSIS METHOD
1	Current Practices	I. Daylight quantity (illuminance measurements II. Daylight quality (uniformity ratios) III. Fenestration types IV. Fenestration designs sizes (ratio of opening to wall and head height). V.	Field survey and interpreting data using graphs and tables.
2	Validation of Tools and Assessment of Modelled lecture rooms in pilot studies	I. Validation of research tools II. Assessment of illuminate levels in modelled lecture rooms from pilot studies III. Assessment of fenestration methods in modelled lecture rooms from pilot studies IV. Assessment of overheating and visual discomfort in modelled lecture rooms from pilot studies	i. Visual analysis ii. Simulation iii. Correlation Test iv. Test of Significance p=0.01 v. Mean Bias Error (MBE) and Root Mean Square Error (RMSE) percentages vi. Average Illuminance Calculations
3	Assessment of Existing window sill height in lecture rooms from each sample for DA and UDI in a Tropical Wet and Dry Climate.	I. Daylight Autonomy (DA) II. Useful Daylight Illuminance (UDI 100>2000) III. Useful Daylight Illuminance (UDI>2000)	Simulation i. Graphs ii. Charts iii. percentage
4	Determination of the effect of change in sill height in lecture rooms for each of the samples	I. Daylight Autonomy (DA) II. Useful Daylight Illuminance (UDI 1002000) III. Useful Daylight Illuminance (UDI>2000)	Simulation i. Graphs ii. Charts iii. Percentage

Table 3.2 b Research Methodology continues

5	Determination of the effect of change inlecture roomsclassroom depth for each of the samples	I. Daylight Autonomy (DA) II. Useful Daylight Illuminance (UDI 1002000) III. Useful Daylight Illuminance (UDI>2000)	Simulation i. Graphs ii. Charts iii. percentage
6	Observations and Inferences from Item 4 and 5 above.	i. Illuminance Sufficiency ii. Probability of Glare and Thermal loads iii. Daylight Distribution	Interpretation of Data generated from simulations using benchmark values for daylighting metrics of DA, UDI and DA Uniformity Index where available.
7	Develop models based on literature review and inferences from above. Optimize same and come up with ranked models	I. Daylight Autonomy (DA) II. Useful Daylight Illuminance (UDI 100-2000) III. Useful Daylight Illuminance (UDI>2000)	Interpretation of Data using ordinal scales and Preference ranking of optimized models based on measured variables of DA, UDI100-2000, UDI>2000.

Source: author, 2016.

3.3 Dependent and Independent Variables

Daylight specific performance indicators have been put forward by the proponents of this concept. These indicators have the ability to quantify and qualify day lighting in climate region, taking into consideration the location of the building and orientation inclusive of most climate peculiarities.

3.3.1 Dependent variables

These includes

1. Window opening head height
2. Position of opening

3.3.2 Independent variables

Based on the climate-baseddaylighting-modeling concept, they are divided into indicators for quality and indicators for quantity.

Indicators for quantity

a) Daylight Autonomy (DA)
b) Continuous Daylight Autonomy

Indicators for quantity

a) Useful Daylight Illuminance

3.3.3 Case study

A case study is an in depth study of a particular situation, it is a method used to narrow down a broad field of research (Shuttleworth, 2008). This approach is used in this research to determine the current practice and daylight strategies used in Universitylecture rooms of the tropic wet and dry climate of Nigeria through objective method of observation.

This case study is based on the design principles that affect the quantity and quality of natural lighting in Universitylecture rooms of the tropical wet and dry climate of Nigeria.

3.3.4 Case study population

The population for the pilot study in the assessment of current practice and validation of this study are the lecture rooms in the Faculty of Environmental Design, Ahmadu BelloUniversity, Samara campus, Zaria, Kaduna state.

The sampling frame consists of departments within faculty of environmental design, Ahmadu BelloUniversity, samara campus, Zaria, Kaduna state as seen in plate ii. These are:

1. The Department of Architecture
2. The Department of Urban and Regional Planning
3. The Department of Quantity Surveying
4. The Department of Building
5. The Department of Geomatics

PlateiiGoogle earth map of case study samples.

Source: google earth maps (2016)

A classroom was selected from each department. Samples were selected based onthe following criteria:

1. Lecture roomsselected must be within the faculty building,therefore spaces as theaters, laboratories, auditoriums and studios are excluded.
2. Lecture rooms with north and south fenestration orientation, therefore lecture rooms with only east and west fenestration orientations are excluded.

3.3.5 Instruments for Data Collection

The methods of data acquisition for the case studies used in the descriptive research of this project include:

1. visual survey and measurements,
2. models and simulation (using eco-tech, radiance and daysim)

Visual survey can be reflected in various formats such as:

Photographs

photographs were taken of relevant case studies to ascertain the features of natural lighting, they possess as well as the extent to, which they were applied that is to say, if their extent of application was strong, weak or non-existent.

Sketches

Sketches were also made of some parts of the selected case studies. These sketches showed the spatial organization of space of some of the case studies.

Notes will also be made in tabular form to outlining the dependent and independent variables.

3.4 Chapter Summary

The Chapter gave a detail description of the methodology of climate based daylight modeling adopted in this study. An exploratory research thataccesses the current daylighting design practices in selected University lecture rooms,determines the influence of head height of openings on the provision of daylighting in University lecture rooms and identifies the optimum head height of openings for adequate lighting of lecture rooms along the north and south axis in a Tropical Wet and Dry Climate.

The tools selected for the study were the case-study and simulations using ecotect, radiance and Daysim, The data was represented in tables, graphs and charts.

4.0 DATA ANALYSIS, DISCUSSIONS AND FINDINGS

This chapter presents and discusses in details the research analysis, discussions and findings as it relates to the three research objectives of this research. The chapter is in four sections. Following the introduction is the discussions and analysis for the research objectives respectively

4.1 Validation studies

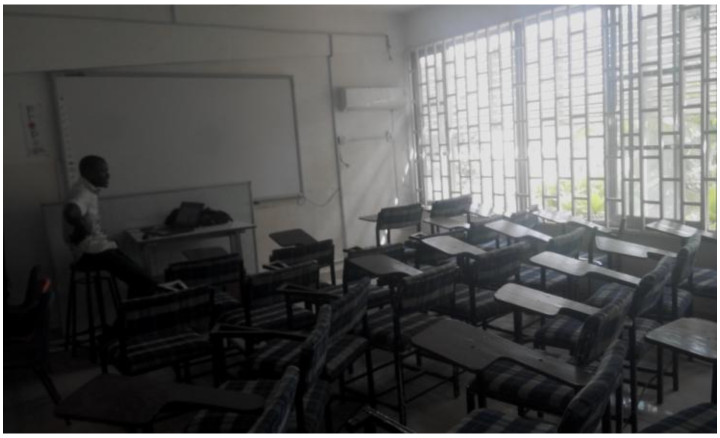
The measured and simulated illuminances from the validation studies were analyzed using descriptive statistics and methods from previous daylighting researches. Visually, the data were analyzed using a two-line graph for comparison, while statistical tests for correlation, mean bias error and root mean square were used to analyze the data. Lighting metrics of uniformity ratio and differences in average measured illuminances to simulated illuminances were also applied in the data analysis.

4.2 Assessment of current practice and Case studies

This section discusses the results of the case studies conducted. Five case studies were conducted within the faculty of environmental design, Ahmadu BelloUniversity, samara campus, Zaria.

1. The Department of Architecture

   The post-graduate lecture room seen in Plate iii was selected for assessment and validation. Opening were oriented to the south with window head heights of 2500mm. sensor points were selected are illuminance level record as seen in fig 4.1



Plateiii Interior Photograph of The post-graduate lecture room, Department of Architecture, ABU, Zaria.

Source: Field study, 2016

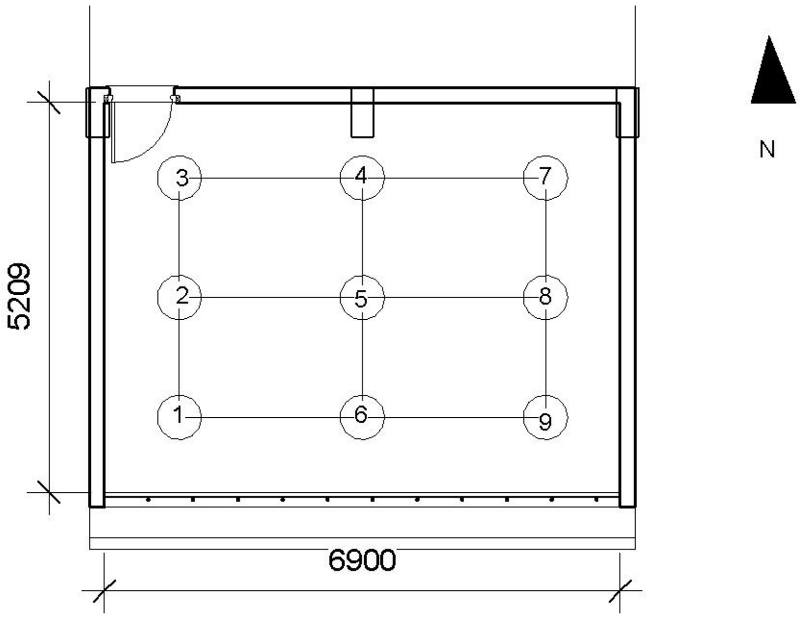


Figure 4.1 The post-graduate lecture room, Department of Architecture floor plan showing sensor points

Source: author, 2016

2. The Department of Urban and Regional Planning

The final year lecture room seen in Plate iv was selected for assessment and validation. Opening were oriented to the north with window head heights of

2500mm. There are shading devices at the openings as well as presence of tall trees.Sensor points were selected are illuminance level record as seen in fig 4.2

Plateivthe final year lecture room, theDepartment of Urban and Regional Planning, ABU, Zaria.

Source: Field study, 2016

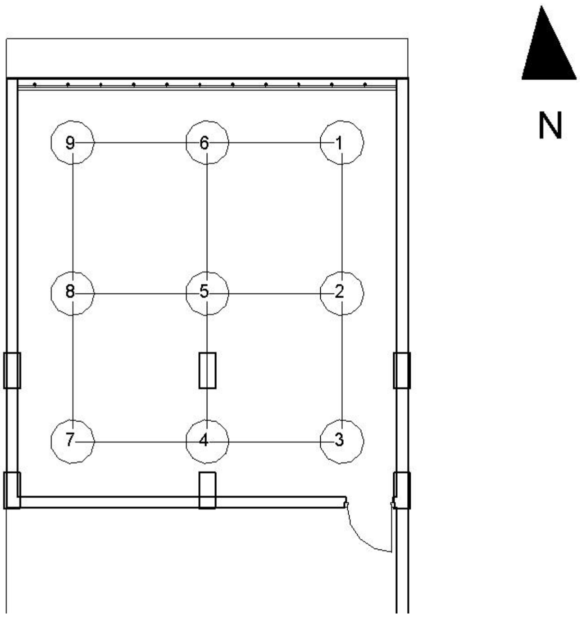
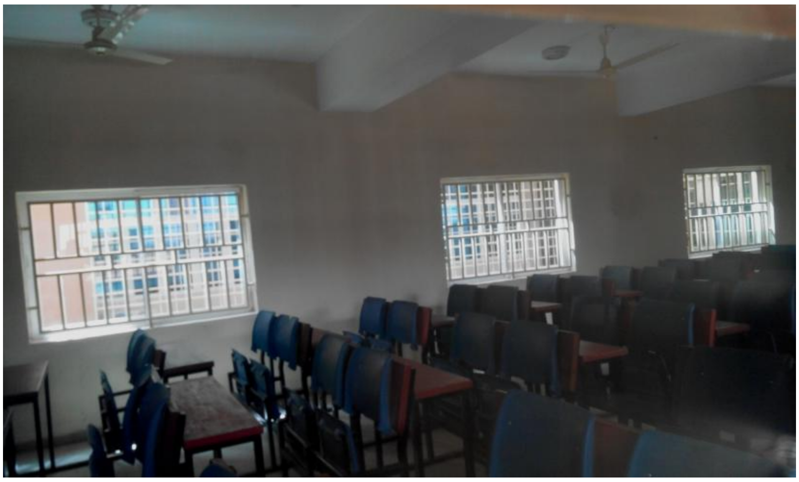


Figure 4.2 The final year lecture room, theDepartment of Urban and Regional Planning floor plan showing sensor points

Source: author, 2016

3. The Department of Quantity Surveying

The lecture room 3 seen in Plate v was selected for assessment and validation. Openings were oriented to the north and south with window head heights of 2100mm. sensor points were selected are illuminance level record as seen in fig 4.3



Platevthe lecture room 3, theDepartment of Quantity Surveying, ABU, Zaria.

Source: Field study, 2016

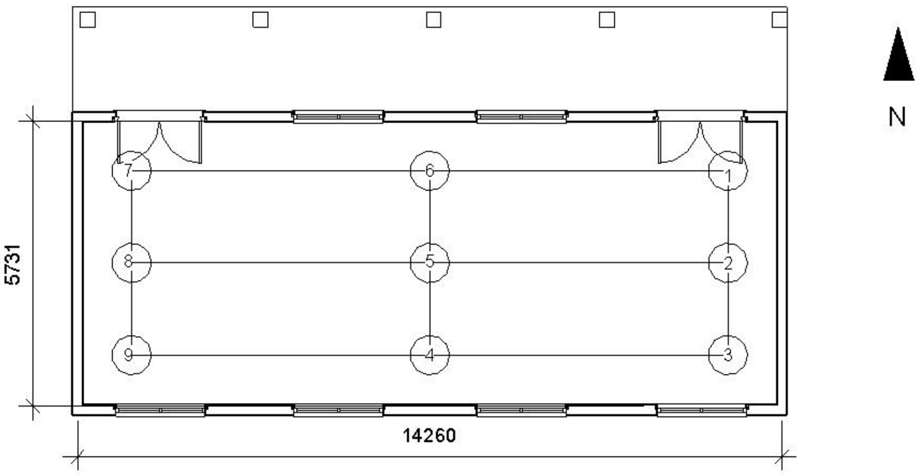


Figure 4.3 The lecture room 3, The Department of Quantity Surveying floor plan showing sensor points

Source: author, 2016

4. The Department of Building

The 300 level lecture room was selected for assessment and validation. Opening were oriented to the north with window head heights of 2500mm. There are concrete shading devices at the openings. sensor points were selected are illuminance level record as seen in fig 4.4

Platevi The 300 level lecture room, Department of Building, ABU, Zaria.

Source: Field study, 2016

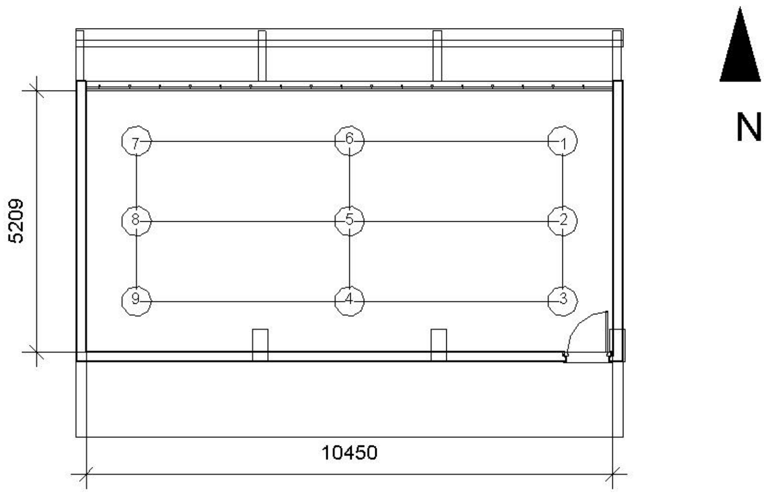
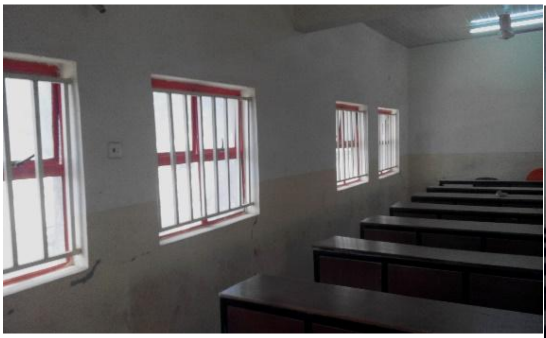


Figure 4.4: The 300 level lecture room, Department of Building floor plan showing sensor points

Source: author, 2016

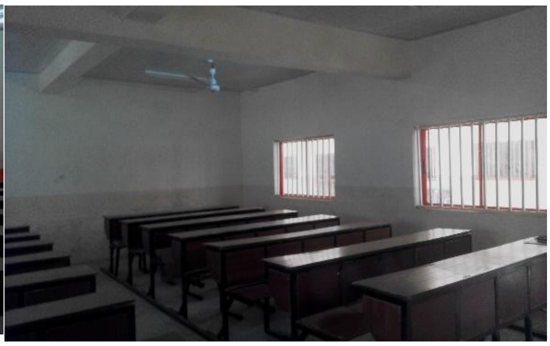
5. The department of geomatics

The 300 level lecture room seen in Plate vii and viii was selected for assessment and validation. Openings were oriented to the east and west with window head heights of 2100mm. fully grown trees are present at the west openings



Platevii The 300 level lecture room,department of geomatics, ABU, Zaria

Source: Field study, 2016



PlateviiiThe300 level lecture room,department of geomatics, ABU, Zaria

Source: Field study, 2017

4.2.1 Assessment of Daylighting in Existing lecture rooms

Based on the two IEA documents referred to earlier, there were four phases of monitoring. These are:

I. The Decision Phase

In the decision phase, the type of variables to be measured together with the type of instruments to be used, number of sensors, the time and frequency of measurements were determined. Illuminances at work plane levels for a minimum of nine sensors were measured.

II. The Preparatory/Monitoring Phase

In the descriptive document, all the information about variables during the monitoring phase with reference to the test rooms, monitoring tools and methods were documented.

III. The Concluding Phase

In this phase, the measured data of illuminances, with the dates were tabulated for comparison to simulated data and statistical interpretations.

Table 4.1 data from case study.

DEPARMENT	LECTURE ROOM	FENESTRATION TYPE	SIZE OF CLASSROOM	NUMBER OF OCCUPANTS	WORKING PLANE LEVEL	WINDOW HEAD HEIGHT (MM)
ARCHITECTURE	PG-lecture room	glazing	35.7m^2	38	800	2500
QUANTITY SURVEY	Lecture hall 3	glazing	83.8m^2	72	790	2100
BUILDING	300 level lecture hall	glazing	53.6m^2	54	850	2500
URBAN AND REGIONAL PLANNING	Final year lecture room	glazing	35.7m^2	52	900	2550
GEOMATICS	300 level lecture room	glazing	66m^2	70	750	2100

Source: author, 2016.

4.2.2 Assessment of Daylighting in case study lecture rooms

The measured and simulated illuminances from the validation studies were analysed using descriptive statistics and methods from previous daylighting researches. Visually, the data were analyzed using a two-line graph for comparison, while statistical tests for correlation, mean bias error and average values were used to analyze the data. Performance metrics of uniformity ratio and differences in average measured illuminances to simulated illuminances were also applied in the data analysis. The measured and simulated data together with the diagrams of their sensor points are listed in Tables 4.2-4.9

Table 4.2 Measured and simulated illuminances The post-graduate lecture room, Department of Architecture, ABU, Zaria.

SENSOR POINTS	MEASURED (LUX)	SIMULATED (LUX)	ERROR (SIM-MEA)
1	1149.0	1160.5	11.5
2	324	407.5	83.5
3	211.5	289.7	78.2
4	265.2	310.9	45.7
5	478	450.8	-27.2
6	1168	1287.64	119.64
7	325	298.54	-26.46
8	437	332.02	-105
9	1070	1082.50	12.5
Average sum	603.1	624.5	

Source: author, 2016.

Table 4.3 Simulation Results for the post-graduate lecture room, Department of Architecture, ABU, Zaria

INDICATORS	s/p 1	s/p 2	s/p 3	s/p 4	s/p 5	s/p 6	s/p 7	s/p 8	s/p 9	avg
DAYLIGHT AUTONOMY	101.85	87.20	31.50	21.15	78.75	101.85	21.15	72.45	100.80	69.2
CONTINOUS DAYLIGHT AUTONOMY	103.95	91.35	81.90	80.85	96.60	103.95	79.80	95.55	103.95	93.1
UDI >100	1	1	2	3.15	1.05	0	3	1	1	1.4
UD1 100-2000	79.80	103.95	102.9	101.8	103.9	76.35	101.8	103.9	77.70	94.7
UDI <2000	25.20	0.0	0.0	0.0	0.0	33.60	0.0	0.0	27.30	9.6

Source: author, 2016.

Table 4.4 Measured and simulated illuminances The 300 level lecture room, Department of Building, ABU, Zaria. Source: Field study, 2016.

WORKPLANE SENSORS	**MEASURED (LUX)**	**SIMULATED (LUX)**	**ERROR (SIM-MEA)**
1	1065	1015.7	-49.3
2	625	529.1	-95.9
3	341	391.6	50.6
4	373	479.3	106.3
5	661	650.74	-10.26
6	1182	1108.4	73.6
7	1008	908	-100
8	503	453	-50
9	336	364.7	28.7
Average sum	677.1	655.6	

Source: author, 2016.

Table 4.5 Simulation Results for the 300 level lecture room, Department of Building, ABU, Zaria

INDICATORS	**s/p 1**	**s/p 2**	**s/p 3**	**s/p 4**	**s/p 5**	**s/p 6**	**s/p 7**	**s/p 8**	**s/p 9**	**avg**
DAYLIGHT AUTONOMY	47.25	0	0	0	0	50.40	80.90	0	0	19.8
CONTINOUS DAYLIGHT AUTONOMY	80.00	65.00	34.00	39.00	62.00	80.0	85.00	55.00	35.0	59.4
UDI >100	2	10	22	18	8	2	1	9	20	10.2
UD1 100-2000	98.00	90.00	78.0	82.0	92.0	98.0	99.0	91.0	80.0	87.7
UDI <2000	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

Table 4.6 Measured and simulated illuminances The final year lecture room, The Department of Urban and Regional Planning, ABU, Zaria. Source: Field study, 2016.

WORKPLANE SENSORS	**MEASURED (LUX)**	**SIMULATED (LUX)**	**ERROR (SIM-MEA)**
1	295	407	112
2	163	174.6	11.6
3	89.4	70.2	-19.2
4	47.8	65.8	18.0
5	140.8	182.2	41.4
6	273.6	398.5	124.9
7	52.5	80.5	28
8	90.6	157.2	66.6
9	166.9	383.0	216.1
Average sum	146.6	213.2	

Source: author, 2016.

Table 4.7 Simulation Results for the final year lecture room, The Department of Urban and Regional Planning, ABU, Zaria.

INDICATORS	**s/p 1**	**s/p 2**	**s/p 3**	**s/p 4**	**s/p 5**	**s/p 6**	**s/p 7**	**s/p 8**	**s/p 9**	
DAYLIGHT AUTONOMY	57.0	0	0	0	0	53.0	0	0	57.0	18.5
CONTINOUS DAYLIGHT AUTONOMY	83.0	44.0	23.0	21.0	48.0	82.0	22.0	42.0	83.0	49.7
UDI >100	2.0	16.0	36.0	40.0	14.0	3.0	39.0	10.0	2.0	18.7
UD1 100-2000	98.0	84.0	64.0	60.0	86.0	97.0	81.8	84.9	98.0	83.7
UDI <2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.

Source: author, 2016.

Table 4.8 Measured and simulated illuminances The lecture room 3, The Department of Quantity Surveying, ABU, Zaria. Source: Field study, 2016.

WORKPLANE SENSORS	MEASURED (LUX)	SIMULATED (LUX)	ERROR (SIM-MEA)
1	85.9	78.97	-6.9
2	75.6	78.71	3.1
3	365	338.25	-26.7
4	176.6	180.0	3.4
5	146.2	120.32	-25.88
6	243.9	181.72	-62.2
7	47.6	50.2	2.6
8	63.1	91.2	28.1
9	135.8	230.2	94.4
Average sum	148.8	149.9	

Source: author, 2016.

Table 4.9 Simulation Results for The lecture room 3, The Department of Quantity Surveying, ABU, Zaria. Source: Field study, 2016.

INDICATORS	s/p 1	s/p 2	s/p 3	s/p 4	s/p 5	s/p 6	s/p 7	s/p 8	s/p 9	
DAYLIGHT AUTONOMY	0	0	56	15	0	0	0	0	35	11.7
CONTINOUS DAYLIGHT AUTONOMY	19.95	36.75	89.25	75.60	53.55	53.55	17.85	31.50	81.90	51.1
UDI >100	48	18	2	4	8	8	63	23	2	19.6
UD1 100-2000	54	86.1	102.9	100.8	96	96	38	80	102.9	84.1
UDI <2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

Source: author, 2016.

4.2.3 Visual analysis

Looking at the preceding tables and figures, the results are not easily indicative of any relationships. Upon comparing the descriptive graphs visually, it can be seen in fig 4.5 – 4.8 that the simulated illuminances followed the measured illuminances closely.

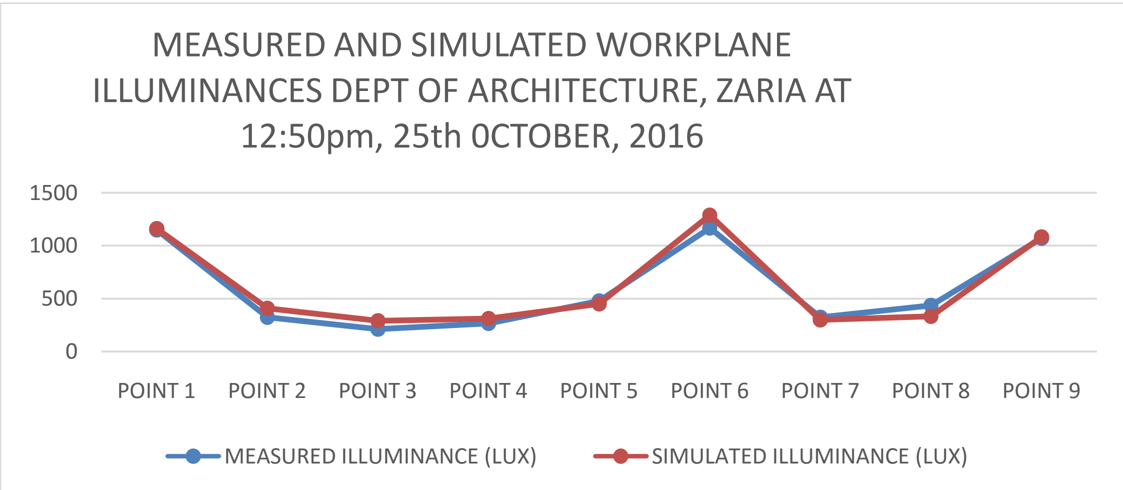


Figure 4.5 Measured and simulated illuminances for Department of Architecture, Zaria. Source: Field study, 2016.

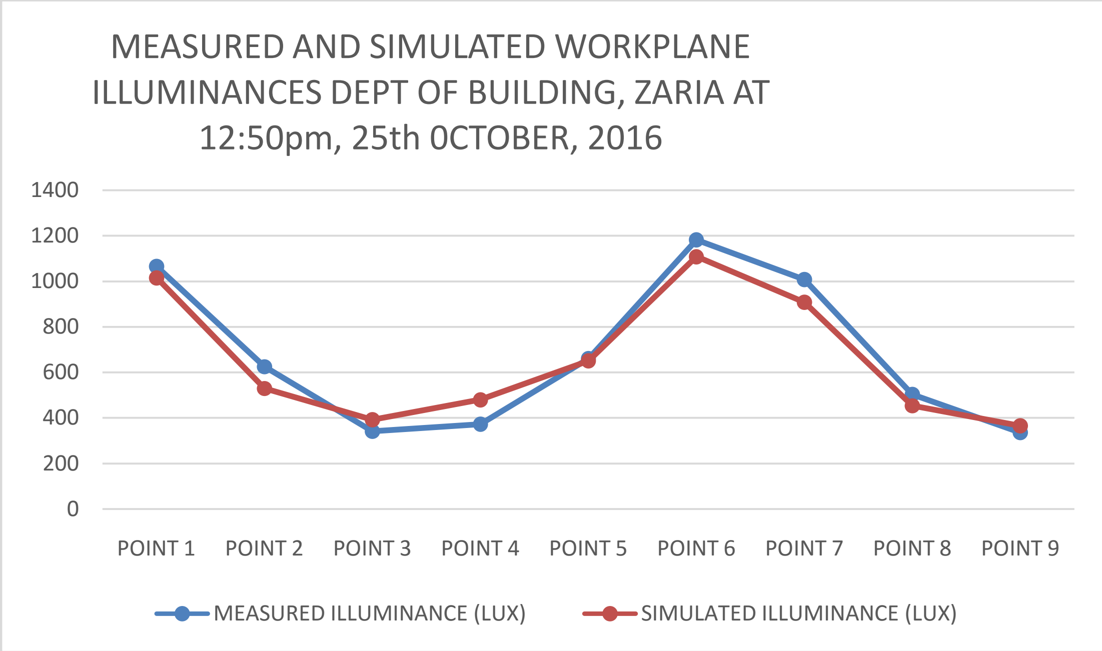


Figure 4.6 Measured and simulated illuminances for Department of Building, Zaria. Source: Field study, 2016.

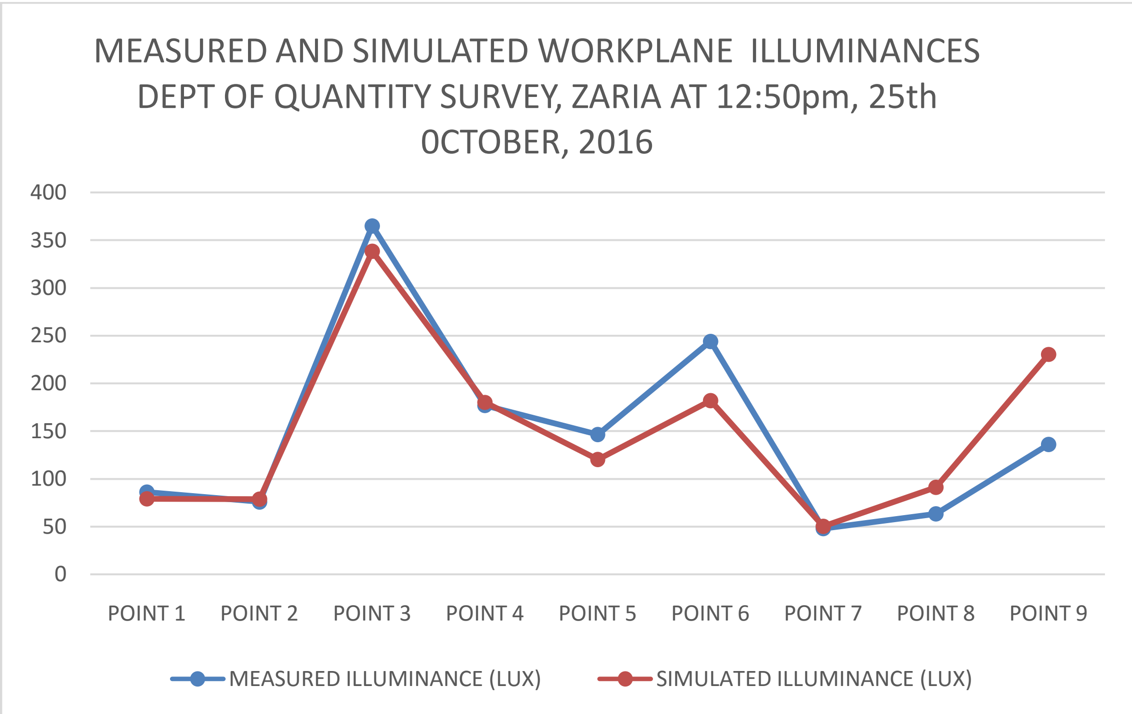


Figure 4.7 Measured and simulated illuminances for Department of Quantity Surveying, Zaria. Source: Field study, 2016.

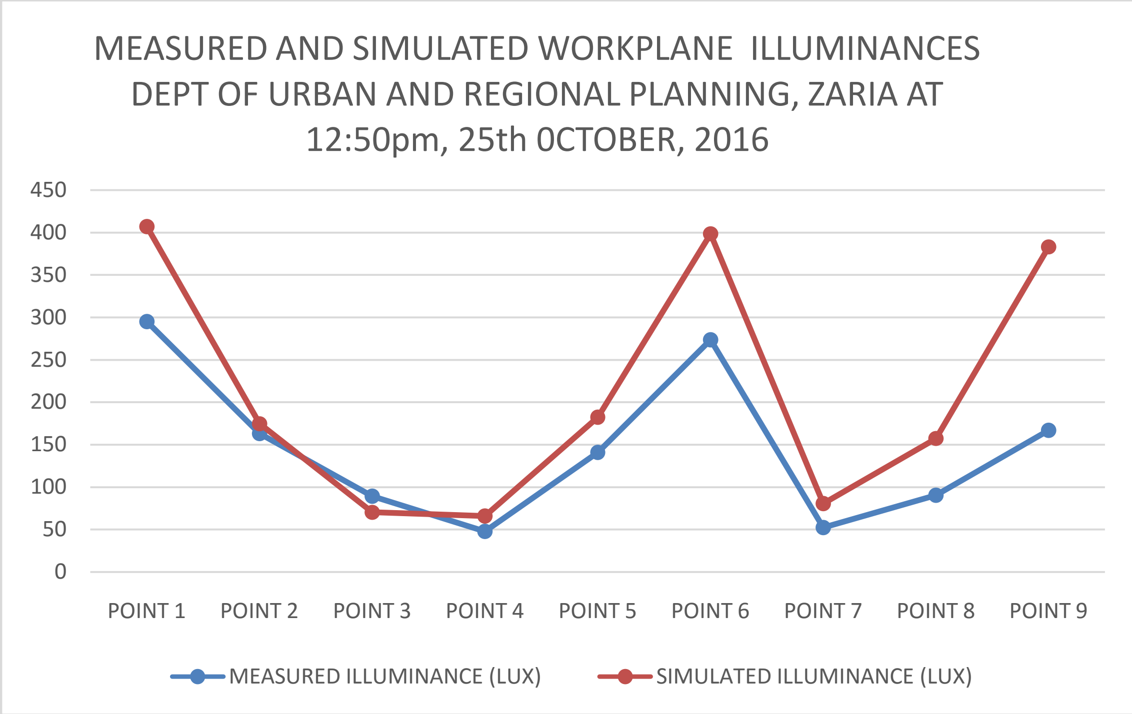


Figure 4.8 Measured and simulated illuminances for Department of Urban and Regional Planning, Zaria. Source: Field study, 2016.

4.2.4 Average illuminances calculations

The use of the average illuminances of simulated and measured points as a guide for accuracy levels was put forward by Commission Internationale de L'Eclairage (CIE) which is a body responsible for the international coordination of lighting related technical standards. It was stated that a range of -10% to 10% differences between the average values of simulated illuminances and measured illuminances in a space is acceptable (Fisher, 1992). Using this postulation, an assessment of the values of both the measured and simulated values for the four samples was done with the results listed in Table 4.10.

Table 4.10 Average Illuminances Percentage Differences.

Department	Average measured illuminance (lux)	Average simulated illuminance (lux)	Percentage difference %
architecture	603.1	624.5	-3.55
building	677.1	655.6	3.17
Quantity survey	148.8	149.9	-0.74
Urban and regional planning	146.6	213.2	-45.43

Source: author, 2016.

The values satisfy the requirement of being less than 10%, making it acceptable except for the results of urban and regional planning. This is due to presence of tall trees at window openings which are difficult to simulate for.

With three of the four results within the guide for accuracy levels was put forward by Commission Internationale de L'Eclairage (CIE) the values satisfy the requirement of being less than 10%, making it acceptable.

The validation approach presents an empirical study in assessing the effectiveness of the tested daylighting simulation tool – Radiance- especially in the tropical wet and dry region of Nigeria. It has shown that with the use of weather files, it is quite possible to predict the performance of both glazed and unglazed openings prevalent in the tropics. This indicates that the simulation method reliably reproduced real world conditions and it is therefore valid.

4.3 Evaluation Studies

The evaluations are undertaken using the concept of 'performance metrics'. A metric can be defined as the use of multiple factors or data to come up with a single parameter which can be used as a measure of quality(Nilson, 2012).

For this evaluation process, sample lecture rooms for north and south orientations seen in fig 4.9 – 4.10were created ,based on the findings from the case study such as average width of lecture rooms, average ceiling height, average work plane level.

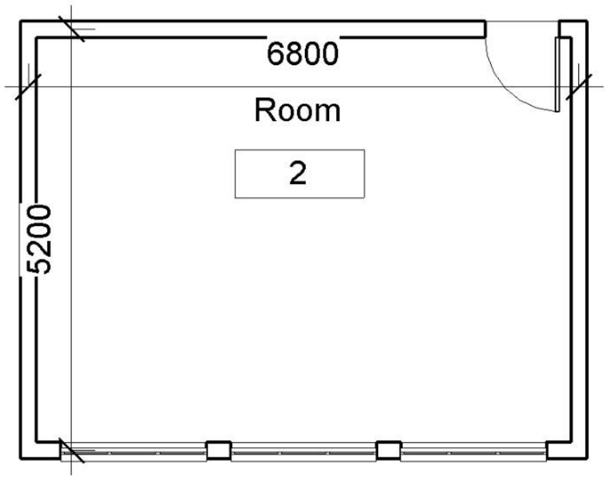


Figure 4.9 sample lecture room for south orientation assessment.

Source: Author, 2017

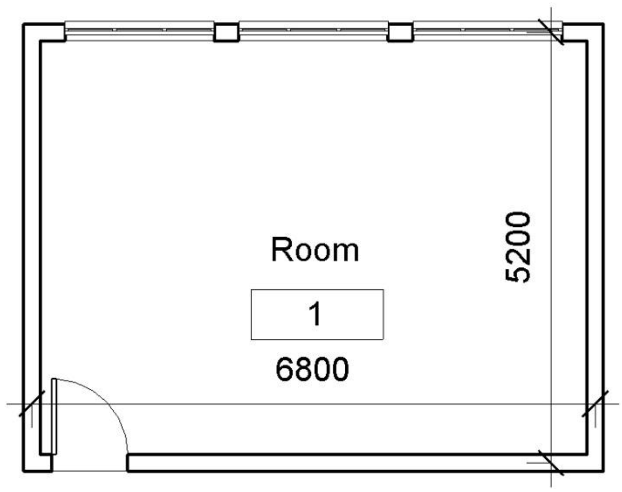


Figure 4.10 sample lecture room for north orientation assessment.

Source: Author, 2017

Performance metrics or indicators used for this evaluation study are Average Daylight Autonomy (DA), Average Useful Daylight Illuminance < 100lux (UDI<100), Average Useful Daylight Illuminance 100-2000lux (UDI100-2000), Average Useful Daylight Illuminance > 2000lux (UDI>2000).

The window head height was varied from 1800mm, 2100mm, 2400mm to 2700mm on both orientations and simulated on ecotect, radiance and Daysim to identify the effect of the change on performance indicators and the optimum height for each orientation.

4.3.1 Assessment of simulated Classrooms with South openings

After simulation on radiance a 3d image is generated which shows a visually the simulated level of light from the south oriented openings as seen in Plate ixas well as performance indicators in table 4.11- 4.13

Plateix computer generated image of the south oriented sample lecture room.

Source: Author, 2017

Table 4.11 Luminance level of the south oriented sample lecture room

Head height(mm)	s/p 1	s/p 2	s/p 3	s/p 4	s/p 5	s/p 6	s/p 7	s/p 8	s/p 9	avg
1800	150.7	219.8	831.1	154.9	248.2	653.9	142.4	209.4	620.7	359.1
2100	217.6	347.2	931.41	239.8	384.2	972.2	210.4	322.9	904.0	498.3
2400	292.9	472.6	1171.7	355.0	512.9	1197.8	301.8	445.6	1123.	652.6
2700	405.6	651.9	1519	453.5	690.9	1566	392.4	577.9	1427	853.8

Source: author, 2016.

Table 4.11, illustrates a relationship between a windows head height and average illuminance levels on the south oriented sample showing a 137% increase in average lux levels from 1800mm at 359.1 lux being the lowest to 2700m at the 853.8 lux as the highest.

Table 4.12 Daylight autonomy of the south oriented sample lecture room

Head height(mm)	s/p 1	s/p 2	s/p 3	s/p 4	s/p 5	s/p 6	s/p 7	s/p 8	s/p 9	avg
1800	0.00	1.00	88.00	0.00	9.00	94.00	0.00	2.00	92.00	31.8
2100	0.00	35.00	98.00	8.00	47.00	97.00	7.00	34.00	97.00	47
2400	27.00	71.00	98.00	45.00	76.00	98.00	27.00	70.00	9800	67.8
2700	57.00	84.00	99.00	69.00	90.00	99.00	61.00	89.00	99.00	83

Source: author, 2016.

Table 4.12, illustrates a relationship between a windows head height and average daylight autonomy on the south oriented sample showing a 52% increase in Daylight autonomy from 1800mm at 31%being the lowest to 2700m at 83% as the highest.

Table 4.13 Useful daylight Illuminance > 100 of the south oriented sample lecture room

Head height(mm)	s/p 1	s/p 2	s/p 3	s/p 4	s/p 5	s/p 6	s/p 7	s/p 8	s/p 9	avg
1800	1.00	9.00	20.00	2.00	8.00	18.00	2.00	10.00	22.00	11.2
2100	8.00	2.00	1.00	4.00	1.00	0.00	4.00	2.00	1.00	2.6
2400	2.00	1.00	0.00	2.00	1.00	0.00	2.00	1.00	0.00	1
2700	0.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00	0.5

Source: author, 2016.

Table 4.13, illustrates a relationship between a windows head height and Useful Daylight Illuminance > 100 on the south oriented sample showing a 10.7% decrease in average useful Daylight Illuminance > 100 from 1800mm at 11.2% being the highest to 2700m at 0.5% as the lowest.

Table 4.14 Useful daylight Illuminance < 2000 of the south oriented sample lecture room

Head height(mm)	s/p 1	s/p 2	s/p 3	s/p 4	s/p 5	s/p 6	s/p 7	s/p 8	s/p 9	avg
1800	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
2100	0.00	0.00	5.00	0.00	0.00	10.00	0.00	0.00	15.00	3.3
2400	0.00	0.00	24.00	0.00	0.00	38.00	0.00	0.00	30.00	10.2
2700	0.00	0.00	45.00	0.00	0.00	61.00	0.00	3.00	46.00	17.2

Source: author, 2016.

Table 4.14, illustrates a relationship between a windows head height and Useful Daylight Illuminance < 2000on the south oriented sample showing a 17.2% increase from 1800mm at 0% being the lowest to 2700m at 17% as the highest.

4.3.2 Assessment of simulated Classrooms with north openings

After simulation on radiance a 3d image is generated which shows a visually the simulated level of light from the north oriented openings as seen in Platex as well as performance indicators in tables 4.15- 4.18

Platex Computer generated image of the north oriented sample lecture room.

Source: Author, 2017

Table 4.15 Luminance level of the north oriented sample lecture room

Head height(mm)	**s/p 1**	**s/p 2**	**s/p 3**	**s/p 4**	**s/p 5**	**s/p 6**	**s/p 7**	**s/p 8**	**s/p 9**
1800	348.8	152.7	107.6	373.4	166.9	116.6	341.5	167.8	108.3
2100	488.3	211.3	150.0	508.8	230.9	171.7	459.8	216.2	148.5
2400	465.3	212.6	152.3	509.4	240.5	173.0	468.8	214.7	145.9
2700	880.8	348.4	249.1	710.7	396.6	287.8	850.8	350.1	240.5

Source: author, 2016.

Table 4.15, illustrates a relationship between a windows head height and average illuminance levels on north openings showing a 122% increase in average lux levels from 1800mm at 108.3 lux being the lowest to 2700m at the 240.5 lux as the highest.

Table 4.16 Daylight autonomy of the north oriented sample lecture room

Head height(mm)	**s/p 1**	**s/p 2**	**s/p 3**	**s/p 4**	**s/p 5**	**s/p 6**	**s/p 7**	**s/p 8**	**s/p9**	**avg**
1800	82.00	0.00	0.00	87.00	0.00	0.00	85.00	0.00	0.00	28
2100	90.00	11.00	0.00	98.00	18.00	0.00	90.00	5.00	0.00	34
2400	92.00	14.00	0.00	94.00	25.00	0.00	93.00	10.00	0.00	36.4
2700	98.00	79.00	38.00	99.00	85.00	46.00	98.00	80.00	27.00	72.2

Source: author, 2016.

Table 4.16, illustrates a relationship between a windows head height and average daylight autonomy on the north oriented sample showing a 44.2% increase from 1800mm at 28% being the lowest to 2700m at 72% as the highest.

Table 4.17 Useful daylight Illuminance > 100 of the north oriented sample lecture room

Head height(mm)	**s/p 1**	**s/p 2**	**s/p 3**	**s/p 4**	**s/p 5**	**s/p 6**	**s/p 7**	**s/p 8**	**s/p 9**	**avg**
1800	1.00	5.00	15.00	1.00	3.00	11.00	1.0	5.00	15.00	6.3
2100	1.00	2.00	7.00	0.00	1.00	6.00	0.00	2.00	8.00	3
2400	1.00	2.00	8.00	0.00	1.00	6.00	1.00	2.00	6.00	3
2700	0.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00	0.6

Source: author, 2016.

Table 4.17, illustrates a relationship between a windows head height and Useful Daylight Illuminance > 100 on the north oriented sample showing a 5.7% decrease from 1800mm at 6.3% being the highest to 2700m at 0.6% as the lowest.

Table 4.18 Useful daylight Illuminance < 2000 of the north oriented sample lecture room

Head height(mm)	s/p 1	s/p 2	s/p 3	s/p 4	s/p 5	s/p 6	s/p 7	s/p 8	s/p 9	avg
1800	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
2100	0.00	0.00	0.00	2.00	0.00	0.00	4.00	0.00	0.00	0.7
2400	0.00	0.00	0.00	3.00	0.00	0.00	7.00	0.00	0.00	1.1
2700	18.00	0.00	0.00	25.00	0.00	0.00	21.00	0.00	0.00	7.1

Source: author, 2016.

Figure 4.18, illustrates a relationship between a windows head height and Useful Daylight Illuminance < 2000 on the north oriented sample showing a 7.1% increase from 1800mm at 0% being the lowest to 2700m at 7.1% as the highest.

4.4 Visual Analysis of simulated lecture rooms

This analysis was done for the simulated lecture roomsfor Zaria, keeping constant the fenestration designs assess the effects of change in window head heights on the performance metrics. The simulations were carried out using the same parameters and material specifications as in the assessment for DA and UDI values. The results averages are presented in Table 4.19 for south oriented openings and Table 4.20 for north oriented openings

Table 4.19 Simulation Results for the south oriented simulated lecture rooms for Zaria

Performance indicators	1800mm	2100mm	2400mm	2700mm
Av daylight autonomy	31.8	47	67.8	83
Useful daylight Illuminance > 100	11.2	2.6	1	0.5
Av Useful daylight Illuminance 100-2000	93.1	95.3	88.6	83
Av Useful daylight Illuminance < 2000	0	3.3	10.2	17.2

Source: author, 2016.

The simulation results show the following:

1. Adequate DA values of 60% over the sensors on the work plane are achieved in the lecture rooms with minimum of 2400mm window head height for opening on the south orientation
2. Change in window head height for opening on the south orientation has a major influence on the performance indicators. This shows by a
   I. 52% increase in average daylight autonomy from 1800mm at 31% being the lowest to 2700m at 83% as the highest as seen in fig 4.11.

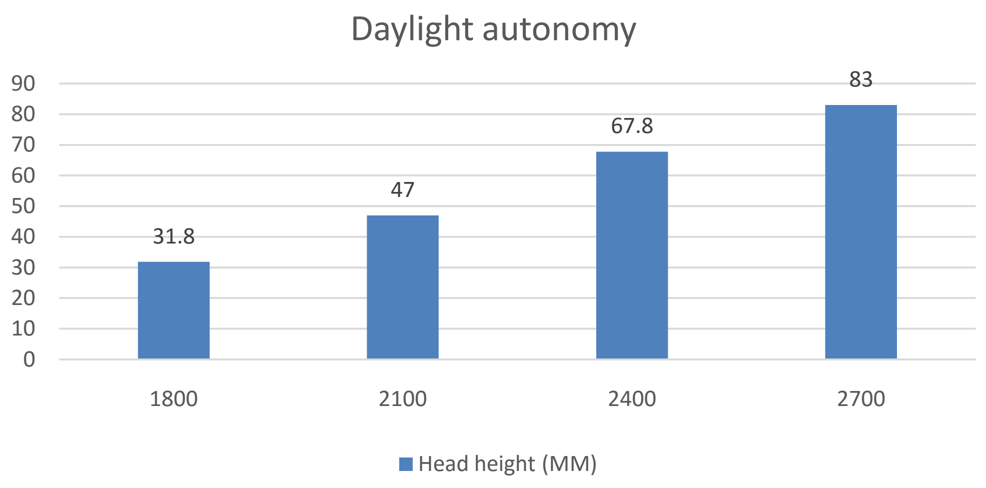


Figure 4.11 average daylight autonomy on south orientation

Source: Field study, 2016

II. 10.7% decrease in average Useful Daylight Illuminance > 100 from 1800mm at 11.2% being the highest to 2700m at 0.5% as the lowest as seen in fig 4.12.

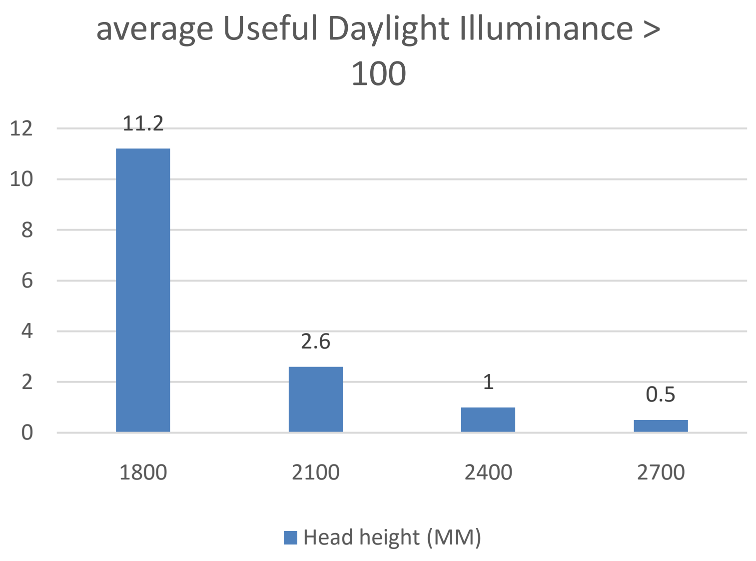


Figure 4.12 average Useful Daylight Illuminance > 100

Source: Field study, 2016

III. 17.2% increase average Useful Daylight Illuminance < 2000 from 1800mm at 0% being the lowest to 2700m at 17% as the highest as seen in fig 4.13.

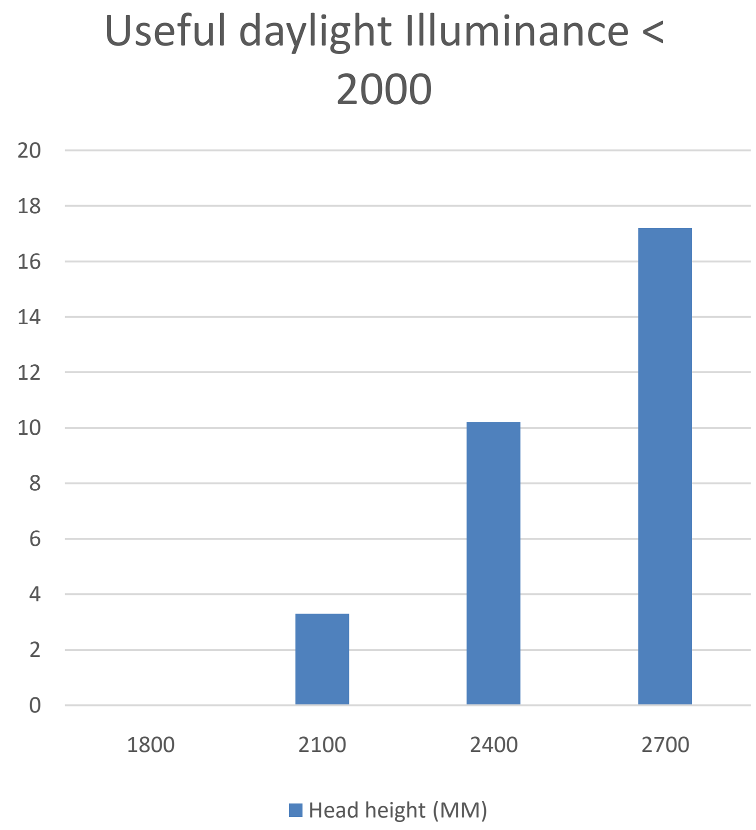


Figure 4.13 average Useful Daylight Illuminance < 2000

Source: Field study, 2016

3. Adequate Useful Daylight Illuminance < 2000 values of 30% over the sensors on the work plane are noticed in the lecture rooms with window head height for opening over 2400mm on the south orientation

Table 4.20 Simulation Results for the north oriented simulated lecture rooms for Zaria

Performance indicators	**1800mm**	**2100mm**	**2400mm**	**2700mm**
Av daylight autonomy	28	34	36.4	72.2
Useful daylight Illuminance > 100	6.3	3	3	0.6
Av Useful daylight Illuminance 100-2000	93.6	96.2	96.3	92

The simulation results fornorth oriented simulated lecture rooms for Zaria seen in table 4.20 show the following:

1. Adequate DA values of 60% over the sensors on the work plane are achieved in the lecture rooms with minimum of 2700mm window head height for opening on the south orientation
2. Change in window head height for opening on the south orientation has a major influence on the performance indicators. This shows by a

I. 44.2% increase in average daylight autonomy from 1800mm at 28% being the lowest to 2700m at 72% as the highest. as seen in fig 4.14.

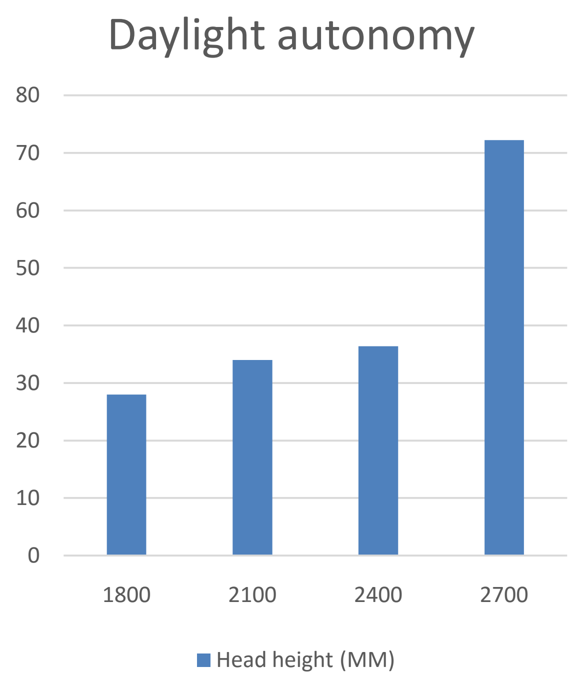


Figure 4.14average Daylight autonomy

Source: Field study, 2016

II. 5.7% decrease in average Useful Daylight Illuminance > 100 from 1800mm at 6.3% being the highest to 2700m at 0.6% as the lowest. as seen in fig 4.15.

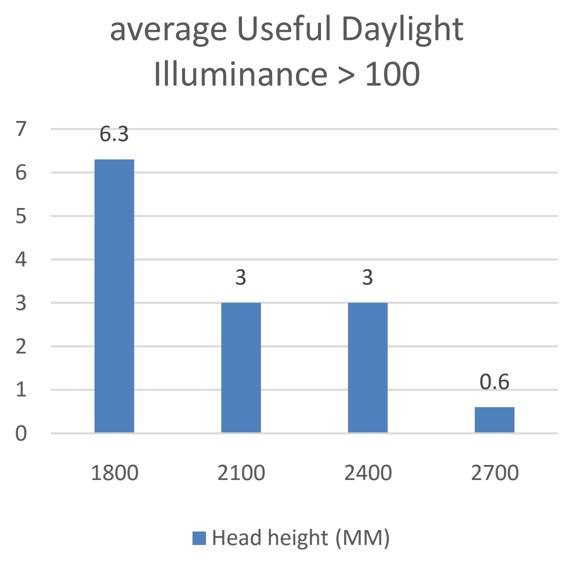


Figure 4.15 average Useful Daylight Illuminance > 100

Source: Field study, 2016

III. 7.1% increase average Useful Daylight Illuminance < 2000 from 1800mm at 0% being the lowest to 2700m at 7.1% as the highest as seen in fig 4.16.

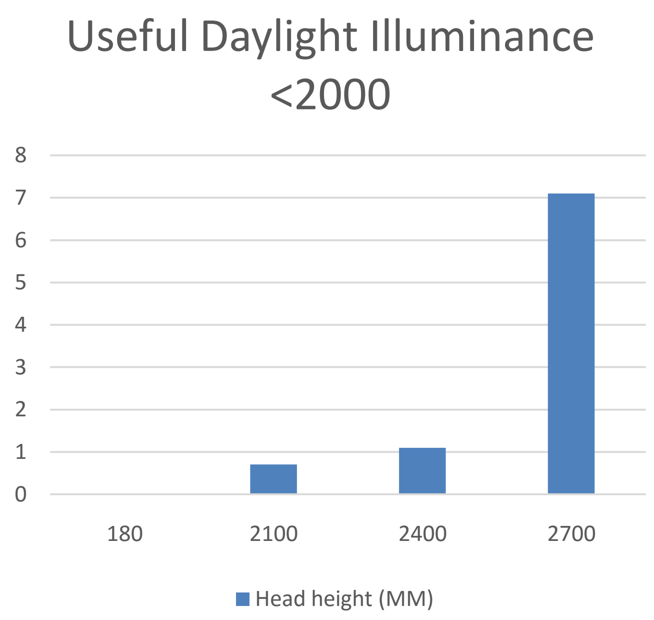


Figure 4.16 average Useful Daylight Illuminance < 2000

Source: Field study, 2016

3. Adequate Useful Daylight Illuminance < 2000 values of 30% over the sensors on the work plane are not noticed in the lecture rooms.

4.5 Summary

This section examines thoroughly the analysis, discussions and findings of the research objectives.First, findings showed thatin case study evaluation, cases of under lighting were observed in three of the lecture rooms especially with respect to the DA values. Inadequate DA values (below 60%) were observed in all the prototype except the Department of Architecture lecture room. Adequate DA values were observed in the Department of Architecture lecture room prototype facing south orientations. It has also been observed that shading devices and tall trees should be avoided on windows at north orientation for the tropical wet and dry region in Nigeria due to its negative effect on the DA values.

Secondly The quantity of daylighting for the two orientations were affected by a change in head height of openings, the effect was higher in the south with a 137% increase in average lux levels from 359.1 lux at 1800mm to the 853.8 lux at 2700mm, a 52% increase in Daylight autonomy from 31% at 1800mm to 83% at 2700mm and a 10.7% decrease in average useful Daylight Illuminance > 100 from 11.2% at 1800mm to 0.5% at 2700mm. On the north there was a 122% increase in average lux levels from 108.3 lux at 1800mm to the 240.5 lux at 2700mm, a 44.2% increase in Daylight autonomy from 28% at 1800mm to 72% at 2700mm and a 5.7% decrease in average useful Daylight Illuminance > 100 from 6.3% at 1800mm to 0.6% at 2700mm.

Finally, for south orientations, 2400mm was found to be the optimum head height of openings for adequate lighting of lecture rooms due to achieving adequate DA values above 60% and remaining within Useful Daylight Illuminance < 2000 at 10.2%. For north orientations, 2700mm was found to be the optimum head height of openings for adequate lighting of lecture rooms due to achieving adequate DA values above 60% and remaining within Useful Daylight Illuminance < 2000 at 7.2.

5.0 DESIGN REPORT

This chapter discusses and analyzes the preliminary design proposal, considerations and requirements for the proposed design, offer a design based solution to the problems identified. I serves as a guideline, which would inform the design of the "Proposed Faculty of Architecture, Ahmadu Bello University Zaria.

5.1 Design Case Study

The purpose of this case study is to survey and analyze the basic principles of design and functionality in existing facility of architecture buildings. These include functional space sizes and position of openings, circulation, facilities, population, fire safety measures, etc. to highlight there merits and improve on their demerits shown in photographs, sketches and tables.

Three cases studies were selected for this research, these include the Department of Architecture Ahmadu Bello University Zaria, Faculty of Architecture –design and built environment, Beirut Arab University Tripoli branch Lebanon, Melbourne school of design, Faculty of Architecture, building and planning. Although it is not a Faculty of Architecture , the Department of Architecture as selected because there are no existing Faculty of Architecture in Nigeria and it the closest in design typology and proximity to the proposed Faculty of Architecture in Ahmadu bello University Zaria

5.1.1 Case-study one -Department of Architecture Ahmadu Bello University Zaria

5.1.1.1 Brief history

The Department of Architecture as seen in Plate xi was established in the 1972 at Ahmadu Bello University, there are currently over 700 students in undergraduate and 400 students in the post-graduate studies, it a has over 40 academic staffs and over 20 non-academic staffs.

PlatexiDepartment of Architecture.

Source: author 2017

5.1.1.2 Facilities

The department consists of four floor, facilities within the department include offices, lecture rooms, design studios, computer laboratories, maintenance office, conference rooms, exhibition spaces, model room and toilet facilities which are detailed in table

Table 5.1 Spaces in the Department of Architecture, Ahmadu Bello University Zaria.

s/n	NAME OF SPACE	NUMBER	AREA (M^2)	TOTAL AREA(M^2)
1	Lecturers offices	29	17.85	517.65
2	Lecture rooms	2	52.02	104.04
3	Post-graduate lecture room	1	33.7	33.7
4	Design studios	2	-	412.07
5	Computer laboratories	2	-	686.45
6	exhibition space	1	51.4	51.4
7	model room	1	46.8	46.8
8	Head of department's office	1	33.7	33.7
9	Secretary	3	17.85	53.55
10	Head of undergraduate	1	17.85	17.85
11	Head of undergraduate	1	17.85	17.85
12	toilet facilities	6	7.6	45.6
	TOTAL			2020.66

Source: author, 2016.

5.1.1.3 Accessibility and circulation

Entrance into the building is from door openings to the north and south of the building, vertical circulation through is done using stairs case which lead to lobbies of 1800mm width confined by offices and lectures rooms on both sides as seen in fig 5.1

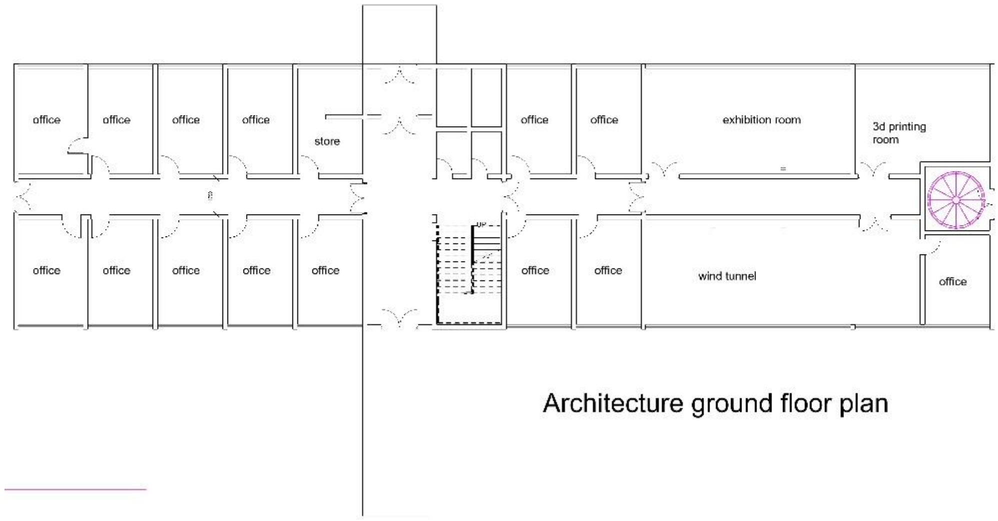


Figure 5.1 ground floor plan of Department of Architecture, A.B.U, Zaria.

Source: author 2017.

5.1.1.4 Structural system and construction material

The department was constructed as a concrete dual cantilever system spanning 5400mm on both sides with all internal sandcrete block walls as non-structural partitions. The staircases within the building also concrete cantilevered structures detached to the building's structural system.

5.1.1.5 Daylight strategies

The Department of Architecture admits daylighting from the north and south orientations using side lighting strategies such as window openings with a typical head height of 2550mm in all spaces except the third floor studios with head heights of 2800mm.there is very little daylighting in the lobbies due to the absence of adequate openings for lighting the lobbies.

5.1.1.6 Shading device

The department has two types of shades devices, these are fixed horizontal louvered shading devices to the south as seen in plate xii and adjustable vertical shading devices along with tall trees to the north as plate xiii.

Platexiihorizontal shading devices and side-openings Department of Architecture, A.B.U, Zaria.

Source: author 2017

Platexiiivertical shading devices and side-openings Department of Architecture, A.B.U.

Source: author 2017

5.1.1.7 Fire safety measures

Fire escapes are located at the end of each lobby on every floor except the ground floor, which is a dead with no access to the outside except through the main entrances as seen in fig 6.1, these fire escapes are locked due to security issues and may therefore be inaccessible during a fire emergency.

Fire extinguishers and fire buckets are located on each floor at the entrance of every lobby. There are no automated fire systems for fire safety.

5.1.2 Case-study two -Melbourne school of design, Faculty of Architecture, building and planning Australia.

5.1.2.1 Brief history

The Faculty of Architecture, building and planning seen in Plate xiv is located in the University of Melbourne, Australia was designed by John Wardle architects and NADAAA in 2014 following a design competition. The design process involved regular briefing meetings, workshops and presentations with various faculty user groups, University committees and reference groups (Archdaily, 2015).

PlatexivThe Faculty of Architecture, building and planning, University of Melbourne.

Source: Archdaily, 2015.

5.1.2.2 Facilities

The Faculty of Architecture, building and planning is made up of seven departments, these includes the Department of Architecture, construction, landscape architecture, property, urban design, urban planning, urban and cultural heritage. The faculty has a total square of 15772.0m^2, it is comprised of six floors (basement and five floors) as seen in fig 5.2. The faculty include functional spaces such as two theatres, workshop, library, two exhibition spaces, café, a series of studios over three levels, a studio hall, and a series of associated academic and professional workspaces (Archdaily, 2015).

Figure 5.2 perspective section of the Faculty of Architecture, building and planning, Melbourne.

Source: Archdaily, 2015.

5.1.2.3 Accessibility and circulation

The faculty building is accessed through the main entrance at the west of the building, which leads to the main circular lobby surrounding the studio hall. Vertical circulation is achieved using stairs and elevators seen in fig 5.3.

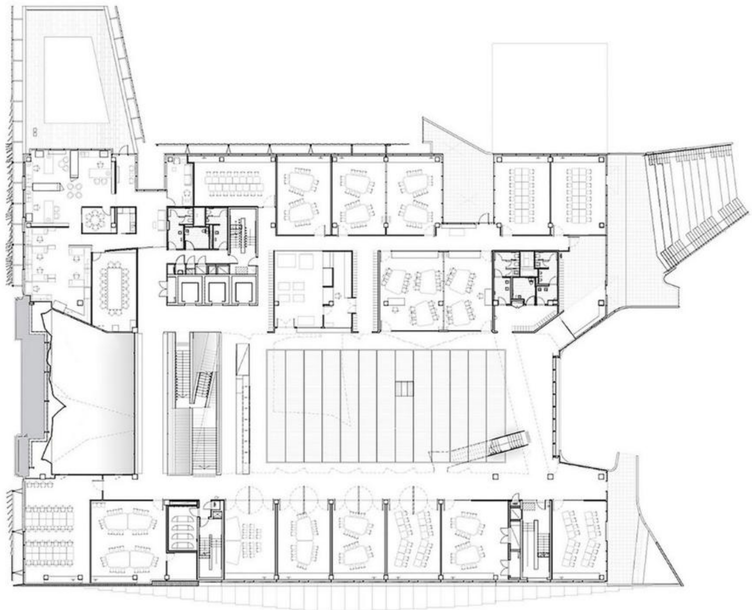
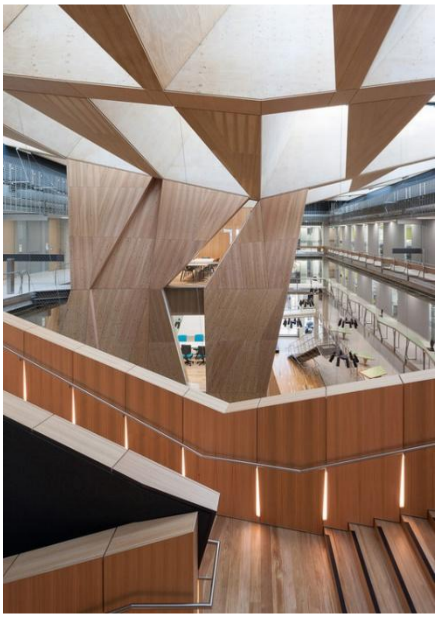


Figure 5.3ground floor plan, Faculty of Architecture Melbourne.

Source: Archdaily, 2015.

5.1.2.4 *Daylight strategies*

The faculty admits daylighting using both side and top lighting strategies. Side lighting is achieved using windows opening on all orientations while top lighting is achieved by a custom coffered timber roof that acts as an atrium which mediates natural daylighting and natural ventilation as seen in plate xv.



Platexvcoffered timber roof over atrium in Faculty of Architecture, building and planning, Melbourne.

Source: Archdaily, 2015.

5.1.2.5 *Shading devices*

The faculty building has vertical and horizontal steel shading devices as in plate xvi on all sides except on the south orientation as seen in plate xvii.

Platexvi Vertical shading devices and side-openings Faculty of Architecture, Melbourne.

Source: Archdaily, 2015.

Platexvii south side of the Faculty of Architecture Melbourne.

Source: Archdaily, 2015.

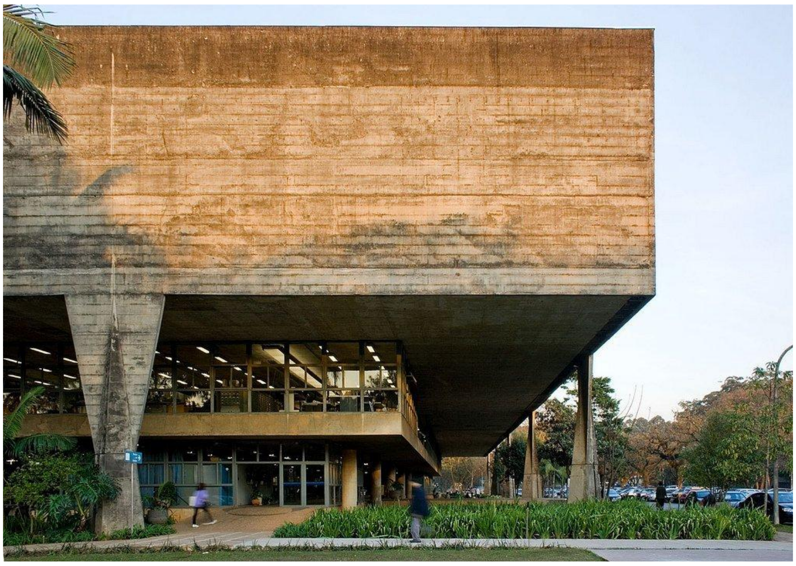
5.1.2.6 Fire safety measures

Active fire safety measures were used in the building such as fire sprinklers, smoke detection systems, fire extinguishers (Archdaily, 2015)

5.1.3 Case-study three –Faculty of Architecture and Urbanism, University of Sao Paulo Brazil

5.1.3.1 Brief history

The faculty seen in Plate xviii was conceived in 1961 by Sao Paulo architects Joao Batista, Vilanova Artigas and Carlos Cascaldi. Together with the architectural movement of the Paulista School, they form part of the most important history of Sao Paulo(Catalina Gutierrez, 2016) .



PlatexviiiFaculty of Architecture, University of Sao Paulo. Source: Catalina Gutierrez, 2016.

5.1.3.2 Facilities

The faculty consists of three departments which are the Department of Architecture history, architecture technology and department of projects. The faculty include functional spaces such as model offices, auditoriums, waiting areas, museum, libraries, conference rooms, toilet facilities, offices, tea room.etc (FAU, 2016).

5.1.3.3 Accessibility and circulation

The project is based on the idea of generating spatial continuity and therefore, its six levels are linked by a system of ramps as seen in fig 5.4in an attempt to give the feeling of a single plane and favour continuous routes, increase the degree of coexistence and interaction among those who use it. The space is open, integrated and avoids divisions as seen in fig . there are no entrance doors or small spaces.

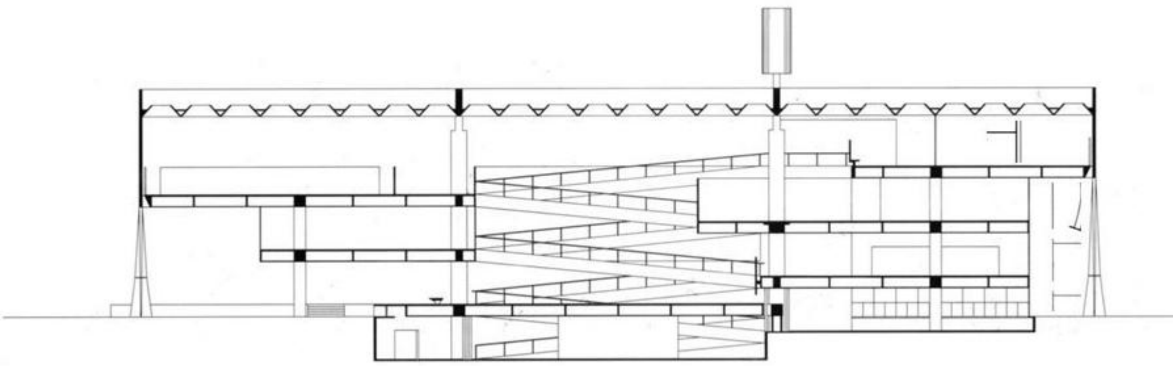


Figure 5.4 section of Faculty of Architecture, University of Sao Paolo.

Source: Catalina Gutierrez, 2016.

5.1.3.4 Structural systems and material

The architects, the founders of the school of architecture and urbanism, adopted reinforced concrete seen in fig as a plastic and constructive language based on the technical possibilities of the material. The roof consist of concrete beams which span the entire building seen 5.4

5.1.3.5 Daylighting strategies

The faculty admits daylighting using both side and top lighting strategies. Side lighting is achieved using windows opening on all orientations on the lower floors seen in Plate xix while top lighting is achieved on higher floors by concrete beams that cross and create spaces for daylight to pass through an light the top floors as seen in plate xx

Platexix Side lighting Faculty of Architecture, University of Sao Paulo.

Source: Catalina Gutierrez, 2016.

PlatexxTop lighting Faculty of Architecture, University of Sao Paulo.

Source: Catalina Gutierrez, 2016

5.1.3.6 Fire safety measures

Passive fire safety measures such as fire escapes and lobbies are not present in the building this may be due to the open style design of the structure, which prevents the buildup of smoke in case of fire and presence of ramps for easy and fast evacuation.

5.1.4 Design case study summary

5.1.4.1 Daylighting strategies

All case studies prioritized daylighting as a source of lighting by including strategies such as windows for side lighting and atriums for top lighting as seen in case studies two and three.

5.1.4.2 Functional space planning

All case studies utilized rectangular shapesfor internal spaces, which maximizes useable spaces and ensures proper placement of standard furniture and services.

5.1.4.3 Circulation

Case studies two and three incorporated circular lobbies around central atrium, which eases reduces traffic within the building, eliminates the need for artificial lighting during the day, improves ventilation and eliminated smoke build up in case of fires.

5.2 Site location

The proposed site is located in the phase II of Ahmadu Bello University, Zaria Kaduna state. Kaduna is a state in Northwest Nigeria covering 46,053 km^2 (17,781 sq.mi)and with the population of more than 6 million.

Ahmadu Bello University (ABU)is a federal government research University located in Zaria, Kaduna State.ABU was founded on October 4, 1962. The University operates two campuses: Samaru (main) and Kongo in Zaria. it covers a land area of 7,000 hectares and encompasses 12 academic faculties, a postgraduate school and 82 academic departments. It has five institutes, six specialized centers, a Division of Agricultural Colleges, demonstration secondary and primary schools, as well as extension and consultancy services. The total student enrollment in the University's degree and sub-degree programs is about 35,000, drawn from every state of Nigeria, from Africa and from the rest of world. There are about 1,400 academic, research staff, and 5,000 support staff.

5.2.1 Proposed site

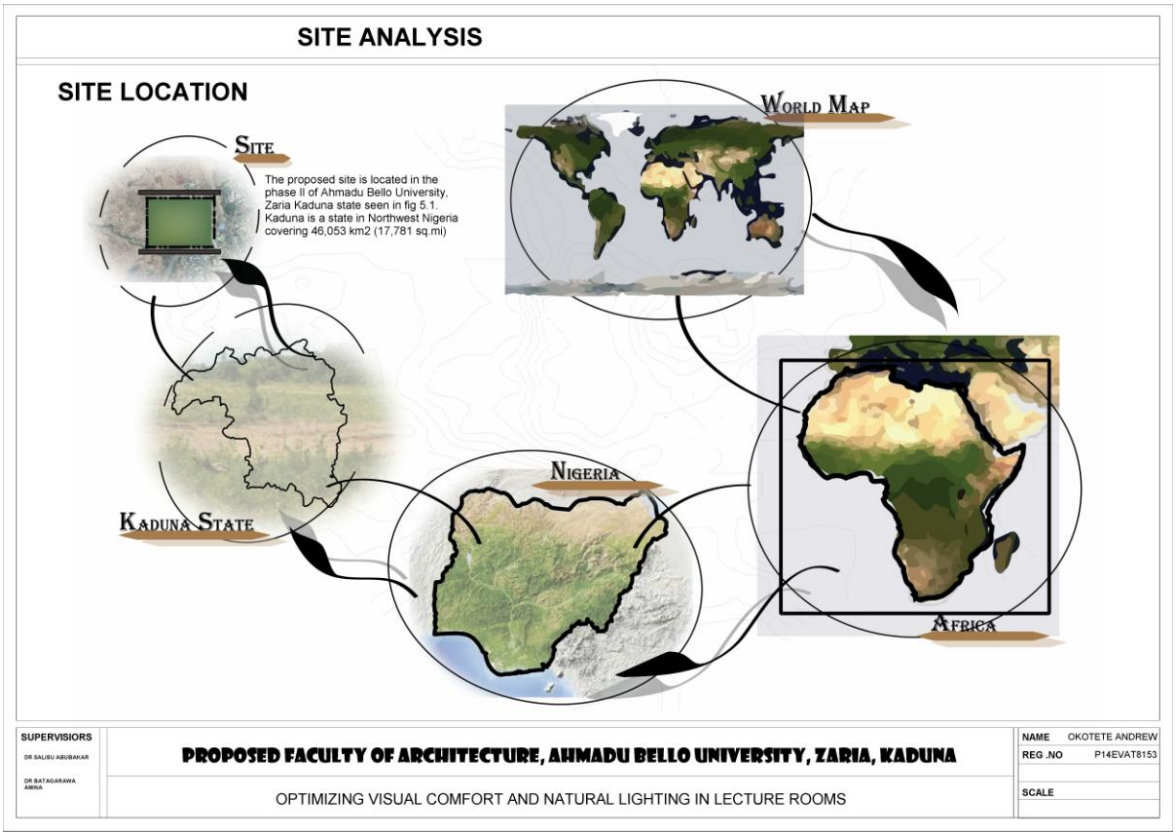


Figure 5.5: Site location of the proposed site.

Source: Author, 2017

5.2.2 Site features

- Total area of site size is 295686.1sq.m and is sparsely vegetated.

- The site has a relative level of 8 meter at the southern part of the site and has a drop in slopes of 1 meter over a distance of about 164 meter forming an angle less than 1 Degree heading North West of the site.
- The site is bordered by good road access in the North, West and south, and a water body on the east.
- Perfectly drained, soils water moves through easily to allow good soil aeration and at the same time sufficient amount is retained for plant growth.
- Service lines are available

5.2.3 Site analysis

A site analysis seen in fig 5.2 involves an in-depth study of the site, it takes into consideration natural and man-made components present about the site, as well as climatic conditions present in and around the site. For a comprehensive site study; a macro and micro site analysis is carried out, which the former takes into consideration environmental factors affecting a larger area than the site, such as a region, state or zone. For this study, the entire Kaduna State is considered for this macro analysis.

5.2.4 Vegetation

The site vegetation is characterized by few grassesand shrubs. This confirms that due to its position close to low land, vegetation is mostly evergreen but not so as we go against the slope gaining altitude.

5.2.5 Rainfall

The rainfall data seen in 5.6 indicates that rainfalls in months of May to October with august having the peak fall. December to March are usually dry. At the peak of rainfall, gutters will be made to efficiently collect the water from roofs and site towards the lowest point of the site.

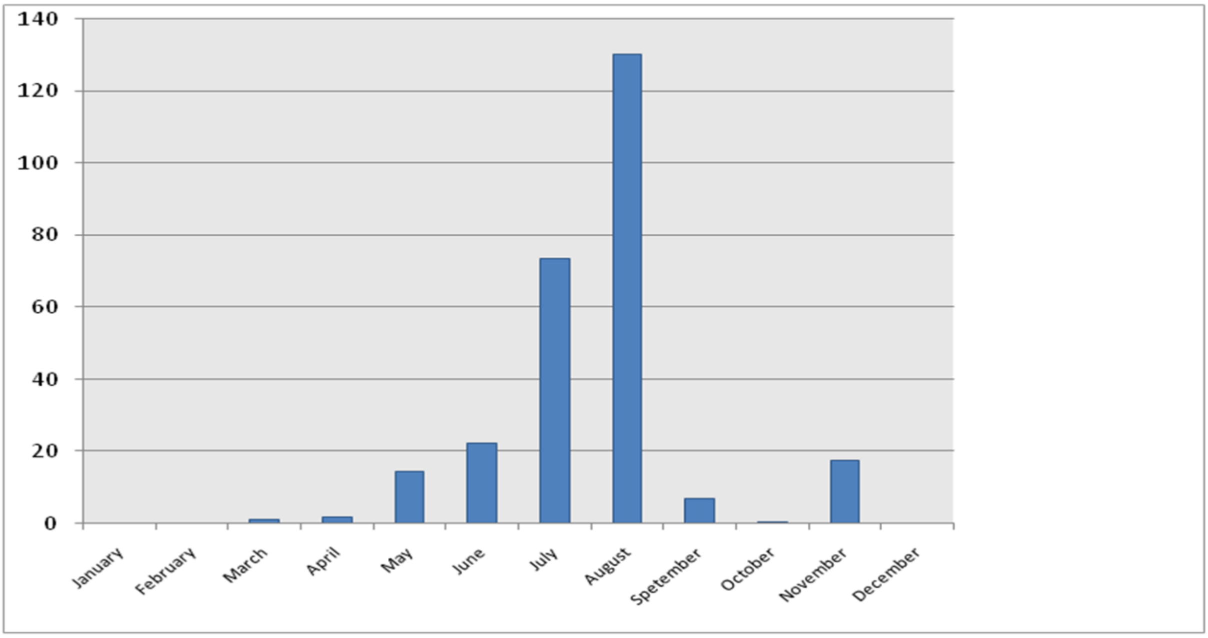


Figure 5.6 average rainfall data for Zaria

5.2.6 Wind

The predominant seasonal winds are the northeast trade wind, which is cold dry and dusty due to its development over the Sahara desert. Most in October to December. Southwest wind is accompanied by moist air. Most in May and July as seen in fig 5.7.

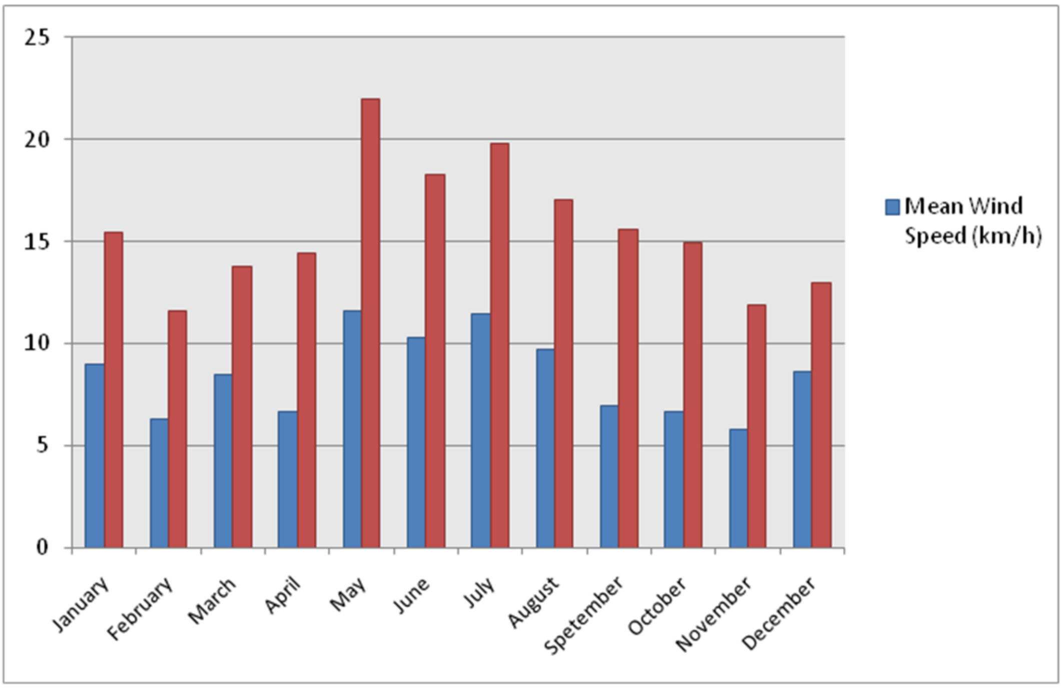


Figure 5.7 mean wind speed for Zaria

5.2.7 Humidity

The relative humidity seen in fig 5.8 for the first quarter of the year is 25% average due to harmattan. The humidity increases during the rainy season up to 77% reaching its peak in august. The relative humidity is high for six months and vapour pressure for four months.

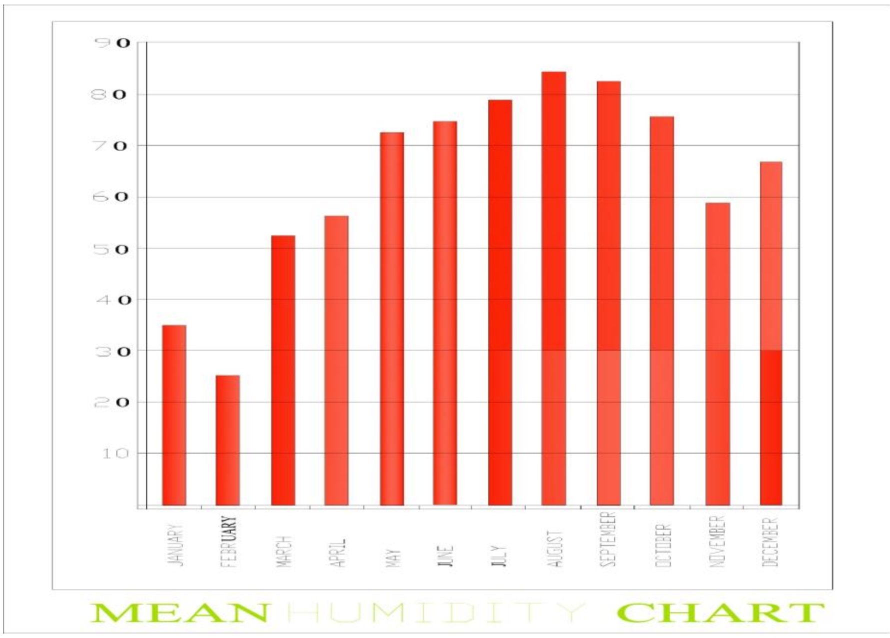


Figure 5.8relative humidity of Zaria

5.3 Brief Development

As Ahmadu Bello University Zaria starts expansion into its second phase of education,academic buildings are to be designed and constructed and among them is the Faculty of Architecture. The proposed faculty comprises of the Department of Architecture, department of interior architecture, department of landscape architecture, department of construction management and other ancillary facilities such theatres, laboratories etc.

With the increasing cost of power, it is necessary that these facilities take advantage of various sustainable criteria in an attempt to achieve a self-sustaining building.

5.4 Design Considerations

The design consideration for this design will be discussed under two consideration, based on data from design case studies and the general design consideration for Faculty of Architecture in Nigeria by the National Universities Commission Benchmark Minimum Academic Standards Nigerian Universities for Environmental Sciences, April 2017 and the design consideration obtained from the research findings.

5.4.1 Resource requirement for teaching and learning in the programme

5.4.1.1 Academic Staff

The academic staff requirement is a staff/student ratio of 1:15. The academic staff should be made up of:

a. Assistant Lecturer

b. Lecturer II

c. Lecturer I

d. Senior Lecturer

e. Reader/Associate Professor

f. Professor

5.4.1.2 Non-Academic Staff

Senior Technical Staff

Considering the technological bias of Architectural education, the ratio of Senior Technical staff is 1:5.

Senior Administrative Staff

The ratio of Senior Administrative staff should be minimal in view of the technical nature of the programme

Junior Staff

An overall ratio of Junior Staff is to be minimal. Two categories of Junior Staff are needed in a School of Architecture: Junior Technical Staff and Junior Non-Technical Staff. The distribution between these two categories should be roughly 1:1.

a) Junior Technical Staff can include:

Computer Graphists, Draughtsmen, Carpenters, Modelists, Masons, Painters, Welders, Photographers, Drivers/Mechanics, Storekeepers, etc.

b) Non-Technical Staff Include:

Clerical officers, Typists, Cleaners, Studio Attendants, Messengers, Gardeners, Library Attendants and so on.

5.4.2 Academic physical spaces

Office accommodation for academic, non-academic staff and students per capital should be based on the following guidelines for each of the departments is shown in table 5.2 below:

Table 5.2Office accommodation for academic, non-academic staff and students.

NO	SPACE	USE	MINIMUM(M2)
1	. Head of Department	Administration	24
2	Professors Office	Academic	24
3	Senior Lecturer	Academic	20
4	Lecturer	Academic	16
5	Asst. Lecturer	Academic	12
6	Senior Technical Staff	Technical	12
7	Senior Administrative Staff	Administration	12
8	Junior Technical Staff	Technical	6
9	Junior Administrative Staff	Administration	4
10	Studio Space	Students	3
11	Lecturer Space	Students	0.5
12	Seminar Space	Students	0.5
13	Seminar Space	Students	2
14	Library	Students	2
15	Social Space	Students	0.5
16	Storage Space	Students	0.5
17	Computer studio	Students	3

SourceNational Universities Commission, 2017

5.4.3 Equipment

Equipment needed for the running of an Architecture programme fall into four categories:

a. Research and teaching equipment

b. Drawing and reprographic equipment
c. office equipment
d. Vehicles.

5.4.3.1 Research and Technical Equipment

Most Schools of Architecture depend on Engineering Faculties for most Material testing equipment for both staff and students. Physics, Building, Survey and Electronic Departments also provide input in Architecture programmes and their equipment and facilities should be available for use(National Universities Commission, 2017). It is important in the area of equipment for teaching research to ascertain that:

a) A school of Architecture is associated with departments, faculties or institutions which can provide the wide range of equipment and facilities required for the proper training of the Architects.
b) Facilities and equipment required for the effective teaching of any particular course on its curriculum are readily available and are used in the education process.

5.4.3.2 Drawing and Reproduction Equipment

Reprographic technology is developing so fast and the rate of obsolescence is so high that any attempt to be specific in this area is fruitless. However, certain categories of equipment can be identified:

a) T-square, Set-square, I-square and Drawing boards; Benchmark and Minimum Academic Standard – Environmental Sciences Page 26
b) Various types of drawing instrument used by staff and students, which are usually owned by them;
c) Plan printing machines, Trimming machines and Light tables for reading drawings etc;

d) Cameras and essential equipment for photographic work should also be considered essential;

e) Slide projectors, Overhead projectors and Epidiascopes can also be included as essential equipment.

f) Computers, Printers, Scanners, UPS, digitizers, Plotters, Multi-media Projector etc.

5.4.3.3 Office Equipment

These include computers, printers, filing cabinets, and photocopiers, duplicating machines, scanning machines and so on.

5.4.3.4 Vehicles

One 40 Seater bus for site visits One car for department use.

5.4.4 Fire escapes

In multi-storey building, it is advisable to place the clearest exit leading out of the building in close proximity to crowded space and free of obstructions. Provisions for the firefighter's lift/stairs should be considered. In this design circular lobbies around courtyards are used the avoid users being trapped in lobbies and avoid area covered in smoke during cases of fire.

5.4.5 Circulation (within and out)

Conscious design efforts were made to separate pedestrian and vehicular traffic. Circulation forms an important aspect of the design and were achieved through the following ways:

- Vehicular traffic: the site is accessible from the north and south ,each department has its own assess point and parking to avoid congestion.

- Pedestrian traffic: Walkways form an integral aspect of the external and internal circulation scheme there 2m wide walkways have been provide. Also, walkways link the building to the parking lots and gardens, outdoor green areas
- Vertical Circulation: the main form of vertical circulation is by means of lifts and stairs to the entrance lobby of the various floors

5.4.6 Design Consideration Based On Findings from Research

This findings form the research have been applied in the design in the following ways.

5.4.6.1 Windows sizes

For window openings to the north the optimumwindow head height is 2700mm while for openings to the south the optimum window head height is 2400m in other for spaces to achieve daylight autonomy

5.4.6.2 Shading devices

Shading devices and trees should be avoided on windows to the north due to its negative effect on daylighting

5.5 Services

The basic amenities provided in the proposed design include:

5.5.1 Water supply

Overhead storage tanks are provide to ensure adequate supply of water. Special underground storage tanks for storing rainwater are also provided for fire fighting and toilets facilities.

5.5.2 Power supply

The main source of power is from the Ahmadu Bello universities power grid. Solar power and inverters are proposed to reduce to reduce dependence on the ABU grid and as backup supplies during power outage.

5.5.3 Ventilation and Air Conditioning

This is achieved passively using courtyard to ensure cross ventilation and open water bodies to cool the air.

6.0 SUMMARY,CONCLUSION AND RECOMMENDATIONS

6.1 Summary

The effects of daylighting in academic buildings such as classrooms,the problems of inadequate methodologies and inadequate consideration of opening sizes based on literature review were discussed in chapter one. the lack of adequate power supply is a major factory which bring about the need for adequate daylight research in the climate region using adequate methologies such as climate based modelling.

Chapter two of this research discusses the requirements for daylight in different spaces, effects of daylighting on students performance, fenestration types, climate regions in Nigeria, previous methods of daylighting assessment, climate based daylight modelling and its significance.

The methodology for this research is explained in chapter three. Climate based daylight modelling was used in this research thought the process of case study of existing lecture rooms and simulation of prototype classrooms with varying window head height and orientationwhere used to gather data for research and data purposes.

Chapter four is a report of results and findings from the case study and daylighting simulation. The research questions are answered, the optimum window head height were found to be 2400mm for south oriented windows and 2700mm for north oriented windows.

Chapter five discusses the location of the proposed site and a thorough analysis of the site and its surrounding features.

The application of the findings is clearly shown in the proposed design, has clearly been discussed in chapter six.

6.2 Conclusions

The study set out to determine the optimum head height of openings along the north and south orientation without shading devices, based on the quality and quantity of daylight in a lecture room while minimizing the probability for glare. Therefore, develop models which can be employed in the design of lecture rooms in the Tropical Wet and Dry Climate of Nigeria.. It evaluated the existing situations using CBDM and identified the influence of climate, orientation,change in window head height and applied same to develop the 'intervention' and 'action' models for the tropical wet and dry region in Nigeria.

The first objective was to evaluate the current daylighting practices in University lecture rooms within the tropical wet and dry region of Nigeria. In case study evaluation, cases of under lighting were observed in three of the lecture rooms especially with respect to the DA values. Inadequate DA values (below 60%) were observed in all the prototype except the Department of Architecture lecture room, adequate DA values were observed in the Department of Architecture lecture room prototype facingsouth orientations. It was also been observed that shading devices and tall trees should be avoided on windows at north orientation for the tropical wet and dry region in Nigeria due to its negative effect on the DA values.

The second objective was to determine the influence of head height of openings on the provision of daylighting in University lecture rooms in the Tropical Wet and Dry Climate of Nigeria. The quantity of daylighting for the two orientations were affected by a change in head height of openings, the effect was higher in the south with a 137% increase in average lux levels from 359.1 lux at 1800mm to the 853.8 lux at 2700mm, a 52% increase in Daylight autonomy from 31% at 1800mm to 83% at 2700mm and a 10.7% decrease in average useful Daylight Illuminance > 100 from 11.2% at 1800mm to 0.5% at 2700mm. On the north there was a 122% increase in average lux levels from 108.3 lux at 1800mm to the 240.5 lux at2700mm, a 44.2% increase in Daylight autonomy from 28% at 1800mm to 72% at 2700mm and a 5.7% decrease in average useful Daylight Illuminance > 100 from 6.3% at 1800mm to 0.6% at 2700mm.

The third objective was to perform daylight simulation to select the optimum head height of openings for adequate lighting of lecture rooms along the north and south axis in a Tropical Wet and Dry Climate. For south orientations, 2400mm was found to be the optimum head height of openings for adequate lighting of lecture rooms due to achieving adequate DA values above 60% and remaining within Useful Daylight Illuminance < 2000 at 10.2%. For north orientations, 2700mm was found to be the optimum head height of openings for adequate lighting of lecture rooms due to achieving adequate DA values above 60% and remaining within Useful Daylight Illuminance < 2000 at 7.2%

6.3 Recommendations

1. Opening at the south orientation should have a head height of 2400mm to ensure maximum levels of daylighting while minimizing risk of glare

2. Opening at the north should have a minimum head height of 2700mm to ensure maximum levels of daylighting while minimizing risk of glare

3. Shading devices and trees should be avoided at opening to north due to its effect of reducing lighting levels

6.4 Areas of Further Research

1. This research was conducted for lecture rooms in tropical wet and dry region of Nigeria only. Further research can conducted on the other climate regions such as the tropical wet region and the semi-arid regions of Nigeria.

6.5 Contributions to Knowledge

Using theoretical sampling theory together with simulation, this study has contributed to the body of knowledge in daylighting through the following:

1. Inadequate DA values (below 60%) together with poor UDI values were observed in all the case study lecture rooms with window head height below 2400m.
2. Shading devices and tall trees should be avoided on windows at north orientation for the tropical wet and dry region in Nigeria due to its negative effect on the DA values.
3. For south orientations, 2400mm was found to be the optimum head height of openings for adequate lighting of lecture rooms due to achieving adequate DA values above 60% and remaining within Useful Daylight Illuminance < 2000 at 10.2%. For north orientations, 2700mm was found to be the optimum head height of openings for adequate lighting of lecture rooms due to achieving adequate DA values above 60% and remaining within Useful Daylight Illuminance < 2000 at 7.2%

REFERENCES

Advanced Lighting Guidelines. (2016). Avoid Glare. *advanced lighting guidelines*.

Ander, G. (1995). *Daylighting performance and design.* New York : Van Nostrand Reinhold. .

Antonutto, G. (2013). new school of thought. *Newsletter the society of light and lighting vol 5 issue 6.nov/dec.*

Archdaily. (2015, april 23). *melbourne-school-of-design-university-of-melbourne-john-wardle-architects-nadaaa*. Retrieved from Archdaily: https://www.archdaily.com/622708/melbourne-school-of-design-university-of-melbourne-john-wardle-architects-nadaaa

Architects & Building Branch. (1999). *Lighting Designs For Schools*. norwich: Her Majesty's Stationery Office.

Architects, M. (2015). *clerestory- architects glossory*. Retrieved july 8, 2016, from m.gerwing architects: http://mgerwingarch.com/2010/12/12/clerestory-architects-glossary/

Architectural Energy Corporation. (2006). *Daylighting metric development using daylight autonomy calculations in the sensor placement optimisation tool.* Technical report prepared for CHPS. Retrieved from http://www.archenergy.com/SPOT .

Aslila, A. K., Lokman, H. I., & Narimah, K. (2015). *Optimization of daylighting system by using light pipe system in a building.* Padang: The 2nd International Conference on Construction and Building Engineering (ICONBUILD 2015), .

Autodesk Sustainabilty Workshop. (2015). *Apertures for Daylighting*. Retrieved 7 7, 2016, from autodesk: http://sustainabilityworkshop.autodesk.com/buildings/apertures-daylighting

Babylon. (2015). *sawtooth roof translation*. Retrieved july 8, 2016, from babylon: http://translation.babylon-software.com/saw+tooth+roof/

Ball State University. (2016). *Climate and Daylight*. Retrieved july 14, 2016, from Ball State University: http://cms.bsu.edu/academics/centersandinstitutes/ceres/mirrorbox/backgroundpages/background/climateanddaylight

Bernfart, E. (2014, may). *solar tube lighting*. Retrieved july 13, 2016, from prezi: https://prezi.com/eji9b9d4fmrq/solar-tube-lighting/

Bokel , R. M. (2007). The Effect Of Window Position And Window Size On The Energy Demand For Heating, Cooling And Electric Lighting. *Building Simulation* . Delft: Delft Technical University.

Brawne. (2003). Architectural thought: the design process and the expectant eye. In Brawne, *Architectural thought: the design process and the expectant eye.* oxford: architectural press.

Bristolite Team. (2014, june 13). *Bristolite daylight system*. Retrieved may 5, 2016, from Bristolite: http://www.bristolite.com/blog/natural-light-and-education-the-benefits-of-daylighting-for-schools-and-colleges/

Build. (2016). *sawtooth roof*. Retrieved july 8, 2016, from http://www.build.com.au/sawtooth-roof

Catalina Gutierrez. (2016, November 12). *faculty-of-architecture-and-urbanism-university-of-sao-paulo-fau-usp-joao-vilanova-artigas-and-carlos-cascaldi*. Retrieved from archdaily: https://www.archdaily.com/799088/ad-classics-faculty-of-architecture-and-urbanism-university-of-sao-paulo-fau-usp-joao-vilanova-artigas-and-carlos-cascaldi

Clear Comfortable Low Energy Architecture. (2016). *daylight factor*. Retrieved july 15, 2016, from http://www.new-learn.info/packages/clear/visual/daylight/analysis/hand/daylight_factor.html

Cole, R., Connery, K., Rousseau, D., & Threaker, I. (1999). *green building design & construction guidelines.* santa monica.

Cundall Johnston and partners. (2015). *Baseline Design – Daylight Strategy.* Baseline Design – Daylight Strategy.

Dahlan, A. S., & Mahmoud, A. E. (2015). The Impact of Day Lighting in Classrooms on Students' Performance. *International Journal of Soft Computing and Engineering*, 9.

Dahlin, E. (2016). *The Rebuilding and Restoration of America: Get What You Want Not What You're Given.* newyork: Dorrance Publishing.

Danny, H. W., Tang, H. L., Eric , W. M., & Tariq, M. (2009). Classification of CIE standard skies using probabilistic neural networks. *INTERNATIONAL JOURNAL OF CLIMATOLOGY*, 1.

Dean, E. (2004). *Daylighting Design in Libraries.* California: Libris Design Project .

Designing buildings wiki. (2017, december 4). *window parts*. Retrieved from Designing buildings wiki: Designing buildings wiki

Dr David Suzuki Public School. (2016). *Light Shelves and Solera*. Retrieved july 13, 2016, from Dr. David Suzuki Public School: http://www.suzukipublicschool.ca/building-features/light/light-shelves-and-solera.html

East Renfrewshire Council Planning Service. (2012, DECEMBER). Supplementary Planning Guidance: Daylight and Sunlight Design Guide. *Daylight and Sunlight Design Guide*, p. 1.

Egan, M. D., & Olgyay, V. (2002). *Architectural Lighting.* New York: McGraw-Hill.

Egeh, E., & Okoloye, C. (2010). *Tropical Climatology.* LAGOS: NATIONAL OPEN UNIVERSITY OF NIGERIA.

Energydesignresourse. (2014). *skylighting design guideline.* california: Heschong Mahone Group, Inc.

Erwine, B., & Heschong, L. (2002). Lighting for Learning. Paper presented at the Lightfair International Seminar Preview.

Expatarrivals. (2016). *Weather in Nigeria*. Retrieved july 14, 2016, from expatarrivals: http://www.expatarrivals.com/nigeria/weather-in-nigeria

FAU. (2016). *A FAUUSAP*. Retrieved from FAU: http://www.fau.usp.br/a-fau/

Femi, A. (2015, november 10). *vangard*. Retrieved june 20, 2016, from vangard: http://www.vanguardngr.com/2015/11/75-nigerians-lack-access-to-regular-power/

Fisher, A. (1992). Tolerances in lighting design. *Proceedings of the CIE seminar on computer programs for light and lighting.* Vienna, Austria: CIE.

Gabe Cross. (2010, January 24). *Daylighting From East and West facing windows*. Retrieved from Green Cross: http://gabe-greencross.blogspot.com.ng/2010/01/daylighting-from-east-and-west-facing.html?m=1

Gerritsen, B. (2016, august). *VisionAware*. Retrieved august 24, 2016, from Lighting and Glare: http://www.visionaware.org/info/everyday-living/home-modification-/lighting-and-glare/123

Grant, M. (2015). 16 - Natural Lighting. *16293: Environmental Engineering Science 1*. Glasgow: University of Strathclyde.

Gut, P., & Dieter, A. (1993). *Climate Responsive Building: Appropriate Building Construction in Tropical and Subtropical Regions.* SKAT.

Heerwagen, D. (2004). *Passive and active environmental controls.* New York: McGraw-Hill.

Heschong Mahone Group. (1999). *"Daylighting in Schools—An Investigation into the Relationship between Daylighting and Human Performance.* Pacific Gas & Electric Company and funded by California utility customers.

Hirning, M. G. (2010). Theoretical comparison of innovative window daylighting devices for a sub-tropical climate using radiance. *Institute for Energy, Congress Centre Messe Frankfurt*.

IEA TASK 21. (2000). *Daylight in buildings: A source book on daylighting systems and components.* Berkeley: Lawrence Berkeley National Laboratory.

IES Daylight Metrics Committee. (2012). *Approved method: IES spatial daylight autonomy (sDA) and annual sunlight exposure (ASE).* new york: Illuminating Engineering Society of North America.

IESNA. (2000). *The IESNA lighting handbook, reference & application.* New York: IESNA.

innovative design. (2004). *guide for daylighting schools.* daylight dividends: lighting research center rensselaer polytechnic institute.

Italcementi. (2015). *Light-trasmitting panels.* italy: italcementigroup. Retrieved july 13, 2016, from Italcementi.

Jakubiec, J. A., & Reinhart, C. F. (2012). The ‘adaptive zone’–A concept for assessing discomfort glare throughout daylit spaces. *Lighting Research and Technology , 44(2)*, 149-170.

Jeong, T. K., & Gon, K. (2010). Overview and new developments in optical daylighting systems for building a healthy indoor environment. *Building and Environment*, 256-269 .

Kennelly, P. J. (2014). General Sky Models for Illuminating Terrains. *INTERNATIONAL JOURNAL OF GEOGRAPHICAL INFORMATION SCIENCE*.

Kensek, K., & Suk , J. Y. (2011). Daylight Factor (overcast sky) versus Daylight Availability (clear sky) in Computer-based Daylighting Simulations. *Journal of Creative Sustainable Architecture & Built Environment, CSABE Vol. 1, November, 2011*.

Khalid, A. A. (1996). *Prediction of interior daylight.* Masdar: Masdar Institute of Science and Technology.

Kjeld, J., & Richard, W. (2010). Daylight in Building. *ECBCS Annex 29 / SHC Task 21*.

Kleindienst, S., Bodart, M., & Andersen, M. (2013). Graphical Representation of Climate-Based Daylight Performance to Support Architectural Design. *LEUKOS The Journal of the Illuminating Engineering Society of North America*.

Kota , S. (2007). *Historical Survey of Daylighting Calculations Methods and Their Use in Energy Performance Simulations.* texas: Department of Architecture, Texas A&M University College Station, Texas.

Kroelinger, M. D. (2005). Daylight in Buildings . *Implications VOL 3 ISSUE 3*.

Ladan, G., Wayne, P., & Soolyeon, C. (2012). *Design Optimization of Daylight Roofing Systems: Roof Monitors with Glazing Facing in Two Opposite Directions.* North Carolina: North Carolina State University.

Liberman, J. (1991). *Light medicine of the future.* mexico: Bear & Company Publishing.

Lighting Research Center. (2006). *Arch Studio: Daylight Characteristics and Design.* Troy: Rensselaer Polytechnic Institute.

Liquidsearch. (2016). *Köppen Climate Classification*. Retrieved july 14, 2016, from liquidsearch: http://www.liquisearch.com/köppen_climate_classification

Low Energy House. (2016). *Sun Tube Lights*. Retrieved july 13, 2016, from Low Energy House: http://www.lowenergyhouse.com/sun-tube-lights.html

lutron. (2013). *Daylight Autonomy made possible by Lutron.* Coscia Moos Architecture.

Magnus, H., & Magnus, O. (2012). *daylight and thermal comfort in a residential passive house.* Göteborg: chalmbers university of technology.

Mahdavi, A., Rao, S. P., & Inangda, N. (2013). Parametric Studies on Window-To-Wall Ratio for Day lighting Optimisation in High-Rise Office Buildings in Kuala Lumpur, Malaysia. *5 Journal of Design and Built Environment Vol.12 June*.

Mandinfinity. (2017). *Parts of a window*. Retrieved from Mandinfinity.com: http://mandinfinity.com/parts-of-a-window/

Marchese, P. (2006). S213 - Introduction to Ecotect Energy Design . *microdesk*.

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

Mardaljevic, J. (2006). Examples of Climate-Based Daylight Modelling. *CIBSE National Conference 2006: Engineering the Future 21-22 March 2006* (p. 2). London: CIBSE National Conference.

Mardaljevic, J., Heschong, L., && Lee, E. (2009). Daylight metrics and energy savings. *Journal of Lighting Research and Technology 41*, 261-283.

Mardeljevic, j., Brembilla, E., & Drosou, n. (2016). Real-world validation of climate-based daylight metrics: mission impossible. *Presented at: CIBSE Technical Symposium 2016, 14th-15th April 2016, HeriotWatt University,* (pp. 1-12). Edinburgh: Chartered Institute of Building Services Engineers (CIBSE.

Mark, K., James, R., & Christina, S. (2012). *Lighting Design Basics.* John Wiley & sons.

Mirrahim, S., Nik Ibrahim, N., & Surat , M. (n.d.). Effect of daylighting on student health and performance. *Computational Methods in Science and Engineering*. Retrieved from http://www.wseas.us/e-library/conferences/2013/Malaysia/MACMESE/MACMESE-20.pdf

Nabil, A., & Mardaljevic, J. (2005). Useful daylight illuminance: A new paradigm to access daylight in buildings. *Journal of Lighting Research and Technology*.

National Universities Commission. (2017). *Benchmark Minimum Academic Standards Nigerian Universities for Environmental Sciences.* Abuja: NUC.

Nigeriaplaces. (2016). *Delta State, Nigeria*. Retrieved july 14, 2016, from nigeria places: http://nigeriaplaces.com/asaba/delta-state-nigeria/

Nilson, A. M. (2012). *Digital systems: Development of techniques for optical characterization and performance evaluation.* Retrieved from http://urn.kb.se/resolve

Ogunsote, O. O., & Ogunsote , P. B. (2002). Defining Climatic Zones for Architectural Design in Nigeria: A Systematic Delineation. *Journal of Environmental Technology 1(2) 2002 1 - 14*.

Oluwatosin, A. O. (2014). *Beauty and Fashion Centre Abuja: Exploring The Use of Daylight to Enhance Visual Comfort.* zaria: AHMADU BELLO UNIVERSITY, ZARIA.

Oyetunmibi, O. (2015). *Applied Climatology:Shading Devices.* akure: DEPARTMENT OF ARCHITECTURE,.

Padma, B., Johnson, D., Afzal , B. P., & Prasanthi, K. (2013). Optical Fibres in the Modeling of Translucent Concrete Blocks. *International Journal of Engineering Research and Applications (IJERA)Vol. 3, Issue 3, May-Jun 2013*, 13.

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). *updated world map of the Koppen-Geiger climate classification.* victoria: the university of melbourne,australia.

Philip, D. (2004). Day lighting :Natural Light in Architecture. In D. philip, *Day lighting :Natural Light in Architecture* (p. 18). italy: Architectural Press.

Plympton, P., Susan, C., & Kyra, E. (2000). Daylighting in Schools: Improving Student Performance and Health at A Price Schools Can Afford. *American Solar Energy Society Conference,* (p. 1). Wisconsin.

Roaf, S., Horsley, A., & Gupta, R. (2004). *Closing the loop: Bechmarks for sustainable buildings.* London: RIBA Enterprises Ltd.

Salisu, A. S. (2015). *Optimising Fenestration For Daylight Provision In The Architecture Of Secondary Schools In Nigeria Using Climate-Based Daylight Modelling.* zaria: Ahmadu bello university ,zaria.

Samani, S. A., & Sanaz, A. S. (2012). *The Impact of Indoor Lighting on Students' Learning Performance in Learning Environments: A knowledge internalization perspective.* Malaysia : University Technology Malaysia (UTM) MalaysiA.

Shaily, R., & Vipul, S. (2011). *Design Guide: Horizontal Shading devices and Light Shelves.*

Shuttleworth, M. (2008, april 1). *case study research design*. Retrieved from explorable: http://explorable.com/case-study-research-design

Siân, K., Magali, B., & Marilyne, A. (2007). *Graphical Representation of Climate-Based Daylight Performance to Support Architectural Design* . Massachusetts: Massachusetts Institute of Technology.

Skylight Council. (2011, march). Daylighting Basics. *Daylighting and Energy Savings*, p. 1.

Society of Light and Lighting, SLL. (2011). *SLL lighting guide 5: Lighting for education.* london: CIBSE.

Supriya, G., & Kavish, M. (n.d.). *daylighting in Schools and related case-studies* . arizona: arizona state university.

Tao. (2010). *daylighting:lighting design*. Retrieved july 8, 2016, from tao for energy codes: http://www.claritylearningsolutions.com/demos/ERS/eed-light-access.html

Thermie Programme Action. (n.d.). Daylighting in Buildings. *The European Commission Directorate-General for Energy (DGXVII).* Retrieved from http://erg.ucd.ie/UCDERG/pdfs/mb_daylighting_in_buildings.pdf

Tukur, R. B. (2013). *Harnessing daylight potentials as a tool for visual and thermal comfort in residential buildings.* Nottingham: University of Nottingham. .

U.S. Library of Congress. (2015). *Climate*. Retrieved july 24, 2016, from countrystudies: http://countrystudies.us/nigeria/33.htm

Ubbelohde, M. S., & Humann, C. (1998). Comparative evaluation of four daylighting software programs. *Proceedings of ACEE Summer Study on Energy Efficiency in Buildings*.

Urban design system. (2016). *Window screening*. Retrieved uly 13, 2016, from Urban Design Systems: http://www.urbandesignsystems.com.au/window-screening.html

Verges, M. (2008). Light in architecture. In M. Verges, *Light in architecture.*

Ward , G. J. (1994). The RADIANCE Lighting Simulation and Rendering System. *Computer Graphics (Proceedings of '94 SIGGRAPH conference)*.

Xtralite. (2012). *Design Principles.* Xtralite.

APPENDICES

Appendix 1Information for case study

1	Researchers information				
name	Okotete andrew				
Phone and email	+234-7067861830 , andrewokotete@gmail.com				
2	Information of case study lecture rooms				
Location:	PG-lecture room ,department of architecture ,Ahmadu bello University Zaria	Lecture hall 3,Department of Quantity Surveying ,Ahmadu bello University Zaria	300 level lecture room ,Department of Building ,Ahmadu bello University Zaria	Final year lecture room ,Department of Urban and Regional Planning ,Ahmadu bello University Zaria	300 level lecture room ,department of geomatics ,Ahmadu bello University Zaria
Fenestration Type	glazing	glazing	glazing	glazing	glazing
Electric lighting	off	off	off	off	off
Internal length, width & height					
Window Head Height	2500mm	2100mm	2500mm	2550mm	2100mm
Were the rooms occupied during measurements	no	no	no	no	no
Position of openings	south	North and south	south	north	East and west
Activity period	5 days a week, from 8:00am to 5:00pm	5 days a week, from 8:00am to 5:00pm	5 days a week, from 8:00am to 5:00pm	5 days a week, from 8:00am to 5:00pm	5 days a week, from 8:00am to 5:00pm

Appendix 2Useful daylight Illuminance 100 -2000 of the north oriented sample lecture room

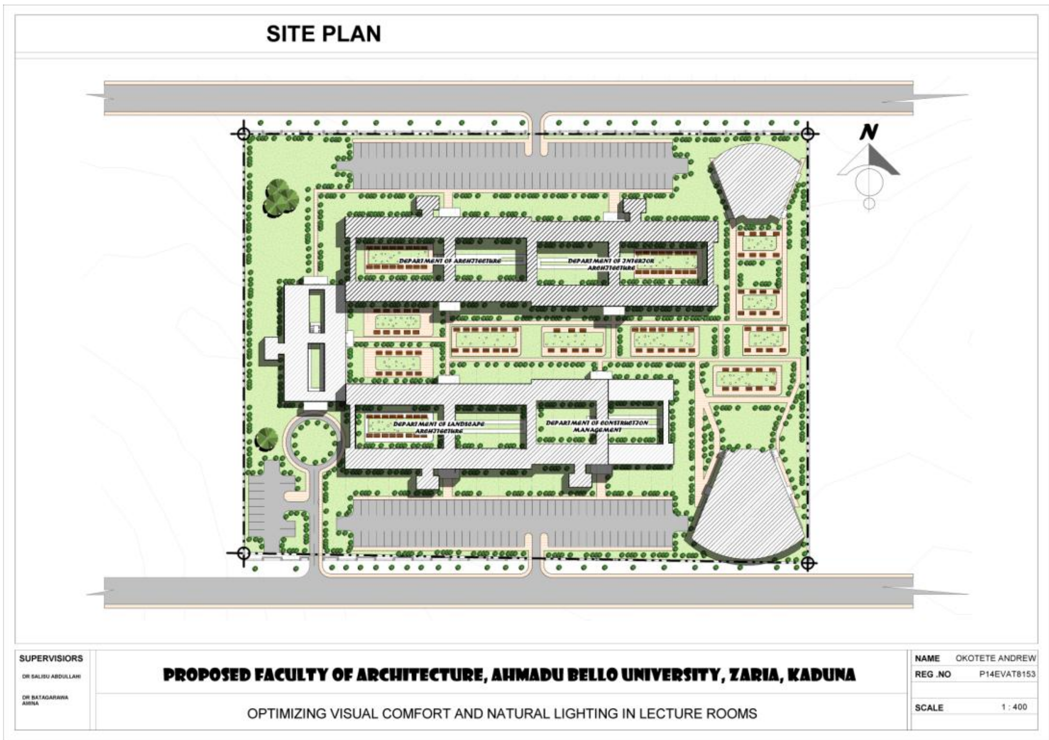
Head height(m)	**s/p 1**	**s/p 2**	**s/p 3**	**s/p 4**	**s/p 5**	**s/p 6**	**s/p 7**	**s/p 8**	**s/p 9**	**avg**
1800	99.00	94.00	85.00	99.00	97.00	89.00	99.00	95.00	85.00	93.6
2100	99.00	98.00	92.00	97.00	99.00	94.00	95.00	98.00	94.00	96.2
2400	99.00	98.00	92.00	97.00	99.00	94.00	95.00	99.00	94.00	96.3
2700	81.00	99.00	99.00	75.00	99.00	99.00	79.00	99.00	98.00	92

Appendix 3Useful daylight Illuminance 100 -2000 of the south oriented sample lecture room

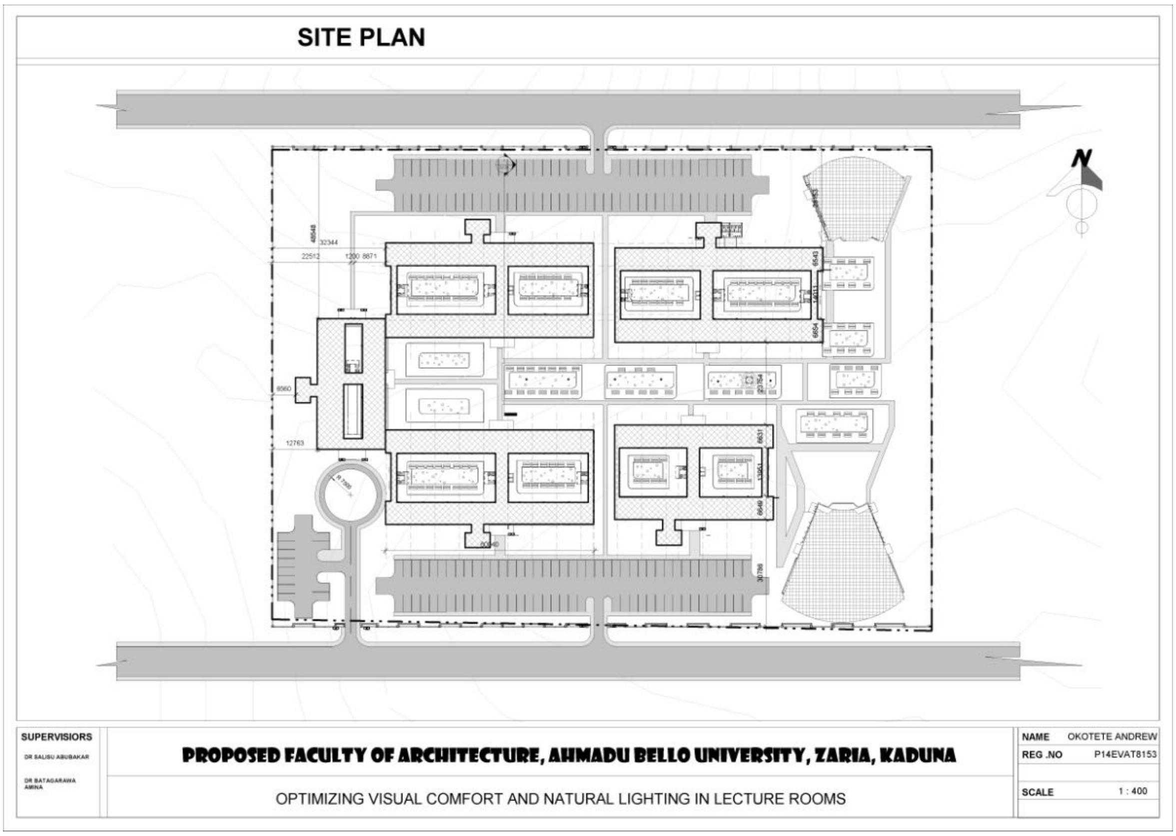
Head height(mm)	s/p 1	s/p 2	s/p 3	s/p 4	s/p 5	s/p 6	s/p 7	s/p 8	s/p 9	avg
1800	81.00	95.00	99.00	89.00	96.00	96.00	90.00	96.00	96.00	93.1
2100	94.00	98.00	94.00	98.00	99.00	84.00	98.00	98.00	95.00	95.3
2400	98.00	99.00	75.00	98.00	99.00	62.00	98.00	99.00	69.00	88.6
2700	98.00	99.00	55.00	99.00	99.00	39.00	99.00	96.00	63.00	83

Table 4.15, illustrates a relationship between a windows head height and Useful Daylight Illuminance 100 -2000 on the south oriented sample.

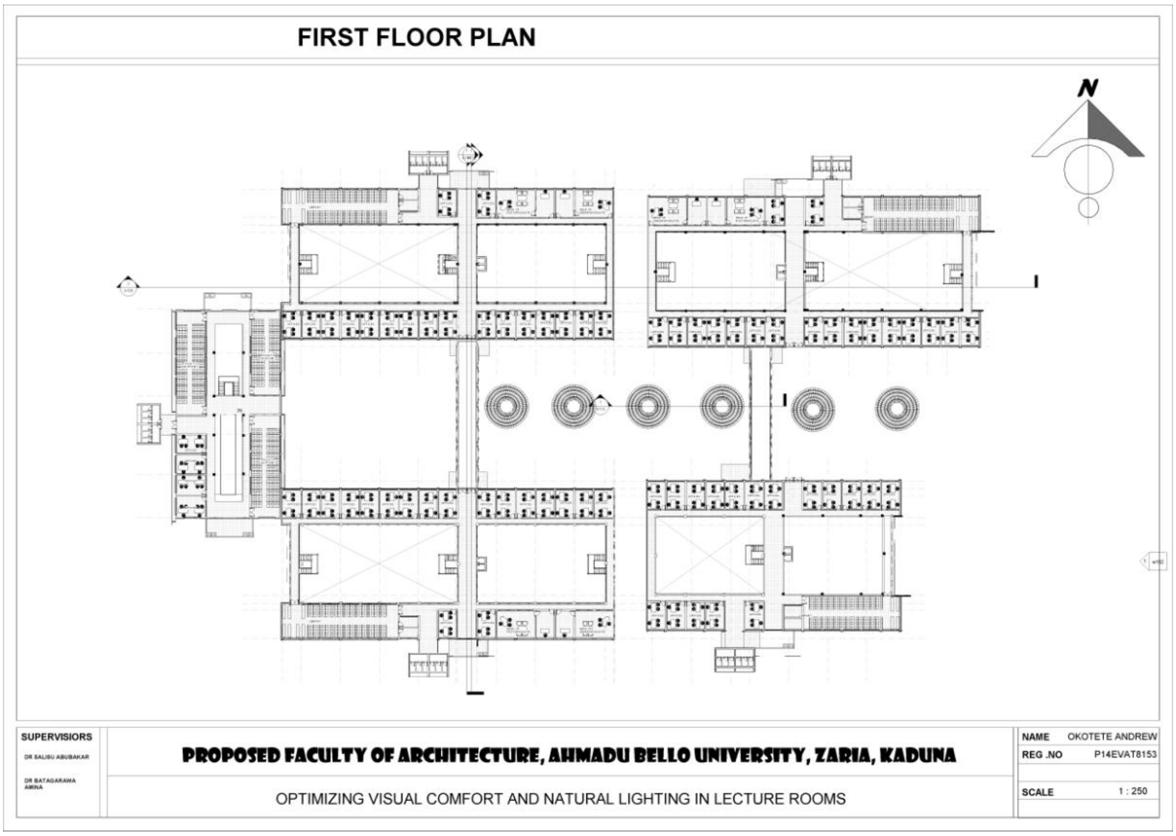
Appendix 4 site



Appendix 5 Ground floor plan



Appendix 6 First floor plan



Appendix 7 Elevation