OPTIMIZATION OF DAYLIGHTING USING LIGHT-PIPE DEVICE IN THE DESIGN OF ACADEMIC LIBRARY FOR SUMMIT UNIVERSITY, OFFA

BY

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

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DEPARTMENT OF ARCHITECTURE,

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ZARIA, NIGERIA

FEBRUARY, 2020

DECLARATION

I declare that the work in this dissertation entitled Optimization of Daylighting Using Light-Pipe Device in The Design of Academic Library for Summit University, Offa has been performed by me in the Department of Architecture. Under the supervision of Dr. R.B. Tukur and Prof. S.N. Oluigbo. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other Institution.

Abdulbasit, ADEGBOYE

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Name of Student	Signature	Date

CERTIFICATION

This dissertation entitled "OPTIMIZATION OF DAYLIGHTING USING LIGHT PIPE DEVICE IN THE DESIGN OF ACADEMIC LIBRARY FOR SUMMIT UNIVERSITY, OFFA." by Abdulbasit ADEGBOYE meets the regulations governing the award of the degree of Masters of Science in Architecture of the Ahmadu Bello University, and is approved for its' contribution to knowledge and literary presentation.

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Dean, School of Postgraduate Studies Signature Date

DEDICATION

Dedicated to the unquestionable Almighty Allah who alone all glory and honour is ascribed for being my strength in times of my weakness and joy in times of sorrows. To my Parents Mr and Mrs AbdullateefOlatunbosunAdegboye.

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ABSTRACT

Daylighting is a copious natural source of light from the Sun. It propagates through the walls or roof apertures into the building for visual task in architectural space. In tropical regions such as Nigeria where there is abundance in sunlight with massive untapped potential, several strategies to admit daylight are set in place which in-turn blocks the daylight penetration. Consequently, it affects the minimum standard daylight requirement for visual comfort in the conventional reading areas of the library which are usually deeply planned. Therefore, the research examines light-pipe device configuration for optimum daylighting and illuminance in the design of conventional reading areas of academic library, in tropical wet-dry climatic zone of Nigeria. The study uses case study and quasi experimental approach to test for daylight performance of light pipe. Moreover, literature review helps establishing the standard minimum amount of daylight requirement together with the base model area in conventional reading area of academic library, while local case study reveals the headroom for the base model. The test for efficiency of light pipes in a base model box (3m x 3m x 3.3m) was modelled and exported from Revit®to Ecotect® Radiance® Daysim® and the illumination received in the box was tested. The simulation test for effect of both diameter and length of light pipe, shows that light pipe with aspect ratio of 1/2 give optimum performance for daylight requirement in conventional reading area within wet and dry tropical climate of Nigeria. Daylight Autonomy of 78%was achieved; 18% addition compare to 60% minimum standard Daylight Autonomy established from literatures and Useful daylight illuminance of 98%. This indicates that if attention is paid to aspect ratio as parameters during the design of a Library conventional reading area, it would go a long way in ensuring that visual comfort for the users. It

recommended that the aspect ratio 1/2 should adhered to as it aids in visual comfort and reducing energy consumption.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to Study

Daylighting is an abundant natural source of light from the Sun. It propagates through the walls or roof apertures into the building for visual task in architectural space. In tropical regions such as Nigeria, there is abundance of sunlight with massive untapped potential. The use of daylight for indoor task illumination has been widely encouraged, so it is a task for the architect, to balance the different environmental parameters with the design variables (Tukur, 2013). In 2014, the world consumed approximately 412 billion kWh of energy just for lighting. This value has steadily increased from the late nineties and is expected to increase to 4250 TWh by 2030. Using natural light instead of artificial light not only reduces lighting costs for the residential, commercial, and industrial sectors but also has additional financial, physiological, and psychological benefits(Brain, 2015). Also, Environmental degradation emanates as a result of the CO_2 generated through the use of fossil fuel for lighting, cooling and heating building. Whereas, Sustainable environment has become the order of the day as a result of man's inability to balance between its activity and that of nature. A journey in such environment without fully considering the importance of daylight would be described as putting the cart before the horse (Ugochukwu, 2011). Razon (2017) opined that daylight is the combination of direct sunlight and diffuse sky light. Sunlight contain the full Spectrum light, the light source that most closely matches human visual response. It requests less light to perform a task than in the case of electric lighting since the human eye is adapted to daylight.Daylighting Concept in a Building like library is important to enhance user's activities and satisfaction. Designing reading area in a library is important to the mood, motivation and performance of individual because interior design of a room plays an important role on human mood and social behaviour. Lighting, as a control architectural tool, gives important influences on users' perception behaviour and visual comfort in libraries (Hasirci, 2011). Studies agreed that lighting is a major factor in determining how people experience the internal environment, buildings, as well as their respondent rate towards achieving certain tasks. Studies further show that daylighting plays a vital role in health and mental development (Tukur, 2013). Therefore, Architects while designing should take proper advantage of daylighting.

The library is atype of building with huge lighting expense (Johannes & Rosalie, n.d). Thus, Researchers have proven that the integration of solar shading devices into buildings has many significant advantages in terms of reducing energy consumption and improving daylight quality (Fenk & Hardi, 2016). In order to avoid excessive solar gains and glare issues to the occupants, it is necessary to adopt suitable solutions that limit the incoming solar radiation, such as highly reflective coatings or movable shading devices. However, such devices must be accurately selected, according to the building location and to the exposure of the glazed façades, while also taking into account possible regulatory measures (Gianpiero, Federica, & Luigi, 2017).

Simple and inexpensive modification of window glazing and shading devices was able to significantly improve daylighting quantity and quality for visual comfort (Lim, Kandar, Ahmad, Ossen, & Abdullah, 2012). Littlefair, Sabry, Sherif, Gadelhak, Aly, and Pokorny study (as cited in Wong, 2017) opined that conventional sun-shading devices, such as, solar screens, roller blinds and venetian blinds are commonly used in buildings because they are relatively inexpensive and easy to use. However, these conventional devices block out natural light and reduce amount of light penetrating into buildings, which would affect the light distribution in the buildings. Ahmad and Maz

(2012) observed that there was a significant relationship between amount of daylight and the seat chosen by the users of the library. More than half of the respondents in the study which was 74% of them agreed that their seating preference is affected by the daylight. In the same study, 37% of the respondent disagreed that daylight affects the amount of the time spent in the library. According to Ebenechi (2015),Shading devices reduce the daylight penetration in some spaces in the library and observed place like reading areas to have their electric light always on during the day under-most sky conditions. Therefore, the need for this study to clearly investigate how light-pipe device can enhance daylighting in the design of reading areas in academic library.

1.2 Problem Statement

Daylighting have substantial effect on the character of building and on the way that individuals use them.In an attempt to prevent solar radiation and at the same time admit daylight in the library,several strategies are set in place which in-turn blocks the daylight penetration. Consequently, it affects the minimum standard daylight requirement for visual comfort,especially in the conventional reading areas of the librarywhich are usually deeply planned.This is reinforced more so, when the most important resource – daylight - is abundantly available in the tropics, but more or less unexploited to the benefits of the users(Salisu, 2015).

Amal (2015) opined that poor daylight quality may be due to the angle at which the louvre shading devices are inclined at, in the design of library. External shading devices can be utilized to block the solar radiation before it reaches the indoor environment, and hence more effective than internal shading devices. However, external shading devices can affect daylighting by reducing daylight intensity (Wong, & Agustinus, 2003). In addition, of all the available innovative daylighting systems, light-pipedevice has the greatest capacity to allow light to penetrate a considerable distance into the building envelope (Shao, & Callow, 2003).Most Studies have been conducted on daylighting in the design of a library to enhance visual comfort using methodologies based on “static metrics” and the use of side-lighting daylight strategy in the Tropics. Little or no consideration is given to how top-lighting daylight strategy can help achieving the daylight requirement in the library. Therefore, the need to test for light-pipe devices using climate-based daylighting modelling concept in tropical wet-dry climatic zone of Nigeria for optimumrequired daylighting in reading areas of academic library.

1.3 Aim

The research aims at the configuration of light-pipe device for optimum daylighting and illuminance in the design of conventional reading areas of academic library, in tropical wet-dry climatic zone of Nigeria.

1.4 Objectives

1. To investigate the performance variables of light-pipe devices that will excellently redistribute and redirect daylighting in academic library.
2. To design a baseline model for testing the performance of the devices for optimum daylighting in reading areas of academic library, in tropical wet-dry climatic zone of Nigeria.
3. To determine daylight performance on changing aspect ratio of light-pipe in academic library in wet-dry climatic zone of Nigeria.
4. To determine the Daylight Autonomy, Useful Daylight illuminance (<100, 100-2000, >2000) of light-pipe aspect ratios above that best suits the reading area.
5. Application of the device in designing conventional reading areas for proposed summit university academic library, in wet-dry climatic zone of Nigeria.

1.5 Research Questions

1. What are the performance variables of light-pipe device that will excellently redistribute and redirect daylighting in academic library reading area?
2. What is the baseline model for testing the performance of the devices for optimum daylighting in reading areas of academic library, in tropical wet-dry climatic zone of Nigeria?
3. How does the changing aspect ratio of light-pipe affect daylighting academic library in tropical wet-dry climatic zone of Nigeria?
4. To what extent can the Daylight Autonomy (DA), Useful Daylight illuminance [UDI] (<100, 100-2000, >2000) of light-pipe aspect ratios above affects the reading area.
5. How can the findings from the research be demonstrated in the design of proposed academic library for summit university, in tropical wet-dry climatic zone of Nigeria?

1.6 Justification of Study

Among different source of lighting, sunlight is the most crucial one and cannot be easily replaced by electric light because of its dynamic quality as well as spectral features (Shishegar & Boubekri, 2016). Moreover, it is the most important source of vitamin D which is necessary for the strength of human bones and overall health. In addition to its role as an agent for vitamin D production, natural light can improve subjective mood, attention, cognitive performance, physical activity, sleep quality, and alertness in students and workers (Shishegar, & Boubekri, 2016).

Due to the establishment of summit university in Offa, Kwara State within the tropical wet-dry climatic zone of Nigeria, the institution has proposed a site to accommodate the design of library. Thus, this study tends to help in proposing a befitting reading area which will improve students’ performance and health by optimizing light-pipe device to enhance daylighting in the reading area of the library.

1.7 Scope

This research is focused on daylighting optimization in conventional reading area of university academic libraries within tropical wet- and dry climate of Nigeria as defined by the Koppen-Trewartha and Horn climatic classification. The research will also consider light-pipe aspect ratio for optimum daylighting considering DA and UDI (<100, 100-2000 and >2000 on the working plane) put forward by Architectural Energy Cooperation (AEC) and Society of light and Lighting (SLL).

CHAPTER TWO

2.0 LITRATURE REVIEW

2.1 Introduction

Admitting natural light from the sun to interior spaces for optimum visual comfort without any undesirable effect is termed as 'Daylighting'. These can be achieved through the use of either top-lighting(light-pipe, skylights and atriums) or Side-lighting (windows) located within the building. In a broader sense, the art and science of proper daylighting design is not how to provide enough daylight to an occupied space, but doing so without any undesirable side effects. There is a need for careful balancing of heat gain and loss, glare control, and variations in daylight availability.

Therefore, in this chapter, the concept, theories, and model of light-pipe device to optimize daylighting in conventional reading area of library, in the tropical wet-dry climatic zone of Nigeria is reviewed. These include daylight and daylighting, daylighting and climate, Nigeria and Koppen-Trewartha-Horn Climate Classification, sky types, conceptual framework of daylighting, Strategies for daylighting, factors affecting daylight performance, energy efficient lighting system. Moreover, light-pipe device types for building, shading device variables, and the performance parameter alongside the benefit of shading device were reviewed. Furthermore, Daylight design in libraries, illumination levels in libraries.

2.2 Daylight and Daylighting

Daylight is described as the combination of all direct and indirect light originating from the sun during daytime (VELUX Group, 2014). Daylighting on the other hand, describes the controlled use of natural light in and around buildings (Reinhart, 2014), It is the practice of placing windows, or other transparent media and reflective surfaces so that natural light provides effective internal illumination during the day (VELUX Group, 2014). The use of daylight for indoor task illumination has been widely advocated so it’s a task for the architect, to balance the different environmental parameters with the design variables (Tukur, 2013).

2.2.1 Daylighting and Climate

Climatic similarities exist across the world and can be used as a foundation for identifying the capabilities that buildings located in these regions should have (Heerwagen, 2004). Weather and climatic conditions are relevant factors in the efficient siting of buildings, choice of materials, design and air conditioning of the structure. Amongst the numerous classification schemes that adopt the empirical approach, the most used is that of W. Koppen (1846-1940) either in its original form or with modifications (Ayoade, 1993). The climate of a region is characterised 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.

2.2.2 Nigeria and the Koppen-Trewartha-Horn Climate Classification

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. The country has three distinct climate types according to the Koppen system as modified by Trewartha and Horn, 1980 as demonstrates in Figure 2.1. This is noticeable as one moves from the southern region through the middle belt and up to the northern states.

Figure2.1:Map of Nigeria showing the Three Climate Zones according to Koppen-Trewatha-Horn classification scheme. Source: Salisu, 2015.

2.2.2.1 Tropical Wet and Dry 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).

2.3 Sky Types

Daylighting design is usually based on the dominant sky condition and the micro-climate for the building site. There are three common sky conditions: clear sky, overcast sky, and partly cloudy sky (Kroelinger, 2010).

Whenever the sky is viwed, its appearance has changes. Whether it is clouds drifting across, the sun making its way from the East to the West, or the blue colour changing into a glowing red-- the sky has many faces. While all those effects are very interesting, they also make it difficult to create an accurate description or even a mathematical model of the sky. Architects and engineers, however, need to be able to model the sky so they can plan the daylight performance of buildings accurately. The CIE (Commission Internationale de l'Eclairage) has made successful attempts to create such model skies that are a very valuable tool for everybody dealing with daylight (Comfortable Low Energy Architecture, 2015). They classified the sky into four categories: clear sky, intermediate sky, overcast sky and uniform sky.

2.3.1 Clear Sky

The luminance of the standard CIE Clear Sky varies over both altitude and azimuth. It is brightest around the sun and dimmest opposite it. The brightness of the horizon lies in between those two extremes (Xtralite Daylight by Design; Comfortable Low Energy Architecture, 2015).Plate Iillustrate this type of sky.

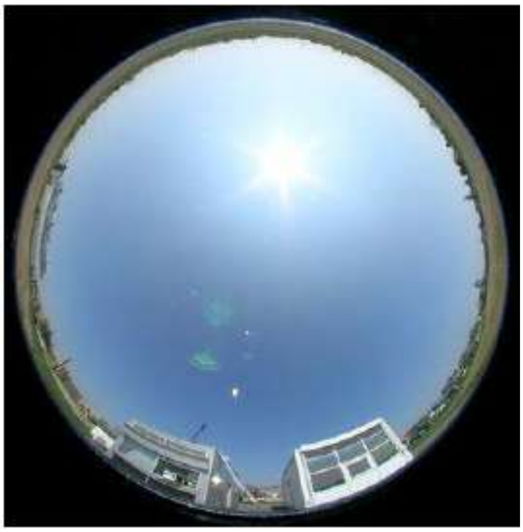


Plate I:Clear Sky

Source: Comfortable Low Energy Architecture (2015)

2.3.2 Intermediate Sky

The standard CIE Intermediate Sky is a somewhat hazy variant of the clear sky as shown in Plate II. The sun is not as bright as with the clear sky and the brightness changes are not as drastic (Xtralite Daylight by Design; Comfortable Low Energy Architecture, 2015).

Plate II:Intermediate Sky

Source:Comfortable Low Energy Architecture (2015)

2.3.3 Over Cast Sky

The luminance of the standard CIE Overcast Sky changes with altitude as demonstrated in Plate III. It is three times as bright in the zenith as it is near the horizon. The overcast sky is used when measuring daylight factors. It can be modelled under an artificial sky (Xtralite Daylight by Design; Comfortable Low Energy Architecture, 2015).

Plate III: Overcast Sky

Source:Comfortable Low Energy Architecture (2015)

2.3.4 Uniform Sky

The standard Uniform Sky is characterised by a uniform luminance that does not change with altitude or azimuthas can be seen in Plate IV. It is a remnant from the days when calculation was done by hand or with tables. Today, it is hardly used at all (Xtralite Daylight by Design; Comfortable Low Energy Architecture, 2015).

Plate IV:Uniform Sky

Source:Comfortable Low Energy Architecture (2015)

2.4 Conceptual Framework of Daylighting

Research in daylighting has been based on various concepts since 1895 (Kota & Haberl, 2009) and these concepts are:

i. The Daylight Factor (DF) Concept

ii. The 'Design Sky' Concept

iii. The 'Total Flux' or Lumen Concept of Day lighting

iv. The 'Split Flux' Concept of Day lighting

v. The PSALI (Permanent Supplementary Artificial Lighting of the Interior)

vi. The Static Point Illuminance and Luminance Measurement Concept

vii. Climate -Based-Daylight-Modelling (CBDM).

2.4.1 Climate based daylighting modelling (CBDM)

The climate-based approach uses time varying sky and sun conditions, whilst predicting hourly levels of daylight illuminance. This is fully parallel to standard practice for indoor climate simulation. The superiority of the method is thus evident against the daylight factor approach, which is a single number taking no account of orientation and considering only overcast skies, therefore not being meaningful for climates with predominant sun conditions. Moreover, the climate-based approach can take solar shading into account (Elpida & Helle, 2015). Climate-based daylight calculations that rely on hourly meteorological data over the year, form much more accurate and informative, yet simple measures of the daylight conditions in a building compared to the DF and could effectively replace the latter in regulation and scheme requirements (Mardaljevic, Heschong & Lee, 2009). Climate Based Daylight Modeling allows for informative analyses of daylight conditions in spaces by taking in account the location-specific climate characteristics of the building's position and showing the impact of the use of solar shadings. This is a feature lacking from the commonly used daylight factor analysis and it makes daylight assessments tailored to each building, whilst producing information on lighting energy savings, indoor illuminance conditions and occupant comfort (Elpida & Helle, 2015).This method has been validated extensively by various researchers to reliably and effectively calculate time series of illuminances up to a time frame of as low as one–minute intervals [Mardaljevic, 2006, Reinhart and Walkenhorst, 2001, Reinhart and Andersen, 2006 as cited in (Salisu, 2015)].

2.4.2 Climate based daylight modelling performance indicators

Based on the 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 any part of the world, taking into cognisance the location of the building and orientation inclusive of most climate peculiarities (Salisu, 2015). The indicators are categorised as follows:

i. Performance Indicators for Quantity

ii. Performance Indicators for Quality

2.4.2.1 Performance indicators for quantity

The performance indicators for quantity consist of three elements, which are described below:

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. Daylight DA provides the benefit of valuing the contribution of daylight to energy savings; however, it is of no value to the occupants' comfort as it does not reflect on the amount of time of extreme illuminance levels causing discomfort or glare. At the same time, the metric ignores illuminances that are below the threshold, which can still be useful to the building users (Elpida & Helle, 2015). 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 (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 as cited in (Salisu, 2015)]. Furthermore, daylight autonomy uses work plane illuminance as an indicator of whether there is sufficient daylight in a space so that occupants can work by daylight alone (Erlendsson, 2014).

b. Useful Daylight Illuminances (UDI) calculates the percentage of total number of occupied hours that 'useful' daylight enters a space at a selected point on the work plane. It is the provision of ambient light at the work plane at illuminance levels categorised into three bins:

UDI<100 represents illumination less than 100lux (light is too low)

UDI100-2000 represents useful daylight

UDI>2000 represents an excess supply of daylight which may lead to visual impairment, solar gains and thermal discomfort (Nabil & Mardaljevic, 2005).

c. Spatial Daylight Autonomy (sDA) is a single quantitative value for a space unlike the multiple values obtained in the Daylight Autonomy (DA) scheme.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).

2.4.2.2 Performance indicators for quality

The performance indicators for quality are:

a. Proposed Daylight Autonomy Uniformity Index (DA_{ui}).

b. Useful Daylight Illuminances greater than 2000 lux (UDI>2000).

   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)

2.5 Strategies for Daylighting

The locations and size of apertures matter a great deal to utilize natural light in the building. Windows and other openings facing the path of the sun receive much more direct sunlight than those facing away. However, more daylighting is not necessarily better. Bringing in too much light can cause glare and overheating. 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 Education Community, 2015)

2.5.1 Side light

This is the location of daylighting apertures (glazed or unglazed) in one or more vertical perimeter walls of a building. Sidelight apertures can be unilateral (fenestration in a single wall), bilateral (fenestrations in two opposing walls) or multilateral (fenestrations in at least two non-opposing walls) (Salisu, 2015). Light coming from side apertures like windows can only penetrate so far into a building. This is the reason why shallow floor plans are usually recommended for daylighting multi-story buildings. Figure 2.2 demonstrateda simple rule of thumb for most latitudes is that daylight penetrates into a room roughly 1.5 to 2.5 times the height of the top of the window (Autodesk Education Community, 2015)

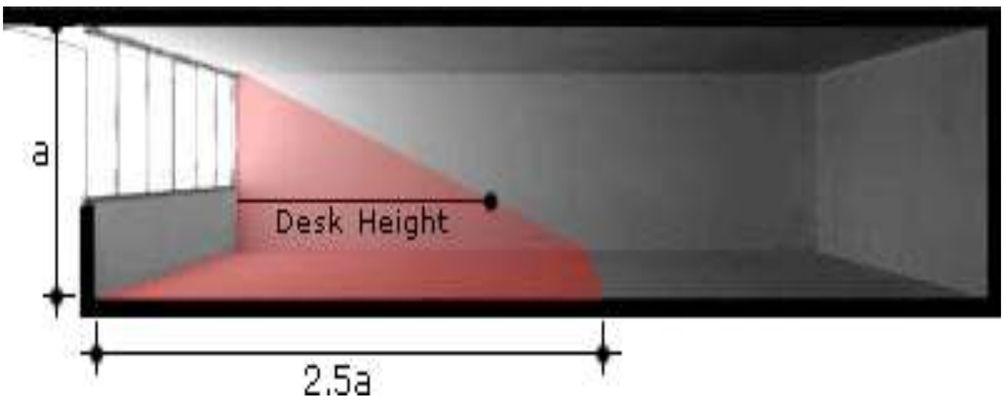


Figure2.2: Side lighting only reaches so far into a room

Source: Autodesk Education Community (2015)

Windows facing away from the sun's path rather than towards the equator provide the most even illumination, though not the brightest. East and west facing windows can provide very bright light in the morning or evening but insufficient light at other times of day, and are very prone to glare. Windows facing towards the sun's path get the brightest light; they can also have glare, but the glare is much easier to control than on East or West walls. In middle latitudes and those closer to the equator, skylights can provide the brightest and most consistent illumination, but in latitudes closer to the poles they are less bright and much less seasonally consistent (Autodesk Education Community, 2015)

2.5.2 Top light

This is the name given to a daylight aperture situated in the ceiling/roof plane (Salisu, 2015). It is also possible to reduce the likelihood of glare by keeping the source of daylight out of direct sight of the occupants (New Buildings Institute Inc, 2003). 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 as shown in Figure 2.3. These each have 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 Education Community, 2015). Their major advantage is that they produce a higher illuminance on a horizontal work plane than side windows of the same area (Tregenza & Wilson, 2011) as shown in Figure 2.3.

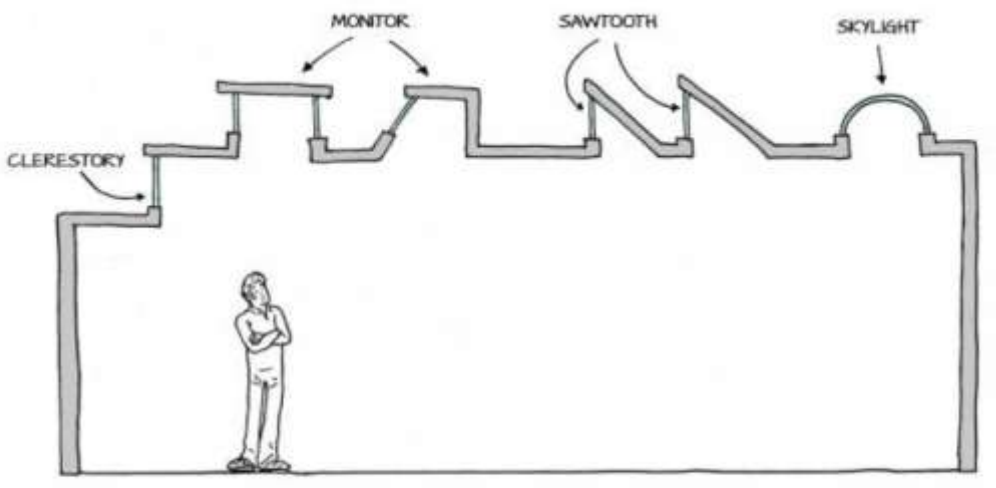


Figure2.3:Different kinds of top lighting

Source: Autodesk Education Community (2015)

Based on the research that has been done by several researchers, top-lights are considered the most energy efficient daylighting strategies (Mandalaki, Zervas, Tsoutsos, & Vazakas, 2012).

2.6 Factor Affecting Daylight Performance

The following factors as opined by (Sharif & Zarin, 2012) affect the daylight performance in the building. These factors are:

a. Building Orientation

b. Types of windows

c. Types of glass

d. Position of the sun

2.6.1 Building orientation

A proper orientation of the building is the major factor which affecting performance of daylight penetration. Standards and Industrial Research Institute of Malaysia [SIRIM] (2006) recognized that direct sunlight easily transmit and result to the increasing building energy consumption by 20% or more when windows facing to the east or west.

2.6.2 Types of windows

Windows have a bigger impact on the quantity of daylight penetration. Casement window is able to provide excellent ventilation and if they seal tightly when closed, it can still allow penetration of natural light. These windows consist of glass as the main material.

Louver windows have horizontal or vertical slats which can angled to admit light and air into the interior space. The angle of the slats can be adjustable. Many houses used this type of window because it can improve indoor daylighting and limit glare or redirect diffuse light.

2.6.3 Type of glass

The glass used for windows in building provides light and allow vision. Different type of glass has different energy-performance characteristic. That is the ability to resist heat transfer (U-value; UV), ability to control solar heat gain through the glazing (Solar Heat Gain Coefficient; SHGC) and the amount of light passes through a glazing material (visible transmittance; VT). By knowing the amount of UV, SHGC and VT of the window, it helps user to select the right window in order maximize daylight effectiveness and occupant comfort.

2.6.4 Position of the sun

The sun position in the sky always changes seasonally and affect availability of daylight. Position of the sun is the true altitude and azimuth of the sun based on geographic location. The day became brighter when the sun angle is higher. The best orientation of the buildings can be determined with the sun angle. The movement of sun from east to west and the angle of the sun to the opening affect the amount of daylight penetration to the building.

2.7 Factors Affecting the Use of Daylighting

The use of daylighting is affected either within building or a given space (room) (Olatunji, 2014). The following are the basic factors that affect the use of daylight within a building:

a. Characteristics of the lighting

b. The task.

c. The visual system of the observer.

While the following affects daylight within a given space (room)

i. Retina illumination to which the visual system is adapted.

ii. Spectral content of the illuminant

iii. Light distributions around the target

iv. Visual size of target (in units of angle or solid angle)

v. Visual size of background (in units of angle or solid angle)

vi. Luminance of the target

vii. Luminance of the immediate background

viii. Luminance contrast of the target

ix. Colour of the target

x. Colour of the background

xi. Colour difference between the target and the background

xii. Duration of the exposure

xiii. Temporal frequency characteristics

xiv. Location of the target relative to the line of sight

xv. Movement of the target in the field of view

xvi. Retinal image quality, as determined by the state of accommodation, pupil size, light scatter, and lens.

2.8 Top-lighting Energy Efficient systems

2.8.1 Lightpipe

Light-pipe devices are another type of top-lighting device. These devices employ a highly reflective film on the interior of a tube to channel light from a lens at the roof, to a lens at the ceiling plane as shown in fig. 2.4. Tubular daylight devices tend to be much smaller than a typical skylight, still deliver sufficient daylight for the purpose of dimming the electric lighting (Ander, 2014). The device allows the increasing use of daylight in buildings. They use the principle of high efficiency reflection to introduce light into interior of a building. They are simply empty pipes which can be straight or angled assemblies. The internal surface of the light-pipe is coated with highly reflective material such as anodized aluminium or coated plastic films to enhance the efficiency of light reflection. The Figure 2.4 provides the typical structure of a light-pipe(Energy Efficient Technologies, 2015). Also, Light-pipes have been tested efficiently to carry light to dark corridors and rooms (Tukur, 2013).

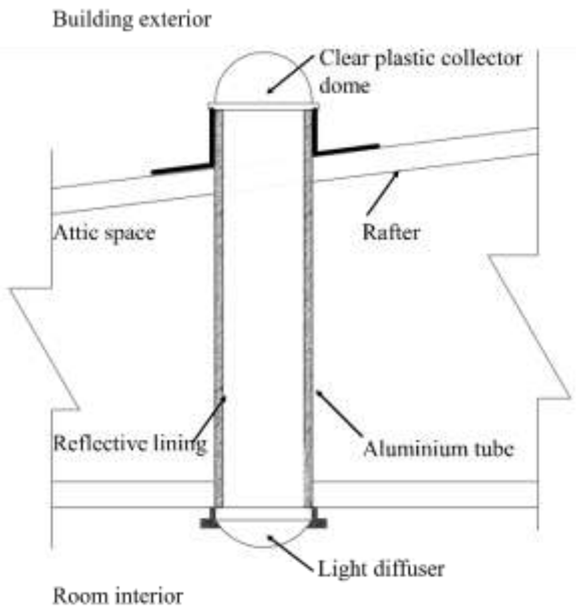


Figure2.4: Schematic of a typical light-pipe

Source:Energy Efficient Technologies (2015)

2.8.2 Light-pipeperformance

The lighting performance of a light-pipe varies according to time of day, outdoor daylight availability, building location, roof orientation and exposure, and tube length-to diameter ratio. A typical device can illuminate an area of 14 to 28 m^2 (Laouadi, & Saber, 2014). The tube with highly reflective internal surfaces, like aluminium sheet with reflectance of about 95–99%, rises the efficiency (Zhang, Muneer, & Kubie, 2002).High efficiency reflection is the principle in light-pipe system. Hence, the use of elbow or bend will result in light loss. In a review done by Abdul-Rahman, & Wang (2010) revealed that, each elbow may loss 8% of light. Studies by Zhang, Muneer, & Kubie (2002) on 330mm diameter on elbows and straight pipe showed that straight pipe performed better than elbows due to light loss.An experimental study carried out by Oakley, Riffat, & Shao (2000) testified that light-pipes are proficient devices for introducing daylight into buildings. Surveys conducted by Al-Marwaee & Carter (2006) on 13 buildings have found that light-pipe systems could provide 25% –50% of the work-plane illuminance and tend to reduce lighting energy consumption. Also, the area of coverage is dependent on the height of the ceiling—the higher the ceiling the more widely the light will be uniformly distributed. In another study byMohelnikova (2009) revealed that interior illuminance on the working plane could vary depends on sky condition. Figure 2.5 shows the intercorrelations between indoor illuminance and sky condition.

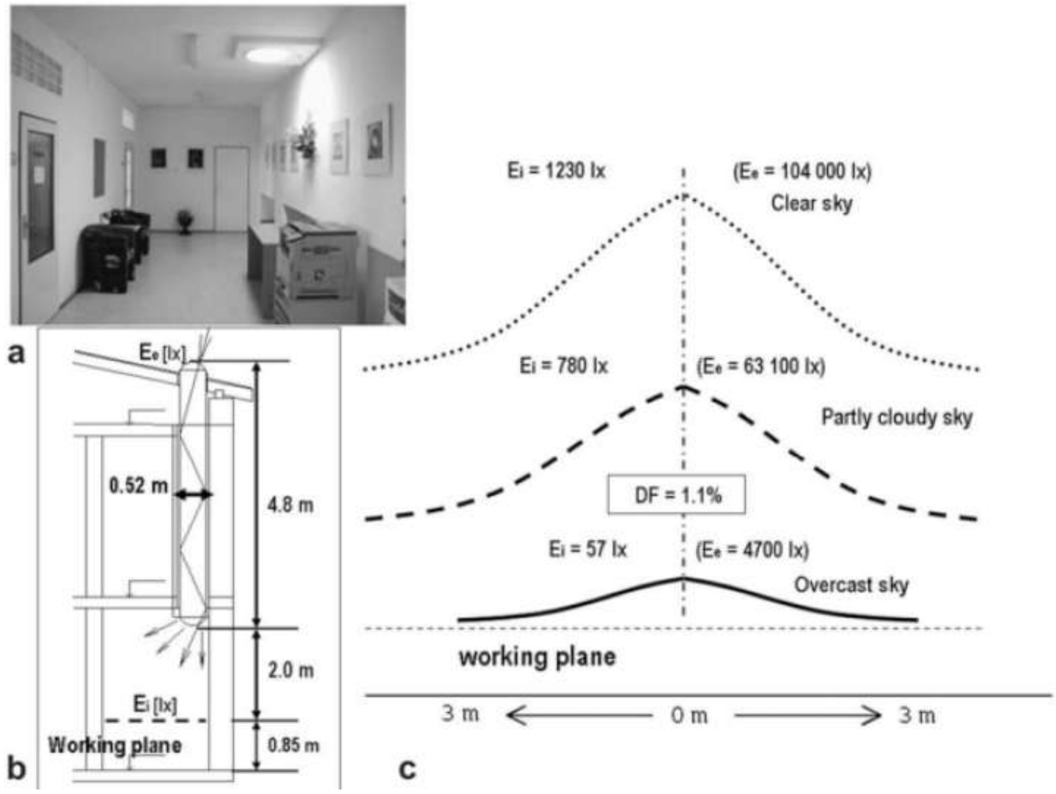


Figure2.5:Illuminance Measurements in the Windowless Corridor

Source:Mohelnikova (2009)

Pipe diameters ranges from about 250 to 560 mm (10 to 24 in.) and more. The ratio of the length of pipe (L) to its diameter (D) is its aspect ratio (L/D). The lower the aspect ratio, the lighter will reach the interior space (Laouadi, & Saber, 2014).

2.8.3 Spacing ratio for lightpipe

Spacing ratio (SR): SR relates to the normalized luminous intensity distribution of Light-pipes. To minimize capital cost (as few as possible installed lightpipes), select Light-pipes with higher spacing ratios. For ideally diffusing lightpipes, SR varies from

1 to 1.5 for illuminance uniformity (ratio of minimum to average work plane illuminance) of 0.95 to 0.8, respectively (Laouadi, & Saber, 2014).

2.8.4 Light-pipesystem

Light-pipe system includes the following:

i. Mirrored light-pipe

ii. Horizontal light-pipe

iii. Vertical light-pipe

2.8.4.1 Mirrored lightpipe

In Mirrored Light-pipe, the light is transmitted inside the pipe from the source to the output aperture by a number of multiple specular reflections at the inner wall surface of the pipe [Aizenberg, 2003 as cited in (Yahaya, 2017)]. Mirrored light-pipe of small-scale have been used quite successfully in domestic and commercial applications for the enhancement of natural light in rooms with poor illumination levels. The technology is also being applied in buildings with a large floor to facade ratio that need to be illuminated through the roof such as supermarket, warehouses and so on. (Aizenberg, 2003). Typical mirrored light pipe is shown in Figure 2.6:

Figure 2.6:Mirrored Light-pipe

Source: (Aizenberg, 2003)

2.8.4.2 Horizontal lightpipe (HLP)

The horizontal light-pipe is a device that brings daylight into the inner parts of buildings without the use of any electrical or other sources of energy. The extraction and emission of daylight is transmitted horizontally and vertically using internal mirrored surfaced within a box-tube structure (hence the term “pipe”) coupled with laser-cut panels at the outer edge of the pipe as collectors. The horizontal light-pipe comprises of a box (i.e. Like a duct, that has highly reflective interior mirrored surfaces and an arrangement of laser cut light deflecting panels (LCP) at the outside edge as sub-light collectors and extractors that redirect light along the pipe to the interior spaces as required and with light emitters to spread the light uniformly around the space as illustrated in Figure 2.7(Energy Efficient Technologies, 2015).

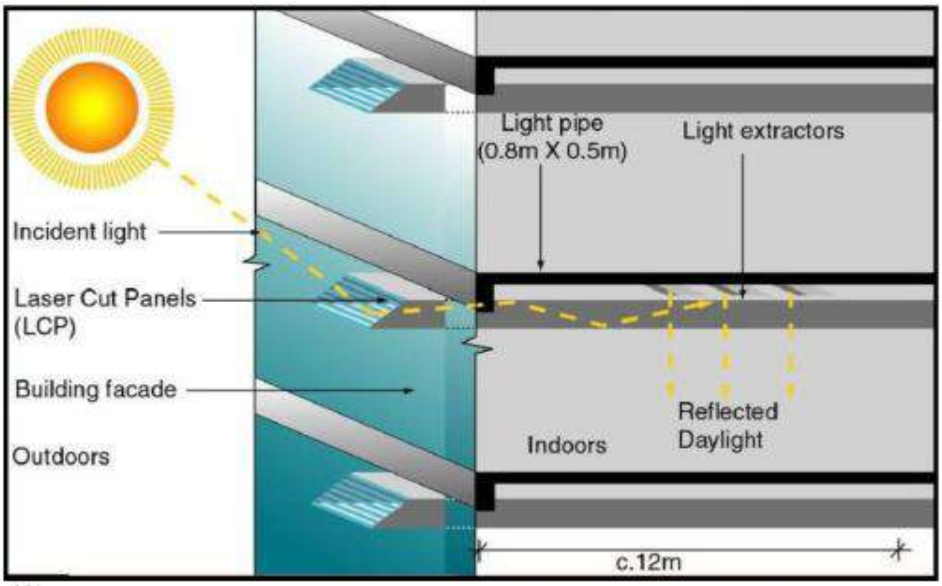


Figure 2.7: Horizontal Light-pipe Illustration

Source: (Aizenberg, 2003)

There is another type of light-pipe that can be integrated in a building façade to capture daylight and distribute it into the deep zone of a building as shown in the following Figure 2.8(Energy Efficient Technologies, 2015).

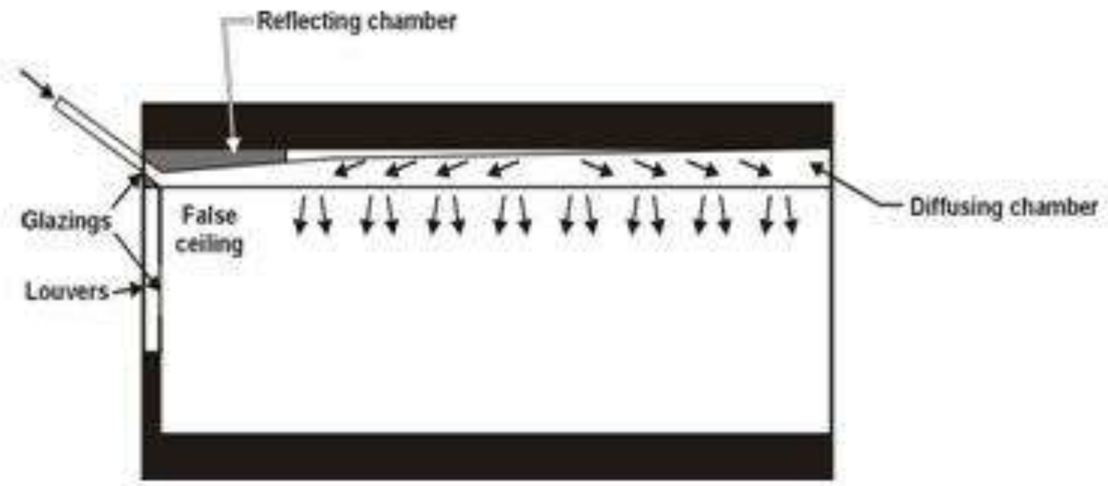


Figure 2.8: Light-pipe integrated in the building façade

Source**:**(Energy Efficient Technologies, 2015)

2.8.4.3 Vertical Light-pipe

The design of the vertical light-pipe follows the same principles as the design of the horizontal light-pipe. Figure 2.9 shows the application of vertical light for a multi-story building.

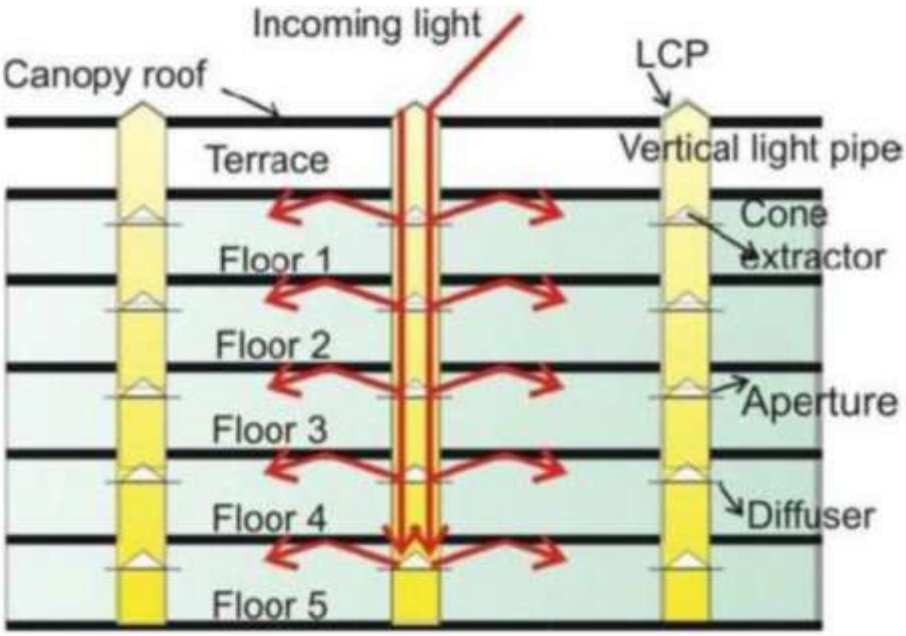


Figure 2.9: Vertical Light-pipe Illustration

Source: Callow (2003)

How much energy can be saved: The amount of energy saving by the use of light-pipe greatly depends on the number of light-pipe used. Usually straight light-pipe perform better than angled ones as light energy decreases with increased reflections. The light-pipe that illustrates in the above Figure is usually integrated on the roof of a building.

2.8.5 Benefits of Tubular Daylighting Devices

There are several different ways to bring natural light into a building. Skylights are one option which comes in a range of types including traditional, prismatic, tubular, and solar-tracking skylight. Below are the highlights of some benefits of light-pipes as well as the disadvantages they present (Brain, 2015).

i. Light Tubes Are Energy-Efficient
ii. Light Tubes Produce More Light than Traditional Skylights
iii. Light-pipes Are More Thermally Insulated One of the biggest concerns with traditional skylights is the lack of thermal insulation
iv. Light-pipes Carry Light to Lower Floors
v. Light-pipes Are Affordable.

i. Light Tubes Are Energy-Efficient

Light-pipes can reduce this energy consumption significantly. With tubular daylighting devices, you can eliminate dependence on artificial lighting, which uses 11% of energy in residential buildings, and reduce dependence on HVAC, which contributes 41% of the cost of energy in residential buildings, resulting in savings between 50-60% of those costs (Brain, 2015).

ii. Light Tubes Produce More Light than Traditional Skylights

The design of traditional skylights produces less light than modern tubular lighting devices of the same size. Light-pipes maximize the light transmitted to the interiors by using special transparent domes. During dawn and dusk, when the sun's angle is low, the dome of tubular daylighting devices capture sunlight more efficiently than traditional skylights and allows light to pass through to the interior of a building (Brain, 2015).

iii. Light-pipes Are More Thermally Insulated One of the biggest concerns with traditional skylights is the lack of thermal insulation. Traditional skylights let more than 70% of external heat into the building. In contrast, light-pipes are far more energy efficient because of their small size and insulated shaft that prevents heat loss during winter and heat gain during the summer. Apart from meeting lighting requirements for your space, they reduce the strain on HVAC systems which is common with traditional skylights (Brain, 2015).

iv. Light-pipes Carry Light to Lower Floors

Light tubes are applicable in situations where other skylights would not be able to function, such as when the room that needs illuminated is not directly adjacent to the roof. Their light-pipe can be flexible and or can bend around obstructions in the building. They are also useful under roofs with drop ceilings and attics. Light-pipe can be 4 to 33m in length and are designed to pass through entire floors so lower floors can receive natural light as well as the top floor (Brain, 2015).

v. Light-pipes Are Affordable

Tubular daylighting devices offer affordability due to their compact size and modular design. The purchase and installation required for a light-pipe is far less than that of traditional skylights. (Brain, 2015).

2.8.5.1 Shading devices and ceiling geometry

It was found that the performance of the shading devices can be improved by changing the ceiling geometry. The illuminance level increased in the rear of the room, and decreased in the front near the window compared to rooms having horizontal ceilings as shown in Figure 2.10.The best ceiling shape was found to be one that is chamfered in the front and rear of the room. (Freewan, A.A. Shao, L. Riffat, S., 2008)

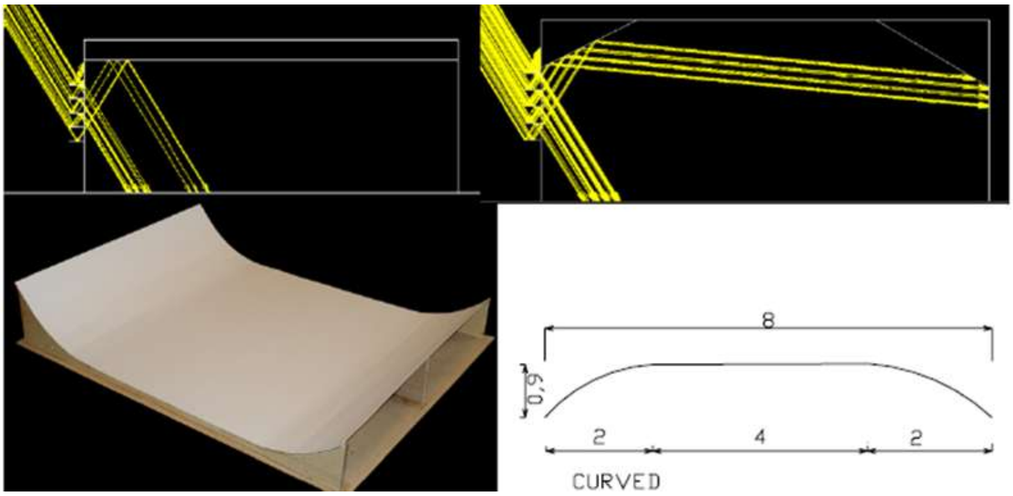


Figure 2.10:Performance of light in a room aided by louvers and has a flat or curved ceiling above and a curved ceiling model with dimensions

Source: Freewan, Shao, & Riffat (2008)

2.9 Daylight Design in Libraries

This focuses on how daylight can be used efficiently in libraries, mostly in university libraries. However, it is not easy to separate the social role of the libraries in the community from the daylighting concepts. This is due to the concept of library as a place that brings the community together to partake knowledge. Since the beginning of the built history, architects have thought about daylight as one of the most important elements of design (Baker & Steemers, 2002). Daylight is not only an element of design but also there are psychological needs for daylight and views as a means for connecting to the outdoors and our internal clock that relies on cues from the environment. These relationships had not been investigated thoroughly until the research of Roger Ulrich and have gained significance especially with health and productivity (Sands, 2004). In the development of the overall building form, it is not always possible for the architect to see daylighting design as a primary consideration. However, with increasing realization of benefits of daylight both from the psychological and physical environment points of view, new technologies in glazing and window construction, especially in terms of, daylight harvesting control systems for a more sustainable use of energy, the daylight criterion is moving up on the list of priorities according to Baker and Steemers as cited in (Kan, 2009) .

The interior layout and circulation of a building affect the built form. The relationship between planning and form is to a certain extent determined by the quantitative daylighting needs of each space and by qualitative intentions of the design team. These two aspects of lighting criteria can be strongly related, particularly in terms of dealing with the transition between spaces and the setting up of a luminous hierarchy between the exterior and the interior. For example, the workplace environment, this issue of relationship between spaces and the lighting criteria have strong implications for internal planning and room layout. In such cases, the relationship between such uses need particular attention. The library is an example for buildings that need particular attention in terms of layout and daylighting (Baker and Steemers, 2002), and how spaces are perceived, used, judged, and evaluated by their users is very important for satisfaction of library users (Kan, 2009).

2.10 Illumination Levels in Libraries

The examples of reinvention of library building viewpoint bring the importance of satisfaction of users when spending time in the libraries. With this viewpoint, the physical conditions of library space affect the length of stay of the users in it. For instance, the light level of reading area affects the duration of library users, if the daylight, orientation of building, window size and shape, artificial light, design layout and contrast between the spaces should be considered. (Kan, 2009).The Illuminating Engineering Society (IES) is an independent organization of professionals that sets light level guidelines which serve as the recognized standards for light in building spaces. table provides the illumination levels recommended for library spaces.

Table 2.1: Recommended light levels for libraries

Function	Illuminance level required (Lux)
Auditorium	100-150-200
Entrance	50
Conference hall	200-300-500
Exhibition hall	1500-3000-5000
Book shelves	200-300-500
Individual carrels	200-300-500
Computer desks	500-750-1000
Desks for handwriting	500-750-1000
Circulation desks	200-300-500
Permanent publications area	200-300-500
Relaxation areas	100-150-200
Circulation path (corridors, stairs, hall)	50-75-100

Source: IES (n.d) and Kan (2009).

In libraries, artificial light must be supported by daylight. Every space of the library building needs daylight for visual comfort, social relationship with others and a sense of well-being. The research on this subject has shown that the information which is learnt in daylit environment is not forgotten easily (Dean, 2005). For good daylighting design, low glare lighting is a principal objective in libraries.However, if computers are present, ambient lighting should not exceed 300 lux(Robinson & Selkowitz, 2013).

2.11 Applications of Light-pipe daylighting device in library

Daylighting in libraries have evolve over time from placing of side windows to a more complex device to bring daylight into interior of the buildings due to its deep plan nature. Some of the examples of the applications of this device in library can be found in South Whittier Library, South Whittier.

2.11.1 South Whittier Library

The South Whittier Library is contracted by County of Los Angeles Community Development Commission; County of Los Angeles Public Library and designed by

Architect of record; Emar studio for public architecture. The Library is located at 11543 Colima Road, South Whittier, CA 90604 which have an area of 14,400 s.f. + 770 s.f. (1337.80 m^2) Outdoor Reading Courtyard and soft landscapes as shown in Plate V. The construction cost is about $ 8.06 million with platinum LEED certification in terms of Energy and Resources.

Plate V: South Whittier Library

Source:(Lena, 2017)

2.11.2 Architecture and daylight of the South Whittier Library

This high-performance building features multiple layers of sustainable building strategies which augment the use of a wide variety of interior spaces, all of which contribute to a modern library experience. A highly insulated, air-tight building envelope with multiple types of exterior shading devices over extensive glazing make for an extremely high level of natural glare-free daylighting. The exterior panel pattern was designed to minimize waste, and leftover scrap was used in a custom shading trellis over an outdoor reading courtyard which can be connected to the interior by sliding glass doors.

The library features several energy and resource saving building systems including: exterior sunshades and fins which shade exposed glass, minimizing solar heat gain; a radiometer-based motorized shade system, eliminating remaining glare; extensive daylight harvesting using solar tubes, dimming nearly every light fixture type when sufficient natural light is available and reducing electrical lighting consumption by 38%; water-saving plumbing fixtures, reducing indoor water demand by 37%; a high percentage of recycled content in the building materials used; extensive permeable and pervious hardscape, reducing rainwater runoff into the municipal sewer system; drought tolerant and native landscaping with irrigation which reduces water consumption by over 69%.

The PV system is designed to offset 27% of the annual energy cost of the building, combining with other design elements to reduce total building energy cost by over 46%. The building's Energy Use Intensity (EUI) of 32.0 kBtu/sf exceeds the 2030 Challenge Target of 36.8 kBtu/sf. Figure 2.11 and 2.12 illustrates South Whittier floor plan and the application of light pipe respectively.

Figure 2.11:Floor plan of South Whittier Library

Source: Lena (2017)

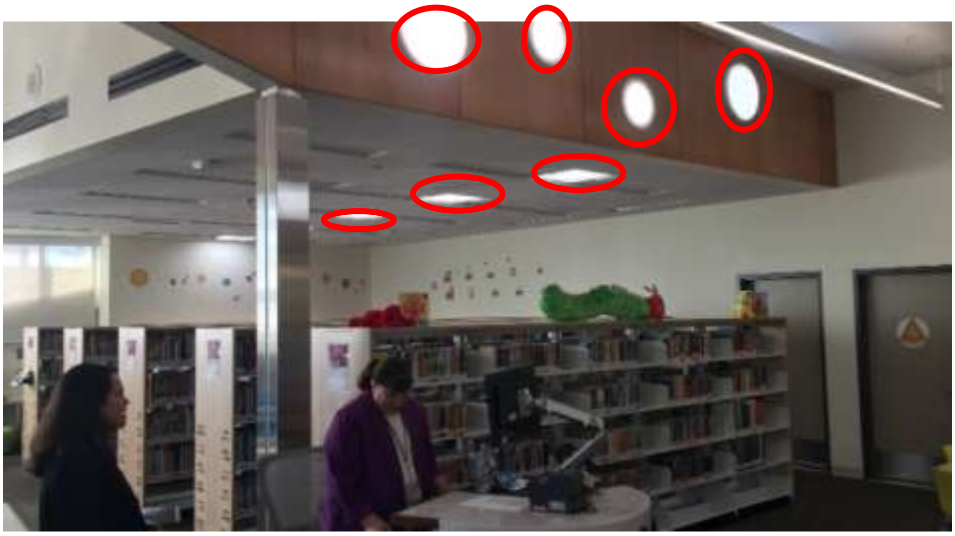


Figure 2.12: Interior view of South Whittier Library with solar tubes

Source: Lena (2017)

2.12 Parametric Study

This section substantiates the choice of considered parameters and defines the way they were studied. To test for the light pipe performance, a standard room of 3mx3mx3.6m is modelled, with light pipe of different aspect ratio (diameter to length) in Ecotect result Visualise in radiance and Daysim (Tukur, 2013 & Gana, 2017). The diameter was first kept constant and the length were varied with performance observation at three different levels: the bottom, middle and top of the modelled room and vice-versa for the length of the light pipe under investigation (Tukur, 2013 & Gana, 2017). The conclusions of the parametric study by (Gana, 2017), research shows that for optimum performance of light pipe in museum in tropical climate the aspect ratio should not exceed 1/10. For this research work, the models have aspect ratio between 1:2/1:10. This is done using daylight model and daylight modelling software a software or physical scale model calculation of interior light levels in a space, using specific sky scenarios, such as clear sky or overcast, or real-world weather data files for a specific location (Vangimalla, P. R., Olbina, S. J., & Issa, R. R, 2011).

Other factors for accurate simulation results that should be taken into consideration include local climate data, building orientation, interior finishes in terms of reflectance which all impact the quantity of daylight availability for a specific project Salisu (2015). Outcomes are usually in colour grid and renderings, once the initial analysis is done, subsequent modification of the building model considering the research variables can be made to reflect opportunities that may enhance daylight design (Gana, 2017). Moreover, Adaji (2015) in his study focuses on the provision of adequate daylight in public library to reduce over dependence on electrical energy for the artificial lighting. Three libraries were studied using Building information modelling (BIM) - Autodesk Revit 2014, Autodesk Ecotect 2011 to design for daylight in library and to analyse Daylight Illuminance level, Daylight Factor (DF) and daylight autonomy. The major factor considered in the study is the level of illumination on the work plane in the interior of the building, the area of the windows and the area floor of the spaces. Some recommendations from the research includes:

i. Remodeling sections of the building to allow for natural lighting

ii. Installation of roller shade blinds which can be easily controlled for optimum light penetration.

iii. Design for buildings should go beyond provision of spaces for activity, but must adequately consider energy efficiency and the science of usability as part of the whole process in a building’s existence.

iv. Use of advanced building materials (smart materials) should be encouraged to achieve needed reading environment.

2.13 Summary

This chapter help the researcher to review the literatures carried out on existing daylight devices available today as well as their applications for the study to be places within an existing body of knowledge; focusing mainly on the core lighting system for reading areas in library. Daylighting and its strategies were studied elaborately concurrently with climate-based daylight modelling. The selection of light pipe as a strategy of bringing daylight into the core area of the reading spaces was also justify from the review of literature. The review also goes further to see different methodology applied by different researchers in their studies, this is to get the author used to different accurate method that can be used to collect and analysis data in the related cases. Since most of the library core reading areas always lack adequate daylighting, this study focuses on light pipe as an innovative means of bringing light to interior core space and other inventive approaches.

To answer research question from the literature reviewed in respect to objective one of this study on the performance variables of light pipe devices that will excellently redistribute and redirect daylighting in academic library. Certain performance variables of light-pipe device were identified. These variables are:

1. Time of day,
2. Outdoor daylight availability,
3. Building location,
4. Exposure, and
5. Tube length-to diameter ratio.

CHAPTER THREE

3.0 METHODLOGY

3.1 Introduction

Research methodology is the plan, mode or conceptual structure of the research and type of approach adopted in the study (Olaofe, 2010).The objective of this segment is to offer appropriate information about the methods embraced in the study to enable replica by others if need be.To properly investigate the issues in this research, this section provides information on the methodology selected and adopted to collect the relevant data that helped achieve the objectives of the research. It covers the research design, the sampling method adopted, research instruments used, pilot study, simulation method and how the data gotten was analysed.

3.2 Research Design

The research design refers to the overall strategy that you choose to integrate the different components of the study in a coherent and logical way, thereby, ensuring you to effectively address the research problem; it constitutes the blueprint for the collection, measurement, and analysis of data (Vaus, 2001). Research design chat the course for how the research will be carried out; it could be called a research framework. There are various research designs, however, for this research, case study research design and experimental research design is considered and used due to the nature of the research and data required. The case study research design is a quantitative research method concerned with identifying, interpreting and describing what already exist. While, experimental research design which is more of qausi-experimental research to be interpreted in quantity with assigned units. The case study research design was used to determine a baseline model headroom for testing the performance of the light pipe devices for optimum daylighting While quasi-experimental research design was used to investigate the daylight performance on varying the aspect ratio of light pipe, daylight autonomy and useful daylight illuminance within the tropical wet and dry climate of Nigeria.

3.3 Case Study and Case Study Selection Criteria

Since the study involve case study, purposive sampling method is adopted for the study. So, one does not require to calculate the population size. Rather, you justify the selected cases to be studied.Kaduna State University Library (KASU), President

Kennedy Library (PKL) at Ahmadu Bello University and Kashim Ibrahim Library (KIL)at Ahmadu Bello University were chosen based on the following criteria:

i. Academic library within the tropical wet-dry climatic region of Nigeria.
ii. The presence of daylight elements in the library.

3.4 Case Study Variables

Case study research in Architecture goes beyond the documentation and description of the physical characteristics of the built environment. Therefore, to give a full assessment of the selected case studies in the research, they have to be judged based on the research question or proposed design problem.

The parameters for the variables which satisfy the research questions and are to be used to assess the case studies are;

i. Types of building materials
ii. Nature of shading devices used
iii. Building orientation
iv. Use of daylighting strategy

3.5 Research Instrument

Research instruments are those tools that help the investigator collect raw data on the research field, simply because our human organs are not reliable. This research is a quantitative research, though there is a level of qualitative measures, the instruments used are to collect numerical values and visual analysis, they are;

i. Light meter
ii. Cam-coder
iii. Measuring Tape
iv. Sketch Pad

v. Ecotect Simulation Software

3.6 Pilot Study (Reliability and Validity Test).

A pilot study was carried out to validate the research instrument, test the reliability of the results and to test the capability of the researcher to handle the tools. These results were compared and assessed using statistical tests to ensure the reliability of the results. The measurements for the validation study were carried out in two phases (test and retest). These are:

i. Assessment of daylight in a library following the two IEA manuals using a calibrated illuminance metre (Konika Minolta T-10A illuminance metre).

ii. Simulation of daylight in library of same properties as above also following the manuals and using the same values for the simulations.

3.6.1 Assessment of daylighting in virtual reading area of academic library for pilot study retest

The process of daylight assessment for the validation was divided into three stages based on the IEA document as extracted by Salisu (2015).

1. The Decision Phase: In this phase, the type of variables to be measured and the type of instruments to be used, the number of sensors and the time of measurements will be determined.
2. The Preparatory/Monitoring Phase: in this phase involves documenting all the information about the decision phase and monitoring phase were documented.
3. The Concluding Phase: in this phase, the measured illuminances were tabulated to be compared with simulated data.

The decision/preparatory/monitoring document on library reading area for validation studies are shown in both Table 3.1 and Table 3.2 respectively.

Table 3.1**:** Decision/Preparatory/Monitoring Document on library reading area for validation studies

1.	Researcher information
Name	Abdulbasit Adegboye
Organization	Ahmadu Bello University Zaria
Email	adegboyeabdulbasit@gmail.com

Source: Salisu (2015)

Table 3.2a: Decision/Preparatory/Monitoring Document on library reading area for validation studies

2.	**Test room information**
Location	
Electric Lighting	
Time and Date of Measurement	
Elevation	
Latitude and Longitude	
Orientation	
Internal length, width and height	
Veranda width	
Window area	
Glazed Area	
Were the rooms oocupied during measurments?	
Activity period	
Occupants activities	
Sensor Height	

Source: Salisu (2015)

Table 3.2b**:**Decision/Preparatory/Monitoring Document on library reading area for validation studies

3.	**Material photometric properties (Reflectance's and Transmittance)**
Walls	
Floor	
Ceiling	
Desk	
Glazing	
4.	**Variables to be measured, Sensor Position and Measuring Tools**
Variables	Illuminace
Measuring Tool	T-10A Konika Minolta Illuminance Metre
Number of Sensors	
Sensor Height	

Source: Salisu (2015)

3.6.2 Simulation of Virtual reading area of academic library

For retesting, the reading area measured above will be modelled in Autodesk Revit and exported to Ecotect for simulation. The properties in the table 3.2a and 3.2b above will be entered in the model and rechecked after exporting to Ecotect. Since daylight is highly dependent on the weather of a particular region, the weather data in Energy Plus Weather (EPW) format had to be sourced from Weather Analytics (which was affiliated to Energy Efficiency & Renewable Energy (EERE)).

3.7 Methodology applied based on the Research Objectives

In order to achieve the aim of the research based on the objectives, methodologies were applied accordingly. Table 3.3 shows the breakdown of the approach.

Table 3.3a:Methodology applied based on the Research Objectives

Research Objectives		**Methods Applied for Data Collection**
1.	To investigate the performance variables of light-pipe devices that will excellently redistribute and redirect daylighting in academic library.	- Literatures were reviewed with focus on light-pipe daylighting devices as a core lighting system for reading areas in library available today as well as their applications for the study to be places within an existing body of knowledge.
2.	To design a baseline model for testing the performance of the devices for optimum daylighting in reading areas of academic library, in tropical wet-dry climatic zone of Nigeria.	- Literatures were reviewed and - Physical measurement were taken from the cases studied to handle the mathematical model within the tropical wet-dry climatic zone of Nigeria.
3.	To determine daylight performance on changing aspect ratio of light-pipe in academic library in wet-dry climatic zone of Nigeria.	i. The baseline model was modelled for different aspect ratios of light-pipe in Autodesk Revit® architecture Design software ii. Exported the model in (i) to Autodesk Ecotect® for parameters inputs and other technical information required. iii. Exported model in (ii) to Radiance for

		simulation to test the illuminance that is effective for reading spaces as established by IEA in the model. iv. Finally, results were obtained back in Autodesk Ecotect® for interpretation and further analysis.
4.	To determine the Daylight Autonomy, Useful Daylight illuminance (<100, 100-2000, >2000) of light-pipe aspect ratios above that best suits the reading area.	i. Reapeat (i), (ii) and (iii) in methodology of objective 3 above. ii. Exported models in (i) above to Daysim Lighting software for Climate-based daylighting modelling simulation. iii. The simulated results were obtained back in Autodesk Ecotect® for interpretation and further analysis.
5.	Application of the device in designing conventional reading areas for proposed summit university academic library, in wet-dry climatic zone of Nigeria.	i. reviewed literature and cases studied to established the design philosophy, strength and its effects on Academic library within the tropical wet-dry climatic zone of Nigeria.

Source: The Researcher (2018)

Table 3.3b: Methodology applied based on the Research Objectives

Research Objectives	**Methods Applied for Data Collection**
	ii. Proper placement of the efficient ligt-pipe ratio for uniform distribution of daylighting in the conventional reading areas of library within tropical wet-dry climatic zone of Nigeria.

Source: The Researcher (2018)

3.8 Data Analysis

This study used descriptive and parametric analysis. Data from case study was describe and quasi experimental (simulation) was performed. Visual survey and observation are based on the descriptive account as observed, the illustrative qualitative method was used because it is descriptive and add detail examples to the research. Simulation was performed using Ecotect, Radiance and Daysim. Data collected on each case study was analysed and represented in different forms which include:

3.8.1 Photographs

Pictures of the existing academic library were taken and documented showing the concept of daylight design has been reflected; as well as the degree of its application.

3.8.2 Tables

Data collected on this research from case studies and simulation were documented and presented in table, which shows the findings and readings taken from field survey.

3.8.3 Figures

Data collected on the case studies were also documented in form of drawings, such as the academic library plans, sketches and details of daylighting elements.

CHAPTER FOUR

4.0 FINDINGS AND DISCUSSION

4.1 Findings

Findings from literature answers research question one “What are the performance variables light-pipe device that will excellently redistribute and redirect daylighting in academic library reading area?”. Findings from both the literature and case studies survey reveal a baseline model for testing the performance of the devices for optimum daylighting in reading areas of academic library, in tropical wet-dry climatic zone of Nigeria by the use of measuring instrument to answer research question three. While simulation answered research question three and four “How does the changing aspect ratio of light-pipe affect daylighting academic library in tropical wet-dry climatic zone of Nigeria? and to what extent can the Daylight Autonomy (DA), Useful Daylight illuminance [UDI] (<100, 100-2000, >2000) of light-pipe aspect ratios above affects the reading area?”. The study areas are located within 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. The study purposivelysamples three case studies from climate region classified according to the Koppen system as modified by Trewartha and Horn (1980).

4.2 Results from Case Study I: Kaduna State University Library (K.A.S.U.L.), Kaduna State.)

The Kaduna State University library is a center of research and scholarship playing a major role in acquiring, processing and disseminating information resources and services and responding to patrons inquires. It is located alongcoordinate 11^{o}9’10” N and 7^{o} 39’ 35” E. The library is established in 2004 and is made up of conventional library, e-library. It has a total holding of 20,000 volumes of books, 2,712 periodical tittles and e-resources in different subject fields. Rapid progress has been made not only in updating the collection, but also in automating the resources and services of the Library system using LIB + Library Application Software. The PlateVI shows the Library approach.

Plate VI: Exterior view of the KASU Library

Source: field survey (2018).

4.2.1 Site planning and landscaping

The cuboid shape structure is located within the university campus with hedges surrounding the building for proper comfort. Parking spaces are provided just a few meters from the opposite entrance to the building, the building is surrounded by shrubs that allows for proper light and air penetration within the building. This has also help in

Plate VII: Site plan showing the building footprint and parking lots

reducing the amount of glare within the spaces as shown in Plate VII.

Source: field survey (2018).

4.2.2 Daylighting strategy

Among the different daylighting strategies applicable within learning environments, only the side-lighting method was applied within the spaces in the building. Some of the spaces uses one side window lighting while others use double side window lighting, this has contributed to the availability and variation of daylight within the spaces. Plate VIII illustrated the aluminium sliding windows with clear and single glazing were the only source daylight within the spaces.

Plate VIII: View of daylighting strategies using sidelight and courtyard

Source: field survey (2018)

4.2.3 Materials and their reflectance

The building incorporated the use of white finishes for both the walls and the ceilings as demonstrated in Plate IX. This however, gives good reflectance of light within the

Plate IX:Material reflectance of different components in the interior space

spaces for the required visual task.

Source: field survey (2018).

4.2.4 Size and depth of spaces

Most of the spaces within the structure are rectangular in nature with them being lighted from one side and 3.51 meters' headroom as shown in Plate X. The depth is not much and this has helped the spaces achieved a considerable level of daylight for

Plate X:Depth of the Conventional reading area

optimum task performance.

Source**:** field survey (2018).

4.2.5 Ceiling geometry

The ceiling is a normal screed floor slab in the ground floor while the upper floor is made up of celotex ceiling board in Plate XI. The design is plain and so doesn't have much impact in determining the distribution of light within the space.

Plate XI: the ceiling and how the book shelves arrangement affects the quality of light that finally reaches the reading table

Source: field survey (2018)

4.2.6 Nature of shading devices used

The building optimizes vertical shading devices for optimum distribution of daylighting. shading devices are made up concrete on the entire façade as shown in Plate XIII.

Plate XII:The e-library with vertical shading devices

Source: field survey (2018)

4.2.7 Daylight situation of Reading Areas

The daylight level across the reading areas in the library are not uniform thereby leading to constant requirement of electricity to power up the electric bulbs in these areas for comfort. Student also prefer sitting very close to the windows for their visual comfort.

4.2.8 Measured illuminance level at Convention reading area in the library

The illuminance measured in the convectional reading areas were usually bright towards the windowwith illuminance range of 718-1751luxand decreases as the measurement moved away from the window with illuminance range of 110.2-196.7lux.

4.3 Results from Case Study II: President Kennedy Library (P.K.L.), Ahmadu Bello University, Kongo Campus, Sabon-Gari Local Government, Kaduna State.

4.3.1 Background

The president Kennedy Library grew out of the collection of the clerical training centre which itself in 1954 evolved into institute of Administration. It is located in Kongo, Sabon-Gari Local Government, Kaduna State along coordinate $11^{o}5'5''$ N and $7^{o}43'26''$ E of the earth (See Plate XIII). A reading room used to exist at the center. Books dealing with typing, office procedure, government rules and regulations were kept there. The reading rooms were managed by the teaching staff of the center. It then operated from temporary quarters, possibly from a mere classroom, in one of the institute buildings. A new library building solely for library use was officially opened in April, 1964. It originally planned to accommodate 30,000 volumes and seat 106 readers but the building was later extended in 1965 due to increase in book stock of the library and in the student population.

At first, its collection was mainly on law, public administration, local government and economics. Later includes accounting and business administration and today, its collection includes materials of insurance, banking and allied disciplines.

Plate XIII:exterior view of President Kennedy Library

Source**:** field survey (2018)

4.3.2 General site planning and landscaping

The cuboid shape structure in Plate XIV is located within the university campus with trees and hedges surrounding the building for comfort. Parking spaces are provided just a few meters from the opposite entrance to the building, the building is surrounded by shrubs that allows forqualitative air penetration within the building. This has also help in reducing the amount of glare within the spaces.

Plate XIV: Site Plan indicating the Building footprint and parking

Source:Field Survey (2018)

4.3.3 Daylighting strategy

Among the different daylighting strategies applicable within learning environments, only the side-lighting method was applied for spaces in the building. Some of the spaces uses one side window lighting while others use double side window lighting, this has contributed to the availability and variation of daylight within the spaces. Aluminum sliding windows with clear glazing were the only source daylight within the spaces and a head height of 3.1m as shown in Plate XV.

Plate XV**:** An interior view of the windows

Source**:** field survey (2018)

4.3.4 Types of building materials and their reflectance

The building incorporated the use of white finishes for both the walls and the ceilings as illustrated in Plate XVI. These however, give good reflectance of light within the spaces for the required visual task in some areas.

Plate XVI:Material reflectance for the reading table, wall and ceiling

Source: field survey (2018)

4.3.5 Building orientation

The longer axis of the building was oriented along the North-South direction; this feature has given the building the advantage of capturing more daylight while reducing the thermal impact of sunlight.

4.3.6 Size and depth of spaces

Most of the spaces within the structure are rectangular in nature with them being lighted from one side. The depth is much and this has not helped the spaces achieved a considerable level of daylight for optimum task performance as demonstrated in Plate XVII.

Plate XVII: An interior view of the windows and the sitting arrangement

Source: field survey (2018)

4.3.7 Ceiling geometry

The ceiling is a normal screed floor slab in the ground floor while the upper floor is made up of celotex ceiling board and Asbestos as illustrated in Plate XVIII. The design is plain and so doesn't have much impact in determining the distribution of light within the space.

Plate XVIII:P.V.C ceiling used in the Library

Source: field survey (2018)

4.3.8 Nature of shading devices used

The building optimizes both horizontal, vertical and egg-create shading devices for optimum distribution of daylighting. shading devices are made up concrete horizontal, vertical and egg-create on the entire façade as shown in Plate XIX.

Plate XIX**:**exterior view of President Kennedy Library with shading devices applied

Source: field survey (2018)

4.3.9 Daylight situation of reading areas

The daylight level across the reading areas in the library also not uniform thereby leading to constant requirement of electricity to power up the electric bulbs in these areas for comfort. Therefore, Student prefer sitting very close to the windows for their visual comfort.

4.3.10 Measured illuminance level at conventional reading area in the library

The illuminance measured in the convectional reading areas were usually bright towards the windowwith illuminance range of 1221-1971lux and decreases as the measurement moved away from the windowwith illuminance range of 118-275lux.

4.4 Results from Case Study III: Kashim Ibrahim Library (K.I.L.), Ahmadu Bello University, Zaria.

4.4.1 Background

The building is a property of Ahmadu Bello University, located within the Samaru campus. The Kashim Ibrahim Library dates back to 1955 when the Nigerian college of Arts, science and technology, the fore-runner of the university was established. It is situated along 11^{o}9’12” N and 7^{o}39’9” E coordinate on the planet earth. It has a capacity for over 500,000 volumes of books and a reading space for almost 2,000 patrons. It also provides the opportunity for external researchers and postgraduates to request the use of its extensive catalogue of books and journals. It is a structure composed of a ground floors, two suspended floor and a roof top- having both the e-library and the traditional library under one roof as evident in Plate XX.

Plate XX**:**Approach view to the Kashim Ibrahim Library

Source: Field survey (2018)

4.4.2 General site planning and landscape.

A significant percentage of the site is completely built up with the parking area restricted to almost 15 meters away from the main structure as illustrated in Plate XXI. Hardscape elements at the building's approach. However, on southern and western part of the site, there is a compact arrangement of trees and shrubs helping in defining pedestrian circulation as well as serving as a sufficient shading device against direct light into the reading spaces which dominates that part of the building. The library's site has about 45 accessible parking spaces.

Plate XXI**:** The site location of the Kashim Ibrahim library, ABU Zaria

Source: Google earth images (2018)

4.4.3 Spatial organisation and design.

The Kashim Ibrahim library (KIL) is a two-storey structure of three (3) floors as illustrated in Figure 4.1, 4.2 and 4.3 respectively. It houses different spaces within a single building for effective learning with parking spaces few meters away from the opposite entrance of the building. The building comprises of several functions offering different services. It features two major entrances; one into the main library while the other leads to the digital section of the library. The first visible part of the library upon entering is the exhibition hall which is bounded by timber-coated columns.

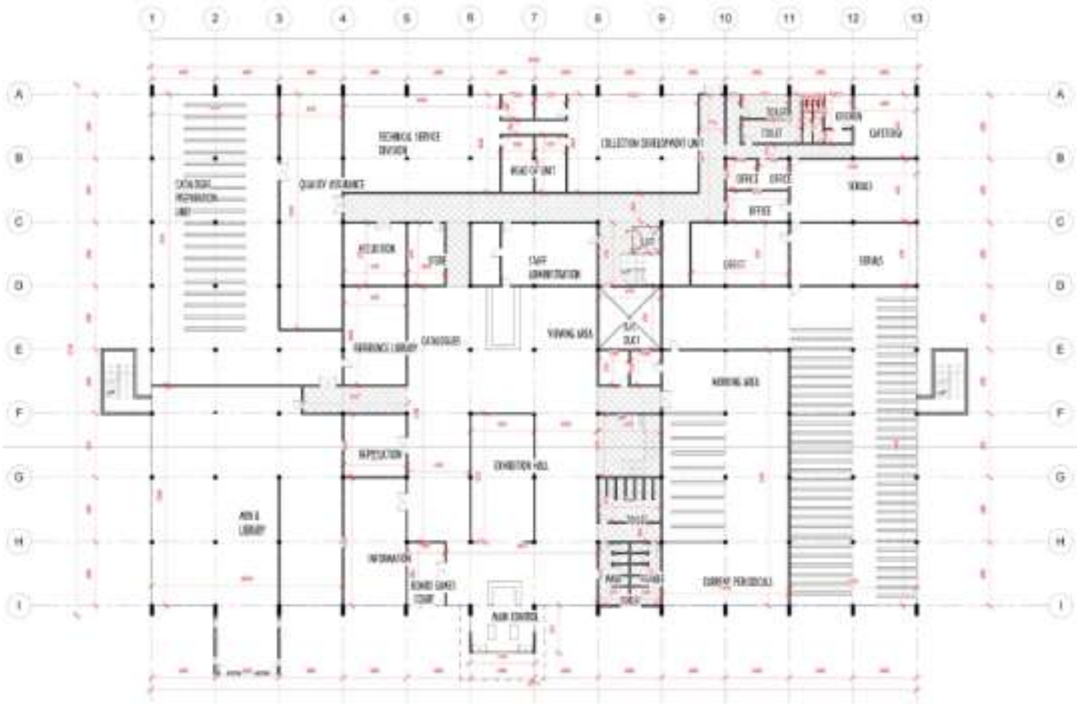


Figure 4.1**:** The ground floor plan of the Kashim Ibrahim library showing spatial interrelationships

Source: Fieldwork (2018)

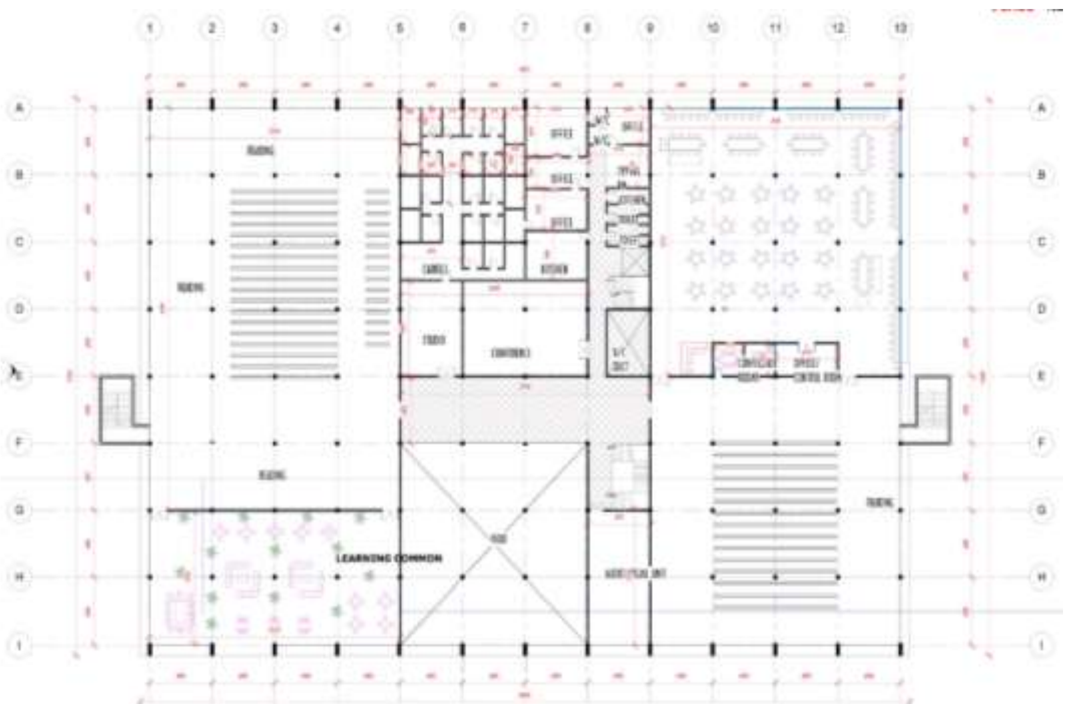


Figure 4.2: The first-floor plan of the Kashim Ibrahim library showing spatial interrelationships

Source: Fieldwork (2018)

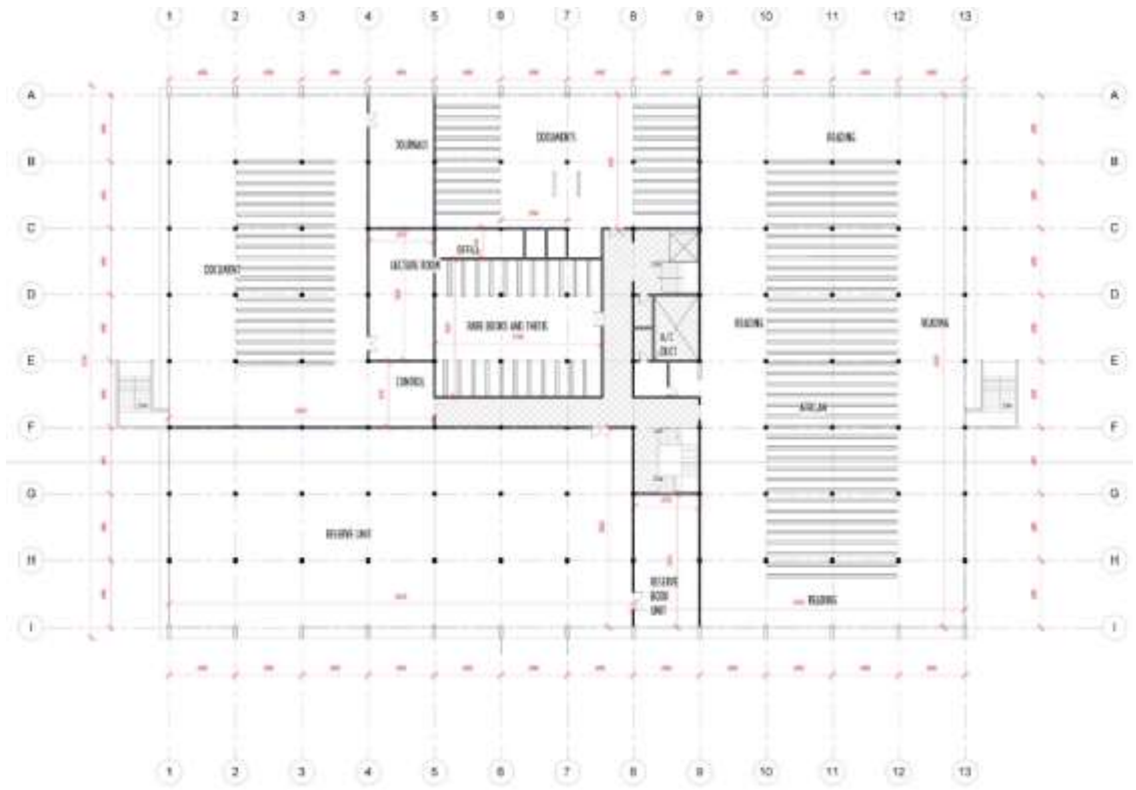


Figure 4.3:The second-floor plan of the Kashim Ibrahim library showing spatial interrelationships

Source: Fieldwork (2018)

The building comprises of three floors which can be accessed making use of a strategically located staircase at the right wing of the library. The entrance hall, security desk, exhibition space, relaxation area are the major functions that makes up the ground floor. The first floor houses the reading areas while the last floor accommodates the reference room and post graduate section, among other supporting facilities. Detached from the buildings is an escape staircase which is linked to the main building using a corridor barricaded by metallic handrails.

4.4.4 Architectural character and circulation.

The Kashim Ibrahim Library building adopted the beam and column structural system. The structure can be said to be an epitome of a good interplay of verticality and horizontality in design, this is evident in the use of adjustable horizontal shading devices in between the vertically stationed columns in controlling the amount of light received into different parts of the building interior, it also creates a physical balance. The main entrance door to the library is sized 1800mm with no change in floor level, and as such relatively convenient for the disabled library patrons. The hallways and corridors leading to the different sections of the library are more than 1800mm in width there aiding in free flow of movement. For vertical circulation, the staircases provided within the library interior is 1500mm wide with a thread of 300mm, 150mm riser, a landing of 1800mm and expectedly, a wooden handrail of 900mm height.

4.4.5 Daylighting strategy used

Among the different daylighting strategies applicable within learning environments, only the window lighting method was applied within the spaces in the building. Some of the spaces uses one side window lighting while others use double side window lighting, this has contributed to the availability and variation of daylight within the spaces. Aluminium sliding windows with clear glazing and a headroom of 3.15m were the only source of daylight within the spaces as shown in Plate XXII.

Plate XXII:An interior view of the windows

Source: field survey (2018)

4.4.6 Types of Building Materials and their reflectance

The interior wall of the building is plastered with cement/sand mortar and painted mostly white for high reflectance of light in the reading areas. This however, gives good reflectance of light within the spaces to enhance the required visual task. Although findings from field survey shows that the side windows with louver shading device give no optimum performance for the reading area in the library when compared to standard reading area lighting requirement. This is due to the deep planning of the reading spaces, different wall paintings, louvre shading devices and distribution daylight with side windows only (see Plate XXIII).

Plate XXIII:Material for the floor finishes

Source: field survey (2018)

4.4.7 Building orientation

The building has a proper consideration for orientation. Simply because, the longer axis of the building was oriented along the North-South direction; this feature has given the building the advantage of capturing more daylight while reducing the thermal impact of sunlight.

4.4.8 Size and depth of spaces

Most of the spaces within the structure are rectangular in nature with them being lighted from one/two side windows. The windows along the perimeter wall has been of vital help in providing daylight into the building. Though, the depth is much and this has not helped the spaces to achieved a considerable level of daylight for optimum task performance as shown in Plate XXIV. Moreover, the headroom measured is 3.15 meters for the conventional reading areas.

Plate XXIV:Interior depth of the reading area in the library

Source: field survey (2018)

4.4.9 Ceiling geometry

The ceiling is a normal screed floor slab in the ground floor while the subsequent floors are made up of celotex ceiling board painted white as shown in Plate XXV.

Plate XXV:interior view showing material used for the ceiling finishes

Source: field survey (2018)

4.4.10 Nature of shading devices used

The building optimizes both horizontal and vertical shading devices for optimum distribution of daylighting as demonstrated in Plate XXVI. shading devices are made up aluminium horizontal on the northern and southern façade while aluminium and concrete vertical on eastern and western façade of the building.

Plate XXVI: Exterior view of Kashim Ibrahim Library shading devices applied

Source: field survey (2018)

4.4.11 Daylight situation of reading areas

The daylight level across the reading areas in the library are not uniform thereby leading to constant requirement of electricity to power up the electric bulbs in these areas for comfort. Student also prefer sitting very close to the windows for their visual comfort.

4.4.12 Measured illuminance level at convention reading area in the library

The illuminance measured in the convectional reading areas were usually bright towards the windowwith illuminance range of 518-1125lux and decreases as the measurement moved away from the windowwith illuminance range of 98-235lux.

4.5 Summary of Case Studies

After studying the existing cases of academic library within the tropical wet and dry climate zone of Nigeria considering both the research aspect and design philosophy of such building, table 4.1a and 4.1bpresented the inference with remarks from the cases studied.

Table 4.1a:Summary of the Cases Studied for the Research.

Case study variables	**Case 1 (K.A.S.U. L. Kaduna State.)**	**Case II (P.K.L., A.B.U. Zaria.)**	**Case III (K.I.L, A.B.U. Zaria.)**	**Remarks**
Types of building materials and reflectance	1)The building incorporated the use of white finishes for both the walls and the ceilings. 2)Single glazed windows	1)The building incorporated the use of white finishes for both the walls and the ceilings. 2)Single glazed windows	1)The interior wall plastered with cement/sand mortar and painted mostly white for high reflectance of light in the reading areas. 2)Single glazed windows 3)Celotex ceiling board painted white	The paints on the materials helps in enhancing the required illuminance for visual task.
Nature of shading devices used	The building optimizes only vertical shading devices.	The building optimizes vertical, horizontal and egg-create shading devices.	The building optimizes both horizontal and vertical shading devices for optimum distribution of daylighting.	the shading devices affects the daylit spaces as a result of improper design consideration.
Building orientation	The longer axis was considerably was oriented along the North-South direction	The longer axis of the building was oriented along the North-South direction	longer axis of the building was oriented along the North-South direction	There is proper consideration for orientation to capture higher daylighting.
Use of daylighting strategy	Side-lighting strategy	Side-lighting strategy	Side-lighting strategy	Side-light was the only strategy employed. This can be improved

				using toplight such as light-pipe.

Source: Fieldwork (2018)

Table 4.1b: Summary of the Cases Studied for the Research.

Case study variables	**Case 1 (K.A.S.U. L. Kaduna State.)**	**Case II (P.K.L., A.B.U. Zaria.)**	**Case III (K.I.L, A.B.U. Zaria.)**	**Remarks**
Other variables 1) Ceiling geometry 2) Size and depth of spaces 3) Daylight situation and illuminance level at Reading areas)	1) Flat Ceiling geometry. 2) Deeply planned with 3.5 m headroom. 3) No uniform daylight across the work-plane used for reading 4) higher lux close to windows but decreases when move away from the window.	1) Flat Ceiling geometry. 2) Deep Spaces with 3.10 m headroom. 3) No uniform daylight across the work-plane used for reading 4) higher lux close to windows but decreases when move away from the window.	1) Irregular Ceiling geometry. 2) The depth is much with 3.15 m headroom. 3) Improper distribution of daylight across the work-plane used for reading 4) higher lux close to windows but decreases when move away from the window.	1)The ceiling has not helped the spaces achieved a considerable level of daylight for optimum task performance. 2) Spaces are deeply planned and average headroom from the cases studied is about 3.25 meters. While the average work-plane for reading is about 0.81 meters. 3) higher lux close to windows but decreases when move away from the window

Source: Fieldwork (2018)

In addition to what the researcher observed from the field, proper attention was not given to students' locker positioning within the building thereby resulting to theft while some academic library even gives little or no attention to provision of students' lockers. Moreover, the universal design approach for the existing were given little or no consideration in all the cases studied. Also, no attention is given to environmental sustainability in terms of bicycle parking provisions to mitigate the greenhouse effect.

4.6 Validation Studies

For reliability and acceptability, researcher used the measured result from the field study of existing daylight situation of Kaduna State University Library and simulated illuminances for validation were analyzed. The simulated results were obtained using Autodesk Ecotect Analysis, Radiance and Daysim Lighting software. The data were analysis using descriptive statistics; visually, the data were analyzed using a two-line graph for comparison, while statistical tests for mean bias error, root mean square and percentage error were used to analyzed the data. Table 4.2 listed the characteristics of the Kaduna State University Library conventional area to be simulated and its state when the research is carried out.

Table 4.2:Information on measured and simulated Conventional reading area in the library.

Location	**Kaduna State University Library, Kaduna.**
Electric Lighting	off
Date and Time of Measurement	8th of May, 2018 by 2:24 p.m.
Latitude and Longitude	11° 9’10” N 7° 39’35” E
Orientation	South-east 89°
Internal length, width and height	12120mm x 11700mm x 3540mm
Veranda width	1800mm
Window area	800mm x 2030mm (12 numbers)
Were the rooms occupied during measurements?	Yes (partially)
Activity period	Yes
Occupants activities	Reading
Material photometric properties (Reflectance’s and Transmittance)	
Walls	0.646
Floor	0.402
Ceiling	0.823
Desk	0.339
Glazing	0.582
Variables to be measured, Sensor Position and Measuring Tools	
Variables	Illuminance
Measuring Tool	Konica Minolta (IlluminanceMeter T-10A)
Number of Sensors	12 points
Sensor Height	810mm

Source: Field study (2018)

Table 4.2 also describes the variable measured, position of sensor and the measuring tools used. The illuminance level was recorded at twelve sensor pointswith a height of 810mm from floor level in clear sky condition between 2:24-2:30pm.

4.6.1 Simulation and Measured Results

The measured and simulated result from field survey, the difference in simulation and measured result (Ɵ) and $(Ɵ)^2$are all shown in Table 4.3.Also, Figure 4.4 represent the result on plan view (measured illuminance level) while Figure 4.5 is simulated illuminance level on plan view. Grid system help in positioning the sensors point for simulation as in measured results from the field.

With the sensors points on the same position, the average illuminance level for the actual measurement shows 662.91lux while the simulated results recorded during the testing was 669.17lux. Variance in actual measured and simulated results can be ascribed to the changing irradiance of the sun as well shading from the surrounding building and vegetation, which is beyond the researcher's control. Although, for a validation simulation to be tolerable as reliable, the values of mean bias error (MBE) have to fall within a range of -15% to 15%, and that of root means square error (RMSE) values have to be less than 35% (Reinhart 2009).

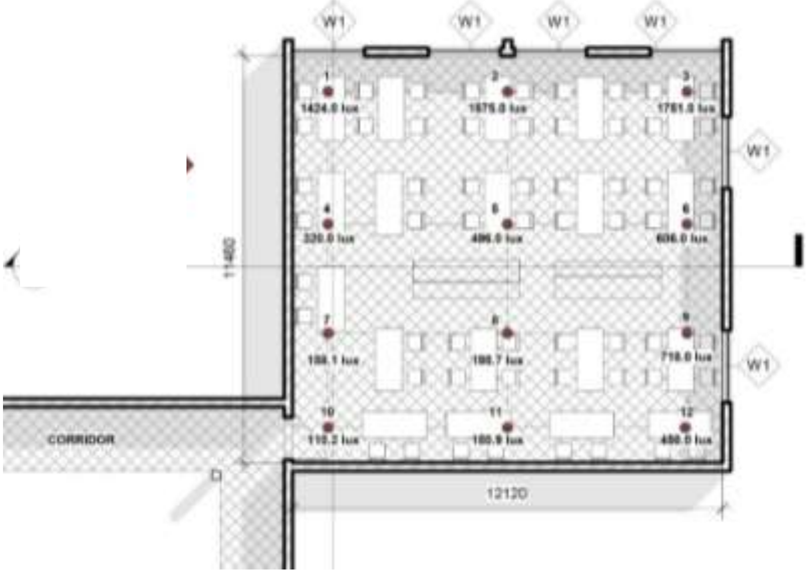


Figure 4.4:The measured Illuminances of a Conventional reading area, Kaduna State University, Kaduna.

Source: Field study (2018)

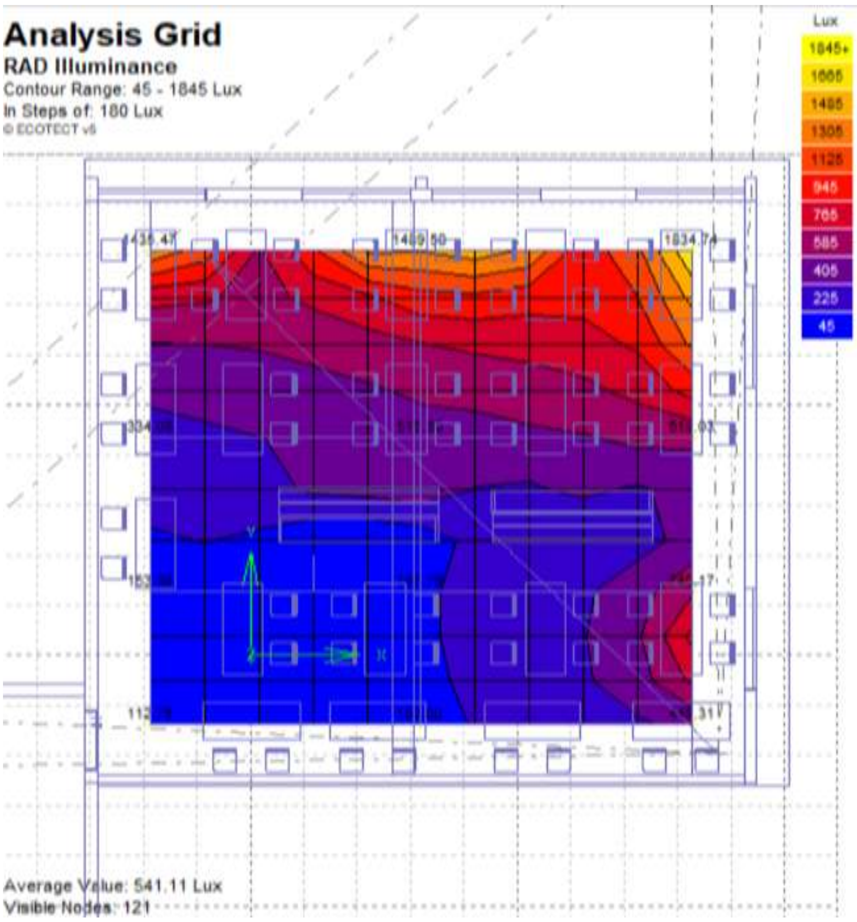


Figure 4.5:The Simulated Illuminances of a Conventional reading area, Kaduna State University, Kaduna.

Source:Researcher (2018)

Table 4.3:Measured and simulated illuminances in the convention reading area, Kaduna State University Library

Sensor's Points	Measured (Lux)	Simulated (Lux)	Sim- Mea (Ө)	$(Ө)^2$
1	1424.00	1435.47	11.47	131.56
2	1575.00	1489.50	-85.50	7310.25
3	1751.00	1834.74	83.74	7012.39
4	320.00	334.08	14.08	198.25
5	496.00	515.80	19.80	392.04
6	606.00	615.03	9.03	81.54
7	158.10	153.38	-4.72	22.28
8	195.70	197.79	2.09	4.37
9	718.00	740.17	22.17	491.51
10	110.20	112.75	2.55	6.50
11	150.90	152.00	1.10	1.21
12	450.00	449.31	-0.69	0.48
Average Sum	662.91	669.17		
Sum			75.12	15652.37

Source: Field study (2018)

The above table shows that sensor points 1, 2, 3, 6, and 9 closest to the windows receives the highest daylight and decreases as the point moves further away from the window deep into the building. Also, from the results for above tests, it can be deduced that there is an indication of relationship, which is also significant between the measured and simulated values of illuminances in the model.

To further reinforce the study, Table 4.4 below shows the condition of the existing conventional reading area considering the Daylight autonomy (DA), Useful Daylight Illuminances greater than 100 (UDI >100), Useful Daylight Illuminances from 100-2000 (UD1 100-2000) and Useful Daylight Illuminances greater than 2000 (UDI >2000).

Table 4.4:The Climate-Based Modelling Daylight test for the Conventional reading area, Kaduna State University Library

Indicators	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	Average (%)
DA	99.0	99.0	99.0	75.0	93.0	95.0	0.0	15.0	99.0	0.0	7.0	97.0	68.75
UDI <100	0.0	0.0	0.0	1.0	1.0	1.0	2.0	2.0	0.0	3.0	2.0	1.0	1.08
UD1 100-2000	34.0	26.0	8.0	99.0	99.0	99.0	98.0	98.0	36.0	97.0	98.0	98.0	74.17
UDI >2000	65.0	74.0	92.0	0.0	0.0	0.0	0.0	0.0	64.0	0.0	0.0	2.0	24.73

Source: Field study (2018)

4.6.2 Visual analysis

Looking at the Table 4.3, it is difficult to trace a relationship due to numeric values. The data’s is plotted on a graph inFigure 4.6 to show the interrelationship between the measured and simulated illuminances in conventional reading area of Kaduna State University Library. Looking at the preceding Figures, the results are not easily indicative of any relationships. Upon comparing the descriptive graphs visually, it can be seen that the simulated illuminances followed the measured illuminances closely. A good qualitative agreement can be seen with the peaks and troughs of the simulated illuminances following that of the measured. However, there are some deviation which is statistically calculated to show it levels of significance and relationship.

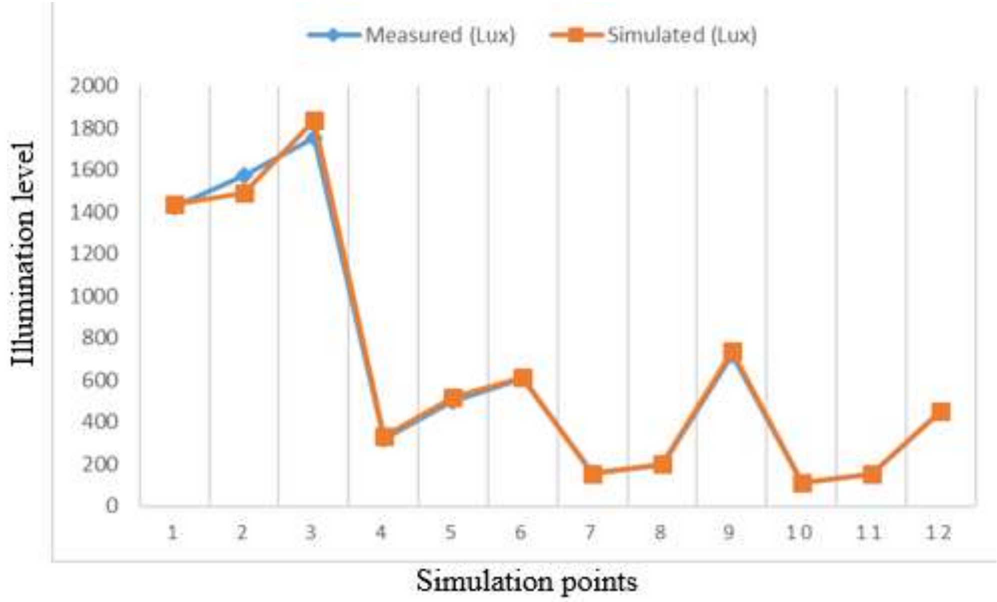


Figure 4.6:Measured and simulated illuminances, Kaduna State University conventional reading area, Kaduna

Source: Field study (2018)

4.6.3 Tests for Relationships

In order to ensure the computational reliability of the proposed daylight performance of light pipe, validation methods have to be applied to assess the model's validity. Thus, rather than to rely on a single statistical procedure, model evaluation was carried out using two statistical procedures the mean bias error percentage (MBE) and the root mean square error percentage (RMSE) (Efim & Kudish, 2009; Katiyar, Kumar, Pandey, Das, 2010, & Gana, 2017). Below is the summary of statistical tools employed throughout this study.

4.6.3.1 Mean bias error (MBE)

Mean bias error percentage (MBE) or Percentage average deviation (PAD) according (Zhang, 2002) simply means that percentages are an indication of the average deviation of the predicted values from the measured values and provide information on the long-term performance of the models. Positive values demonstrate that the predicted values overestimate the measured values while negative values demonstrate an underestimation of the measured values (Falayi, Rabiu, & Teliat, 2011).

The %MBE for this study is;

$$\%MBE = \frac{100}{Xmea\ (ave)} \sum \frac{(Xsim - Xmea)}{N}$$

Where;

X_{sim} is the simulated illumination value,

X_{mea} is the measured value of illumination,

$X_{mea(av)}$ is the average value of measured illuminance and

N is the frequency of measured illumination value (No of sensor points).

Data;

$X_{mea(av)} = 662.91$

$\sum_{(Xsim\text{-}Xmea)} = 75.12$

$N=12$

Therefore %MBE= 0.94%

4.6.3.2 Root mean square error percentage (RMSE)

The RMSE percentage is a measure of variation of predicted values around the measured values and is always a positive percentile and it provides information on the short-term performance of the models and the lower its value, the more accurate the prediction.

$$\%RMSE = \frac{100}{Xmea\ (av)} \sqrt{\frac{1}{N}} \sum (Xsim - Xmea)^2$$

Where;

X_{sim} is the simulated illumination value,

X_{mea} is the measured value of illumination,

$X_{mea(av)}$ is the average value of measured illuminance and

N is the frequency of measured illumination value (No of sensor points).

Data;

$X_{mea(av)} = 662.91$

$\sum(Xsim-Xmea)^2 = 15652.37$

$N=12$

Therefore % RMSE = 5.45%

The above results of %MBE= 0.94% and % RMSE = 5.45% shows that the instrument for test of daylight performance of the variable is reliable. For a validation with simulation data to be acceptable as reliable, the values of mean bias error (%MBE) have to fall within a range of -15% to 15%, while for RMSE, the values have to be less than 35% (Reinhart ,2009). The result from the test shows a strong relationship which is also significant between the measured and simulated values of illuminances in the model.

4.6.3.3 T-Test for relationship

To further strengthen the relationship between the simulated and measured values, a T-test was conducted using SPSS software. Table 4:5 shows the T-test for relationship between the simulated and measured values.

Table 4.5:T-test for relationship between the simulated and measured values

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Lux	Equal variances assumed	.000	.993	.026	22	6.26000	-494.92228	507.44228
	Equal variances not assumed			.026	21.999	6.26000	-494.92320	507.44320

Source: Field study (2018)

Since the Sig. value is greater than 0.05, column under the Sig.=0.99(when rounded up) were considered. The Sig. value, shows that the simulated and measured values were relatively the same (no significant different).

4.7 Evaluation Studies

For the entire research, the aspect ratio of light pipe was analyzed for better performance and also, based on daylight autonomy, continuous daylight autonomy and useful daylight illuminances (UDI100, UDI100-2000, and UDI2000). For all performance metrics, the same annual illuminance profiles were based on Daysim calculations. The simulation time step was one hour and default radiance simulation parameters were being used for the computer simulation.In the test for the performance of light pipe, the independent variables; sky condition are fixed while the dependent variables; light pipe aspect ratio is adjusted to test for its daylight performance. The results are recorded to score the extent to which aspect ratio of light pipe affect it daylight performance.Table 4.6 is the list of the variable to be tested for. While Table 4.7 represent sensor position on the room.

Table 4.6:The conditions of simulation

Condition	Light-pipe diameter (mm)	Light-pipe height (mm)	Aspect ratio	Area lit (m^2)
Aa	300	1800	1/3	9
Ab	600	1800	1/2	9
Ac	900	1800	1/2	9
Ba	900	2700	1/3	9
Bb	900	3000	1/3	9
Bc	900	3300	1/4	9

Source: Researcher, 2018

Six conditions were set for the test of light pipe aspect ratio performance. Condition Aa, Ab and Ac vary in diameter with constant height while condition Ba, Bb, Bc vary in height with constant diameter.

Table 4.7:Sensor positions in the test room

Point	Position in the test room
Sensor A	800mm from floor level
Sensor B	Top entry of the test room

Source: Researcher, 2018

4.7.1 Room reflectance

In architecture, Light Reflectance Value (LRV) is a measure of visible and usable lightthat is reflected from a surface when illuminated by a light source (Jefferies, 2010).Light distribution is highly dependent on room reflectance. In general, the ceiling is themost important light-reflecting surface (Queen, 2008). The IESNA guideline of70/50/20 (ceiling/walls/floor) for minimum reflectance follows this principle(Mankova, Hraska, & Janak, 2009). Therefore, for the study the reflectance's index ofthe material used are listed on Table 4.8.

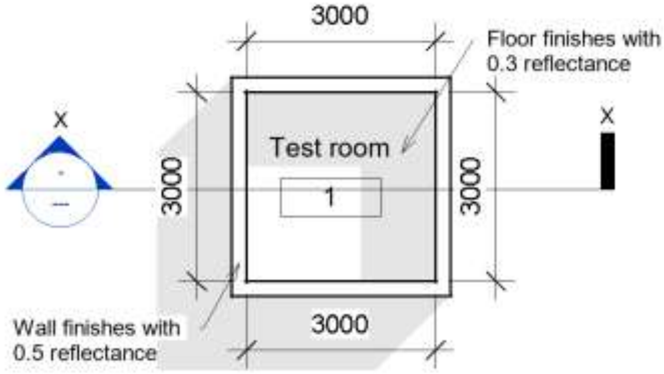
Table 4.8:Material reflectance for the simulation

Material index	Reflectance index
Mirrored light pipe	0.98
Wall	0.55
Floor	0.30
Ceiling	0.75

Source: Researcher, 2018

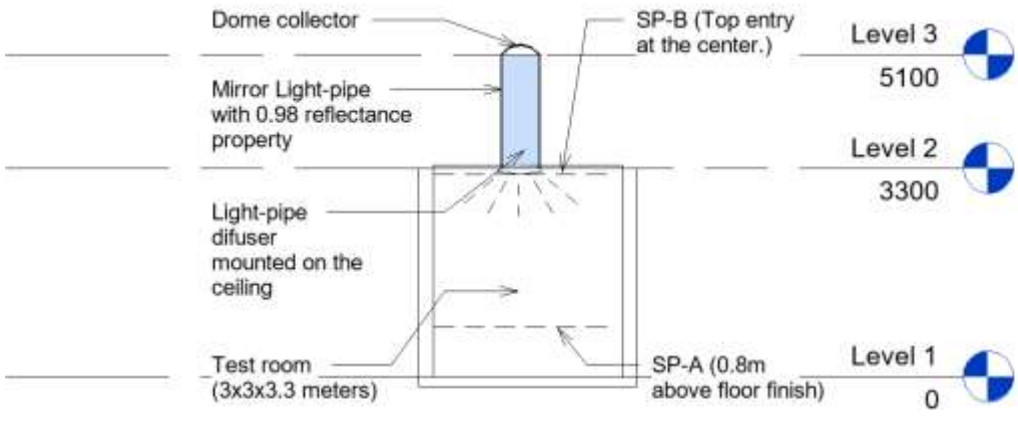
4.7.2 Software application and computer model processes

The parameters were inputted into the Ecotect®, Radiance and Daysim® software so as tocompare and validate results. The room was modelled in Revit® architecture Designsoftware as seen in Figure 4.7.



Plan

Section



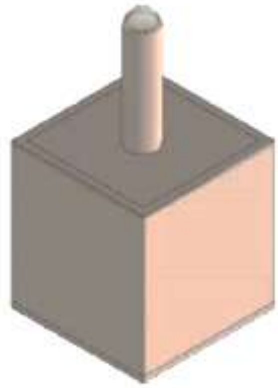


Figure 4.7:The Baseline Model

3-D Model

Source: Researcher (2018)

Further modelling was carried out through the employment of the same process under a given number of conditions as seen in Table 4.6. The sensors were kept as listed in Table 4.7 for all the simulations carried out under conditions Aa, Ab, Ac, Ba, Bb and Bc. The result is shown in Table 4.9

Table 4.9:Test result and Generation of design frame work for light pipe design

Condition of simulation	Sensor-A light level (lux)	Sensor-B light level (lux)	Area lit (m^2)
Aa	187.20	190.54	9
Ab	249.70	276.44	9
Ac	510.15	557.38	9
Ba	493.15	520.38	9
Bb	473.09	484.78	9
Bc	428.09	449.09	9

Source: Researcher, 2018.

The above simulation result shows that, the illuminance level at Sensor Point B (top entry of light) 190.54 lux which later increases to 276.44 lux with increase in diameter of light pipe by 150mm then to 557.38 lux with additional 150mm increase. While the test for effect of increasing diameter of light pipe on daylight performance at working plan (800mm above the floor) reveals that with increase in diameter of light pipe, there was steady increase in illumination level from 187.20-249.70 lux and 249.70-510.15 lux. Therefore, condition Ac at sensor point A is within the minimum required illumination for reading. Considering the increase in height of light pipe in condition Ba, Bb and Bc, results show that there is decrease in average illumination (light level) from 520.38-484.78 lux and 484.78-449.09 lux at the test room sensor point B(Sensor at top entry) while the average light level decreases from 493.15-473.09 lux which is slightly below the standard illumination at working plane for effective reading in a conventional reading area as established by previous study and 473.09-428.09 lux at the test room sensor A(working plane) . The result at different sensor points are shown in Figure 4.8, 4.9 and 4.10 respectively in respect to light pipe aspect ratio variation.

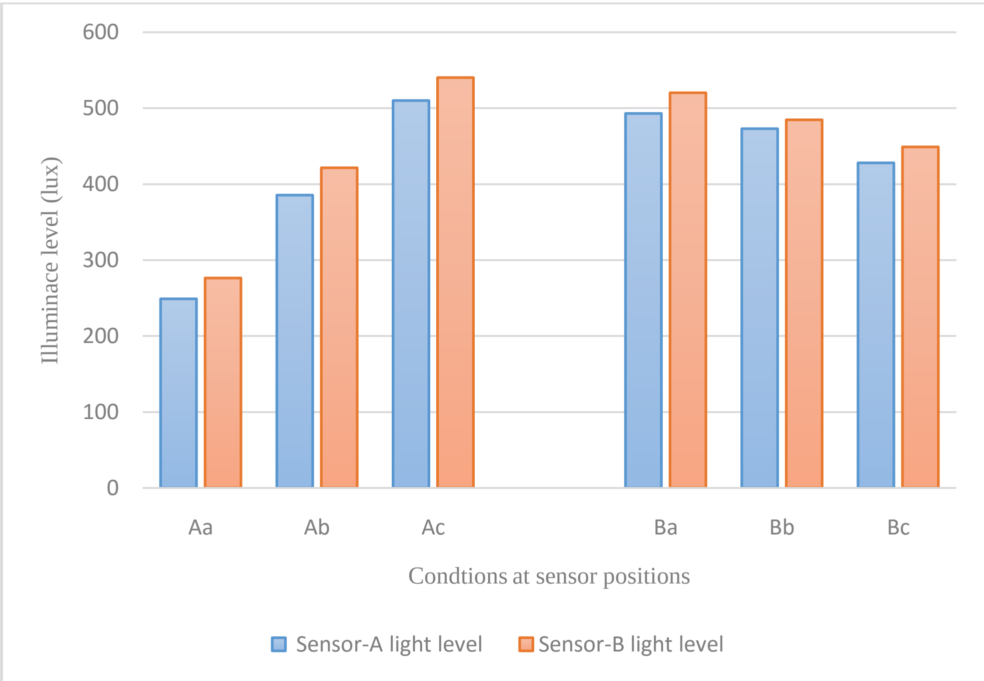


Figure 4.8:Illumination Quality for all Conditions at all Sensor Positions

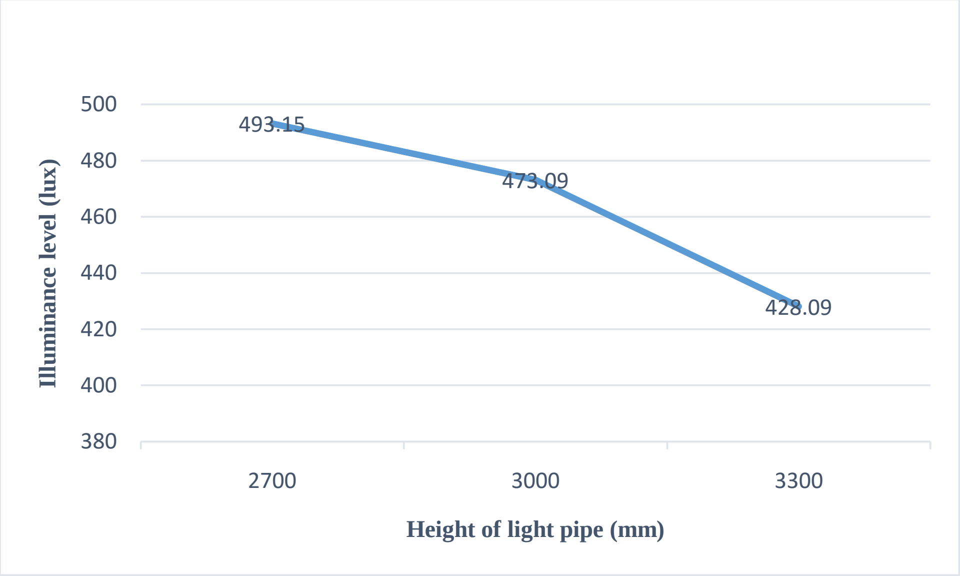


Figure 4.9:Daylight performance of light pipe with increase in height

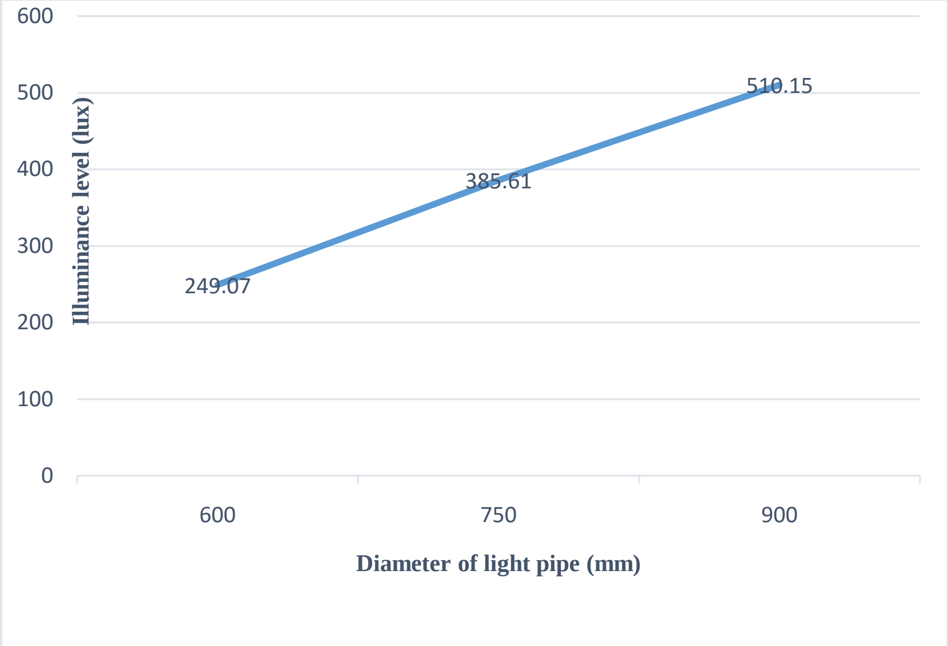


Figure 4.10:Daylight performance of light pipe with increase in diameter

Moreover, Table 4.10 shows the average daylighting in respect to the climate-based daylight modelling (CBDM) framework. While Figure 4.11 illustrated the CBDM in Chart.

Table 4.10:The conditions of light-pipe simulated at work plane considering the CBDM framework on average

Condition (Sensor-A/work-plane)	D.A.	UDI <100	UD1 100-2000	UD1 >2000
Aa	0.00	44.00	56.00	0
Ab	0.00	15.00	85.00	0
Ac	78.00	2.00	98.00	0
Ba	19.00	3.00	97.00	0
Bb	8.00	5.00	95.00	0
Bc	2.00	6.00	94.00	0

Source: Researcher, 2018.

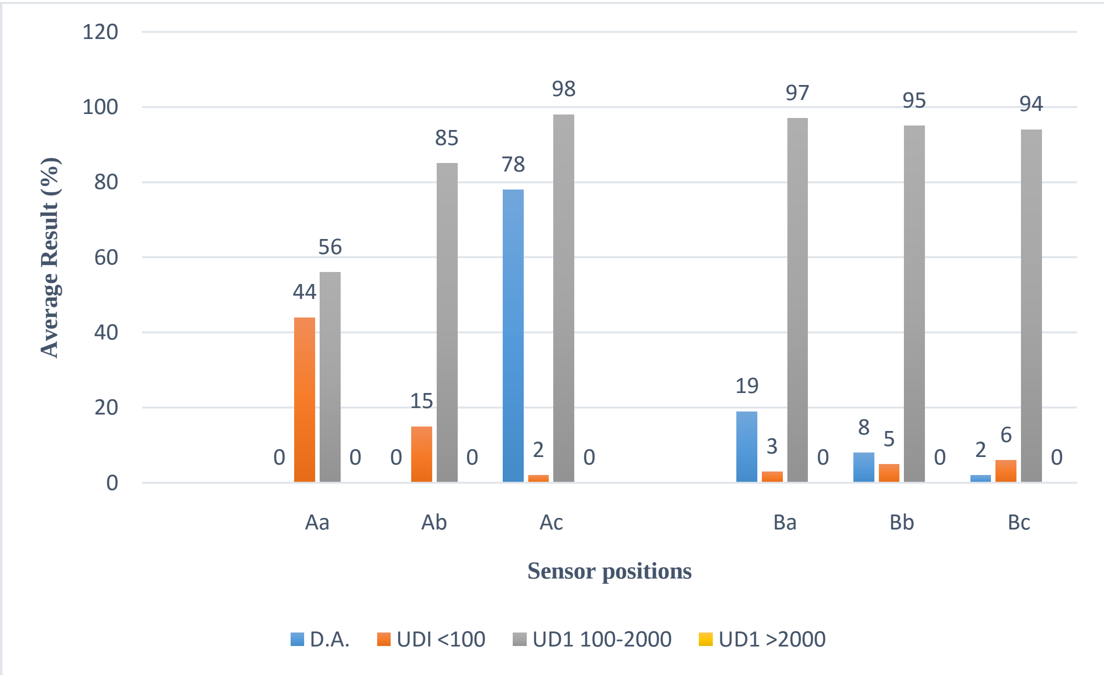


Figure 4.11:Daylight performance of light pipe at condition Aa, Ab, Ac, Ba, Bb and Bc on working plan for D.A., UDI<100, UDI 100-2000, and UDI>2000.

4.8 Analysis Summary

The test for efficiency of light pipes in a baseline model box (3m x 3m x 3.3m) was modelled and exported to Ecotect® Radiance® Daysim® and the illumination received in the box was tested. Varying lengths of light pipes while keeping the diameters of the Light-pipe constant to test how far the illumination within the Light-pipes can travel while meeting the minimum illumination requirement for a conventional reading spaces in library. The results show that the illumination increases for condition Aa to Ab and Ac at sensor A (249.70 lux to 385.61 and 510.15 lux respectively) with increase in diameter at constant length. While, at condition Ba, Bb and Bc, the illumination level decreases from 493.15 to 473.09 and 429.09 respectively with constant diameter but varying length. The simulation test for effect of both diameter and length of light pipe, shows that light pipe with aspect ratio of 1/2 give optimum performance for daylight requirement in conventional reading area design in wet and dry tropical climate. The Daylight Autonomy of 78% and Useful daylight illuminance at condition Ac of Table 4.10 further strengthen the aspect ratio of light-pipe 1/2 to be highly effective for visual comfort in the conventional reading spaces design for wet and dry tropical climate in Nigeria.

4.9 Summary of Findings

Research Question two: Findings from both the literature and case studies survey, a baseline model for testing the performance of the devices for optimum daylighting in reading areas of academic library, in tropical wet-dry climatic zone of Nigeria by the use of measuring instrument were established. The average headroom from the various cases studied is about 3.3 meters and various literature reviewed test the performance of light-pipe using 3 by 3 meters enclosed box. This help the researcher to generate a baseline model of 3X3X3.3 meters' test room that will effectively affect the conventional reading areas. Also, the average work-plane off-set from the ground for reading is 800mm.

Research Question three and four: “How does the changing aspect ratio of light-pipe affect daylighting in conventional reading area of academic library in tropical wet-dry climatic zone of Nigeria? and “To what extent can the Daylight Autonomy (DA), Useful Daylight illuminance [UDI] (<100, 100-2000, >2000) of light-pipe aspect ratios above affects the reading area?”. For a test room of 3x3x3.3m, an increase in diameter of light pipe in series with other variable keep constant, there was steady average increases in illuminance output of 17.96% with aspect ratio of between 1/2 to 1/3. But, For the increase in length of light-pipe with constant diameter 900mm, the illuminance level slightly decreases with illuminance output 3.54%. the illuminance recorded from the study shows that a light with aspect ratio of 1/2 with 900mm diameter and 1800mm length is 510lux at working plane which along-side is able to meet the minimum requirement as established by IESNA and Kan. In addition, Climate-based Modelling Daylight approach also reinforced the performance of light-pipe aspect ratio of 1/2 to be effective for this study.

CHAPTER FIVE

5.0 DESIGN REPORT

5.1 Introduction

This chapter gives concise information about the design proposal. It is an attempt to answer the last research question via demonstration of architectural design. It contains the design brief and brief development, site location details, analysis of the site, design parameters from the site analysis, site zoning/organization/development, site planning, design considerations and philosophy/ concept, schedule of accommodation, and strategies of daylighting demonstrated on the design of a proposed Academic library, Summit University, Offa, Kwara State.

5.2 Brief and Brief Development

Summit University, Offa, the University of Ansar-Ud-Deen Society of Nigeria (ADSN), is a product of many years of painstaking planning and harnessing of human and material resources. Indeed, the Society remains one of the foremost religious organizations with impressive record in the provision of education for Nigerian students at primary, secondary and tertiary levels irrespective of their religious, ethnic, geographical and political affiliations. The vision to establish a faith-based university with world-class standard of teaching, research and community service began on 27th February, 2002, when the National Education Board of the Ansar-Ud-Deen Society of Nigeria set up the Higher Education Committee with a view to actualizing the dreams and yearnings of members. On 3rd April 2004, the National Executive Committee of the Society resolved to locate the University at Offa, Kwara State. On June 2005, the Society applied formally for operating licence for its private university from the National Universities Commission (NUC) Abuja. Following the recommendation of the

National Universities Commission, the Federal Executive Council of the Federal Republic of Nigeria on 25 February 2015 gave its approval to Ansar-Ud-Deen Society of Nigeria to operate Summit University Offa as a private university. The formal presentation of the provisional licence to the Society was held at a ceremony presided over by Mallam Ibrahim Shekarau, the Honourable Minister of Education on 5 March 2015 at the National Universities Commission, Abuja. The Pioneer Vice-Chancellor, Prof H.O.B. Oloyede assumed duty on 1st September, 2016 to commence preparation for the beginning of academic activities in the University.

In addition, the Universities is granted the right of running a variety of programs at undergraduate level though, the society has a projection of running graduate and associate programs in the nearest future. therefore, the institution's management board is proposing a new library to carter for the academic needs of the Summit University community currently alongside with future projection population. The proposed library should have the capacity to accommodate 900 reading spaces for both undergraduate program and the future programs while meeting other basic requirements which includes;

i. Administrative areas
ii. Internet café
iii. Better facilities for social exchanges
iv. Quiet individual study areas (carrels)
v. Improved accessibility and ease of wayfinding
vi. Wi-Fi garden
vii. Sustainable parking spaces.

Deduction from the brief; It is imperative that the proposed design meet the functional requirement of a public space for which it is design for and make statement about the issue at stake, this is achieved through the understanding of the site. A thorough analysis of the functional and organizational requirement of the library at the various units

5.2.1 Provide facilities

Exhibition area: Easily accessible from the main entrance, but with a distinct identity and with suitable security, an area for exhibitions is desirable (40mz)

Staff Office: With a total staff of approximately 50, the staff room should accommodate seating for 30 and also be suitable for relaxation. During special events, staff will work outside normal working hours so there should be an adjacent kitchen area suitable for making light meals and drinks; a dishwasher may be desirable.

Janitor: are ideally located in a separate room and storage for wet clothing is also required.

System room:Needed to house computer equipment for library circulation and other information systems.

Seminar room: Required for meetings and training sessions, facilities must be suitable for current technology and equipment.

Self-issue terminals: The space required is 3 m2/terminal and at least three terminals are required at various points in the library. Smartcards The inclusion of a 'smartcard' system is increasingly likely, to allow students access services (e.g. photocopying, overdue charges, borrowing videos, etc.). The machines will be located throughout the library.

librarian's office: The base for the manager in charge of the whole building, the room must be close to the administrative support and interview rooms. Apart from everyday managerial tasks, the room will be used for small discussions with up to two people and project work.

library manager ‘s office: This includes one office for two assistants, shared desk, and also room for small meetings of one to three people. Privacy is necessary, although easy access/overview is required for counters and customer services. The office should be located near the branch library.

Reserve stacks: Certain sections of stock will be housed in closed-access rolling stack storage, including: semester overflow (during the examination periods. The weight of rolling stack storage is substantial and will need to be taken into account in structural calculations.

Security control room: This acts as the base for control attendants, and for the closed-circuit TV system

Entry/access areas: One main entrance and two others are required, preferably separate:

Main entrance foyer/lobby: it should be clear and inviting, and be sufficiently spacious to cater both for students, visitors who have a specific destination and those who may wish to wander around.

Customer services/reception: An informal and welcoming atmosphere is required, as this is the first major point of contact for students; space is required for three staff.

Internal circulation: The flow of people and materials (particularly the two-way flow of trolleys) should be made as easy as possible. Note that circulation areas provide opportunities for vandalism and concealment of theft, and should therefore: be kept to a minimum; follow a logical route; allow visual control by staff (closed-circuit TV may be installed); allow segregation of staff and public areas; and allow easy emergency evacuation.

Internal vertical circulation: This should be by lift and stairs, ramp, and possibly escalator.

Security generally: The key considerations concern the control of access between staff and public areas, and prevention of theft. These issues can be addressed by: strategic location of staff enquiry points, with line-of- sight control; CCTV cameras; electronic book sensors at exit points; and security personnel.

Refreshment/coffee bar: For 50 students' maximum, providing drinks, snacks and light meals.

Sales point: An area to promote sales is required: the strategic location is important, but it may be combined with another area.

Study desks: These should be suitable for use with personal computers (which may be the students' own machine, necessitating simple plug- in compatibility). The integration of PCs with study furniture is very important. Two power sockets are also required.

Secure area: for exhibits A secure storage area is required, with easy access to both the delivery area and the exhibition area.

Other areas are;

stores,

parkings,

WCs; shower if possible.

5.3 Site Location

The site for the proposed project is located in within the university along 4°42’00.01” E and 8°08’42.98” N, it is bounded by Faculties by the east and North, lecture theater by the east of the site. Elevation of 423m and eye alt of 644m. This position is in Offa local government and Offa is located in South-East of Ilorin, the capital of Kwara State of Nigeria. The town is situated on longitude 500E and latitude 800N. It is about 56 kilometers from the state capital. Offa is situated on a gentle Plateau, which is about 1429 feet (408.9m) above sea level. It has indeed been aptly described as a watershed between the Ogun-Osun River Basin and Niger Basin.

5.4 Site Analysis

The site designated was analysis critically based on the design consideration and the need to comprehend the site and its features for the building of library and the incorporation of delight devices in it design.

5.4.1 Climate

Offa under Köppen climate classification features a tropical wet and dry climate. In Offa, the wet season is warm, oppressive, and overcast and the dry season is hot, humid, and partly cloudy as shown in Figure 5.1. Over the course of the year, the temperature typically varies from 63°F to 92°F and is rarely below 57°F or above 97°F. the chart below shows the climate summary of Offa.

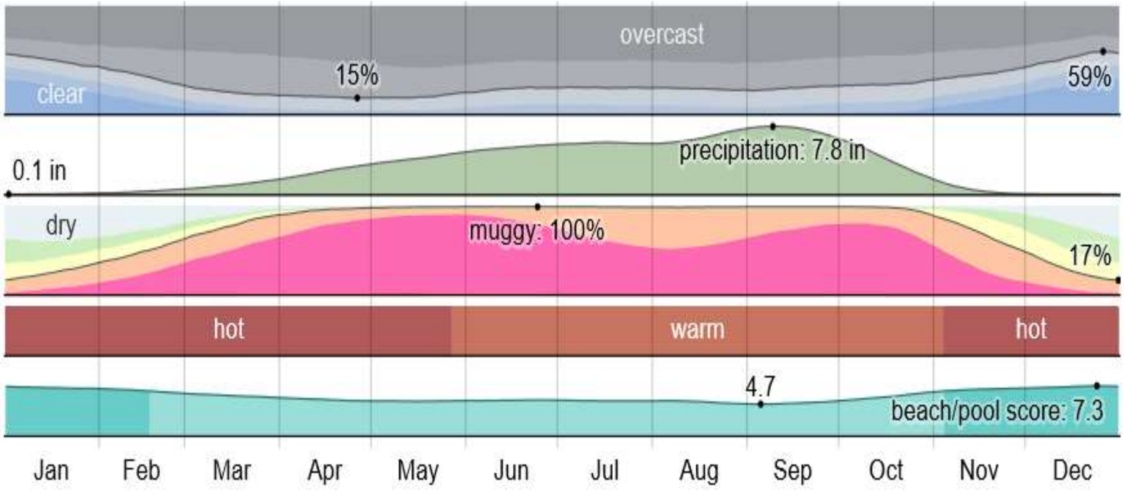


Figure 5.1:Climate summary

a. Average high and low temperature

The hot season lasts for 2.4 months, from January 23 to April 4, with an average daily high temperature above 90°F. The hottest day of the year is February 19, with an average high of 92°F and low of 69°F. The cool season lasts for 3.8 months, from June 19 to October 11, with an average daily high temperature below 83°F. The coldest day of the year is December 30, with an average low of 63°F and high of 88°F.

b. Rainfall (average monthly rainfall)

Offa experiences extreme seasonal variation in monthly rainfall. The rainy period of the year lasts for 8.8 months, from February 20 to November 15, with a sliding 31-day rainfall of at least 0.5 inches. The most rain falls during the 31 days centered around September 10, with an average total accumulation of 7.8 inches. The rainless period of the year lasts for 3.2 months, from November 15 to February 20. The least rain falls around January 2, with an average total accumulation of 0.1 inches.

c. Clouds (cloud cover categories)

In Offa, the clearer part of the year in Offa begins around November 14 and lasts for 3.0 months, ending around February 13. The cloudier part of the year begins around

February 13 and lasts for 9.0 months, ending around November 14. On April 26, the cloudiest day of the year, the sky is overcast or mostly cloudy 85% of the time, and clear, mostly clear, or partly cloudy 15% of the time.

d. Precipitation

The wetter season lasts 6.3 months, from April 14 to October 23, with a greater than 42% chance of a given day being a wet day. The chance of a wet day peaks at 83% on September 11. The drier season lasts 5.7 months, from October 23 to April 14. The smallest chance of a wet day is 1% on December 22. Based on this categorization, the most common form of precipitation throughout the year is rain alone, with a peak probability of 83% on September 11.

e. Sun (hours of daylight and twilight)

The length of the day in Offa does not vary substantially over the course of the year, staying within 35 minutes of 12 hours throughout. In 2018, the shortest day is December 21, with 11 hours, 39 minutes of daylight; the longest day is June 21, with 12 hours, 36 minutes of daylight.

f. Sun (sunrise & sunset with twilight)

The earliest sunrise is at 6:21 AM on May 27, and the latest sunrise is 39 minutes later at 7:01 AM on January 30. The earliest sunset is at 6:18 PM on November 14, and the latest sunset is 45 minutes later at 7:03 PM on July 14. Daylight saving time (DST) is not observed in Offa during 2018.

g. Humidity (humidity comfort levels)

Base on humidity comfort level on the dew point, as it determines whether perspiration will evaporate from the skin, thereby cooling the body. Lower dew points feel drier and higher dew points feel more humid. Unlike temperature, which typically varies significantly between night and day, dew point tends to change more slowly, so while the temperature may drop at night, a muggy day is typically followed by a muggy night. Offa experiences extreme seasonal variation in the perceived humidity. The muggier period of the year lasts for 10 months, from February 2 to December 8, during which time the comfort level is muggy, oppressive, or miserable at least 38% of the time. The muggiest day of the year is June 24, with muggy conditions 100% of the time. The least muggy day of the year is December 31, with muggy conditions 17% of the time.

h. Wind (wind direction)

The predominant average hourly wind direction in Offa varies throughout the year. The wind is most often from the south for 4.7 months, from February 2 to June 22 and for 1.7 months, from September 15 to November 7, with a peak percentage of 58% on May 13. The wind is most often from the west for 2.8 months, from June 22 to September 15, with a peak percentage of 61% on July 26. The wind is most often from the east for 2.8 months, from November 7 to February 2, with a peak percentage of 45% on January 1.

5.4.2 Site vegetation

The nature of the vegetation is sparsely green, the site being covered by few trees, shrubs, and grasses. Some of these features should be retained to enhance comfortable landscape environment. While others on the proposed building footprint are to be removed.

5.4.3 Source of noise to site

The major sources of noise to the site are from the vehicles moving along the roads around the site and other activity from the various faculty and Lecture theater around the site. Planting of Trees is encouraged along the site boundaries to serve as buffer to the proposed building.

5.4.4 Access to site

The site is located within the University premises along the faculty and administrative sections road which brings in the flow of traffic from major way as well as the immediate environs of the site. The main access into the site is directly from the road along the south.

5.4.5 Site topography

The site is undulated and slopes towards the northern part of the site. Surface drainage of the site is excellent due to the nature of the site and its slope. The soils underlying the site are deep and well drained. Therefore, drainage as a design consideration has already been taken care of by the topography of site.

5.4.6 Services on site (electricity, water supply, sewage)

There is electricity supply around the site. The electricity supply system is of three-phase; four wire grid systems. water supply is readily available from the central water supply system. Both telephone service line and G.S.M exist around the site. however, a central sewage disposal system (soil and water) can be constructed to collects sewage from the site and channel to the central collection points.

5.5 Design Parameters from the Site Analysis

From the site analysis conducted, the following parameters shall be used in the proposed design:

i. Major Access into the site shall be via the South while minor access shall be via the North/East.

ii. The orientation of the building shall be done to maximize natural lighting and ventilation.

iii. Existing tress shall be retained and more shall be planted in order to create a shade

onsite especially along pedestrian walkways and reading garden.

iv. The parking will be located towards the Southern part of the site to allow view.

v. Provision of basic components of a Reading garden such as the flora, fauna, water body, constructed garden elements and hard landscapes to reduce solar radiation and avoid soil erosion

vi. The North-west part of the site will be left for future expansion of the Library.

5.6 Design Concept

The concept for Summit library emanates from the iconic look considering a stacked book in a reading space. It exemplifies a system of organization, study, efficiency and flexibility, all of which concludes into high demand for purposeful daylighting redirection and redistribution. The Figure5.2 below display the various transformations leading to the main building final form which also affects the form of smaller supporting facilities on site.

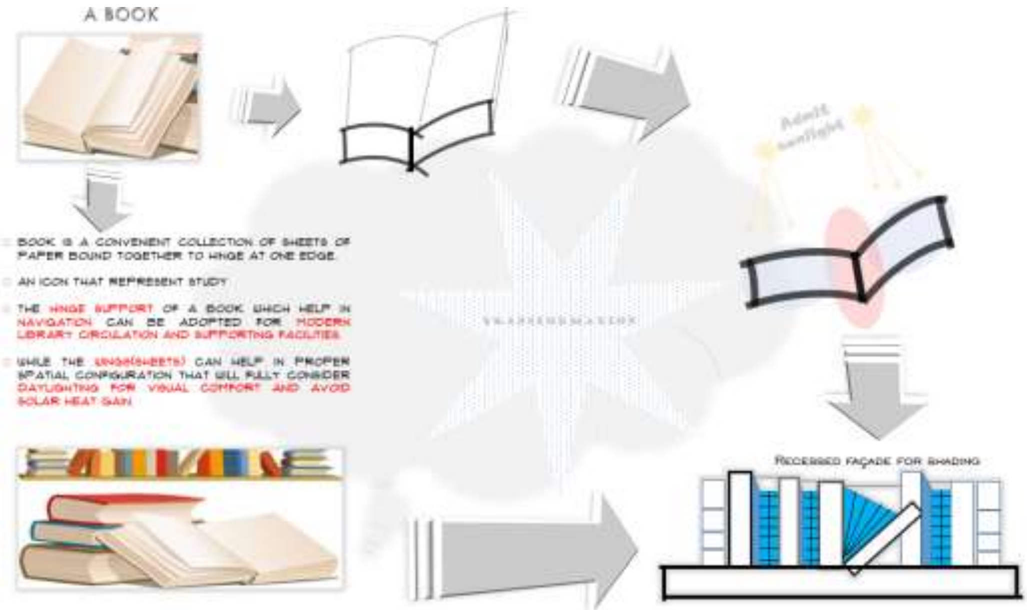


Figure 5.2:Concept development

The hinge support of a book which help in navigation can be adopted for modern library circulation and supporting facilities. While the wings(sheets) can help in proper spatial configuration that will fully consider daylighting for visual comfort and avoid solar heat gain.

5.7 Schedule of Accommodation

To determine the number of Books to be stocked, the following assumption were set in place:

a.A new university library can hold between 5,000-10,000 volumes of Books before the first accreditation as stipulated by the National Universities Commission (NUC).

b.The ratio of collection size between Science and Social science is 60% Science to 40% Social science.

c.The equation (i); size of collection/ capacity per unit is used the determine the number of Bookstacks (Siems & Demmers, 2002).

But, capacity of the shelving section is derived from the equation (ii);

Volume per Linear foot of shelve X number of shelve X width of shelve

i. Where 8 is the average volumes per linear foot(300mm) of shelf for common print materials.
ii. Assuming 6 as the number of shelves for a 1900mm high, 250-300mm deep, double faced, cantilever-style steel shelving (complete with canopy top and end panels).
iii. Assuming the width for a typical industry standard cantilever-style steel shelving of 3ft (900mm).

Therefore, capacity of shelving section is 8 x 6 x 3 = 144 volumes. This translates to 288 volumes for double faced, cantilever-style steel shelving.

Assuming a projected collection size of 10,000 volumes, and substituting the Figures in the equation (i);

Number of stacks unit = size of collections/ capacity per unit

Number of stacks unit = 10,000 / 288 = 34.72 stacks.

Approximately 35 stacks unit. However, 60% (21 stacks) will house the Science volumes and 40% (14 stacks) will house the Social Science volumes.

a. Using a structural grid of 6000mm x 6000mm, the suitable center-line distance between shelving units is 1200mm -1500mm for open access shelves and 1600mm – 2000mm for reading areas respectively. This will help achieve adequate circulation in the bookstacks.

b. For the periodicals in the Section, 1.7m high, 3 degrees sloped shelves is used.

c. A minimum of 300mm deep shelving units are used for Reference, Technical and Sciences collections.

In order to meet the space requirement of the NUC standard guides for universities, the writer has adopted the following assumptions:

1. The student population of 3,750 represents the Full Time Equivalent (FTE) and not actual headcount.
2. This Figure was derived from the NUC requirement of providing accommodation for 25% of projected student population.
3. The university brief projected a student population 5,000 students for the first of three phases of population growth for the university.
4. The unit areas given are ‘usable areas’ only, without consideration for ‘balance areas’ (corridors, storage spaces, toilets, service rooms).

However, the CILIP’s guideline for Academic library from Metric Handbook (3rd Edition) are as follows;

a. 1 seat per 6 fulltime students from the overall university population.
b. Between 2.5 and 4.5 square meters per student’s workspace in University library.
c. Reader module of 900 x 600mm minimum.
d. Information Communication technology (I.C.T) space of 1200 x 800mm minimum.
e. Circulation space (gangways) of 1200mm minimum (1800mm preferred); access to desk or workstation requires 1000mm minimum; private space for user is 600mm outward from desk.

f. Parking provision for staff in terms of cars is 1 per 2 members and 1 per 6-10 staff for cycle parking.

g. 1 per 3-6 students cycle parking and 5 visitors car parks for library population below 1,000 students.

The Table below shows the different spaces in modern library design, parameters for space configurations and units required.

5.8 Light Pipe Device Application

The light pipe 0.9meter diameter by 1.8meters height with aspect ratio 1/2 are placed 3m centers as the spacing ratio as derived from the previous study. This light pipe redistributed and redirected daylighting uniformly on the reading work plane of 9 square meters. The offset of light pipe from the side lighting strategy (windows) according to the rule of thumb established by the literature reviewed is1.5x (where x is the headroom). Therefore, the proposed headroom for this study is 3.3meters making the minimum distance of light pipe daylighting area from the window to be 4.95meters.

5.9 Other Factors considered for Daylighting Applied in the Proposed Design of Summit Academic Library

5.9.1 Types of glass and window

UV filter: UV light is invisible to the naked eye but capable of causing both short term and long-term harm with exposure. The opening shall be glass with UV filter material to avoid components deterioration within the proposed building. The light tube collecting dome will also be made of UV filter. Casement window is able to provide excellent ventilation and if they seal tightly when closed, it can still allow penetration of natural light. These windows consist of glass as the main material.

5.9.2 Building orientation

The orientation of the building shall be 20 degrees north-east and west-south to maximize natural lighting and ventilation.

5.9.3 Building materials reflectance

Wall, furniture, floor and ceiling finishes which affect daylighting redistribution and redirection in terms of painting shall be light colours for good reflectance which aid uniform daylighting redistribution and redirection in a daylit space.

5.9.4 Nature of shading devices

Egg-crate shading devices shall be adopted for the south and south-east of the proposed building to enhance daylighting and balance of façade.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

The study focused on Daylight optimization with light pipe in the design of Academic library within the tropical wet and dry climate of Nigeria. The major problem identified is that, inadequate daylight distribution and re-direction for uniform daylit space have potential of making some spaces within the library dormant and also discourages the readers which has led to overdependence on artificial means despite the abundance availability of natural light within the climatic zone. The fact that, better daylight when incorporated within a learning space can provide many important benefits to both the users and owners of facility influence the research. The researcher went further to conduct case studies on three of the Nigeria academic libraries within the tropical wet and dry climatic zone of Nigeria and also conducted a validation study on one of the samples as well as performing a computer simulation with Ecotect and Daysim in addition to evaluate the performance of light pipe. Findings from the research is the basis for design of Academic library for Summit University in Offa, Kwara State.

6.2 Conclusion

This study is on light pipe as an effective top daylighting system in building. The emphases are not only the studies of theory and performance of light pipe, but also on Nigeria climate in optimizing daylighting using light pipe system. For optimum performance of light pipe in reading areas of library within tropical wet and dry climate of Nigeria, the aspect ratio should not be more than 1/2. In addition, this dissertation also discusses the common advantages of using light pipe as a daylighting system. With the benefits offered by light pipe system, it has the potential to be widely used in Nigerian buildings. Light pipe system has practical application in many buildings whether in deeply planned building or windowless building.

6.3 Recommendations

From the research conducted, the key findings suggested a comprehensive way that architects can follow in providing a deeply planed library with less dependent on artificial lighting within the tropical wet and dry climate of Nigeria. The analysis has shown that problems associated with light use and control technique, as regards conventional reading areas is common concern in almost all deeply planned libraries. The shortcomings are tailed towards the fact that most of the library buildings were deeply planed. After much observation and discussions, it was revealed that little measures were put in place in considering the effective use of day lighting in libraries. Therefore, problem regarding deeply planned conventional reading areas in the library needs proper treatment and these can primarily be achieved by:

i. Architects should ensure that light-pipe design is achieved and integrated at all design stages and contribute to the design and construction process.

ii. Relevant bodies or authorities should be involved in the design and construction processes of light pipe in library for adequate measures to be taken at every stage for optimum daylighting.

iii. Aspect ratio 1/2 should be widely advocatedfor optimum performance of light pipe in reading areas of library within tropical wet and dry climate of Nigeria.

6.4 Contribution to Knowledge

The study made the following contribution to knowledge:

i. Determined that light pipe with aspect ratio of 1/2 gives optimum performance for daylight requirement in conventional reading area design in wet and dry tropical climate of Nigeria.

ii.Daylight Autonomy of 78%was achieved compared to 60% minimum Daylight Autonomy established from literatures to be good daylighting which resulted to additional 18%.

iii. Useful daylight illuminance of 98% further strengthen the aspect ratio of light-pipe 1/2 to be highly effective for visual comfort in the conventional reading spaces design for wet and dry tropical climate in Nigeria.

iv.Established procedures for the application of light pipes for optimum daylight performance in library design in tropical wet and dry climate of Nigeria.

6.5 Area for further research

The study has identified areas in which further inquiry into other top lighting strategies can be made and use to enhance daylighting performance, these includes; firstly, conducting the same study in a different location having a different climate, this is in a bid to develop an accurate local standard and guidelines for optimum light pipe design in Nigeria. Secondly, further research should be carried out to find out how horizontal light pipe can be used to enhance daylighting in other spaces within the library or spaces that have less access to vertical light pipe, this is to take away the bulk of energy consumption in terms of artificial lighting for sustainability.

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APPENDIX

Appendix 1: Schedule of Accommodation

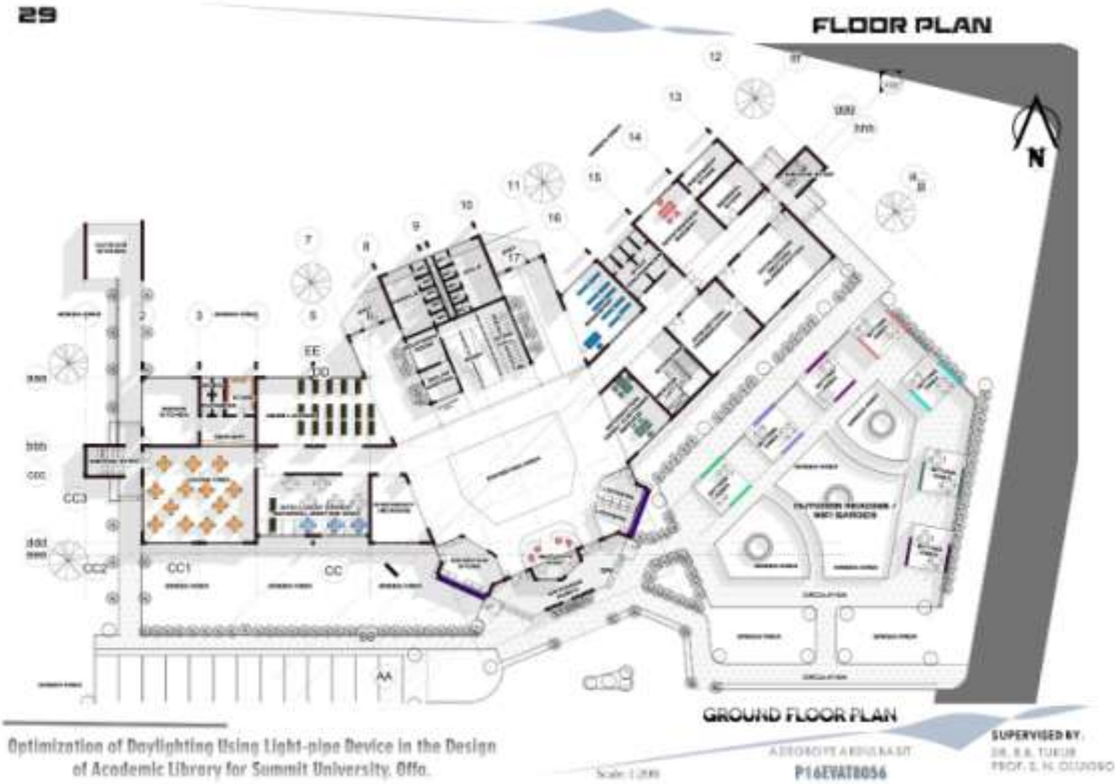
The following table gives an overview of the approximate floor area of the provided spaces, which will fall within the range of 25% more or less in the design proposal.

S/N	Space	Sub-Spaces	Parameters	Unit	Area (m²)	Total Area (m²)
1.	**Security/Post**		--------	1	19.81	19.81
2.	**Lockers**		--------	2	20.00	40.00
3.	**Exhibition Area**		--------	1	100.00	100.00
4.	**Photocopy & Scanning**		--------	1	27.00	27.00
5.	**Customer service / Information Desk**		10m² per seat for 2 With waiting	1	34.70	34.70
6.	**News Lounge**		0.7x 0.6 per seat	1	80.00	80.00
7.	**Cafeteria**	- Kitchen - Servery - Store - Dining area - Changing	-------- -------- -------- 3.64m² to 4-seat table --------	1 1 1 1 1	190.00	190.00
8.	**Solar Control**		--------	1	13.00	13.00
9.	**Equipment Room**			1	13.00	13.00
10.	**Bookshop**		Minimum space required is 60m²	1	60.00	60.00
11.	**Bookshop Store**		--------	1	12.00	12.00
12.	**Maintenance Division**		--------	1	40.00	40.00
13.	**Equipment room**		--------	1	15.00	15.00
14.	**General Store**		--------	1	21.00	21.00
15.	**Classification & Cataloguing Section**		--------	1	65.00	65.00
16.	**Acquisition & Preservation**		--------	1	50.00	50.00
17.	**Janitor**		--------	1	7.00	7.00
18.	**Server/Control**		--------	1	50.00	50.00
19.	**Group Discussion**		1.5 per seat for 50	1	78.00	78.00
20.	**Seminar room**		2.5 per seat for 15	2	37.50	75.00
21.	**Intelligent Games**		1.2m2 per seat3.64m2 to 4-seat table	1	60.00	60.00
21.	**Reference**		--------	1	81.00	81.00
22.	**E-Library**	- Control - Server	--------	1	207.29	207.29
23.	**OPAC/Bibliography**		--------	1	30.00	30.00
24.	**Serials/Periodicals**		0.98-1.2m² per seat for 36	1	83.23	83.23
25.	**Offices**		12m² per seat for 2	1	16.00	24.00
26.	**Secretary**		16m² per seat	2	16.00	32.00
27.	**Librarian Archive**		--------	1	6.00	6.00
28.	**University Librarian**		Minimum space required is 25m² plus mini-lounge en-suite.	1	35.00	35.00
29.	**Kitchenette**		--------	1	13.00	13.00
30.	**Deputy Librarian**		Minimum space required is 20m²	1	20.00	20.00
31.	**Conference room**		2.5m² per seat for 25	1	62.50	62.50
32.	**Multi-Media**		--------	1	25.00	25.00
33.	**Bibliography**		--------	1	27.00	27.00
34.	**Under-graduate Section**	- Reading area - Reading Commons - Control - Study carrels	0.98-1.2m² per seat, 3.25m for research work. To contain 268 Students	2	400.00	800.00
35.	**Post-graduate Section**	- Reading area - Reading Commons - Control	0.98-1.2m2 per seat, 3.25m for research work. To contain 108 Students	1	276.84	276.84
36.	**Conveniences**	- Students - Staff	2.1m per toilet and 2.7m for physically challenged	17	36.90	36.90

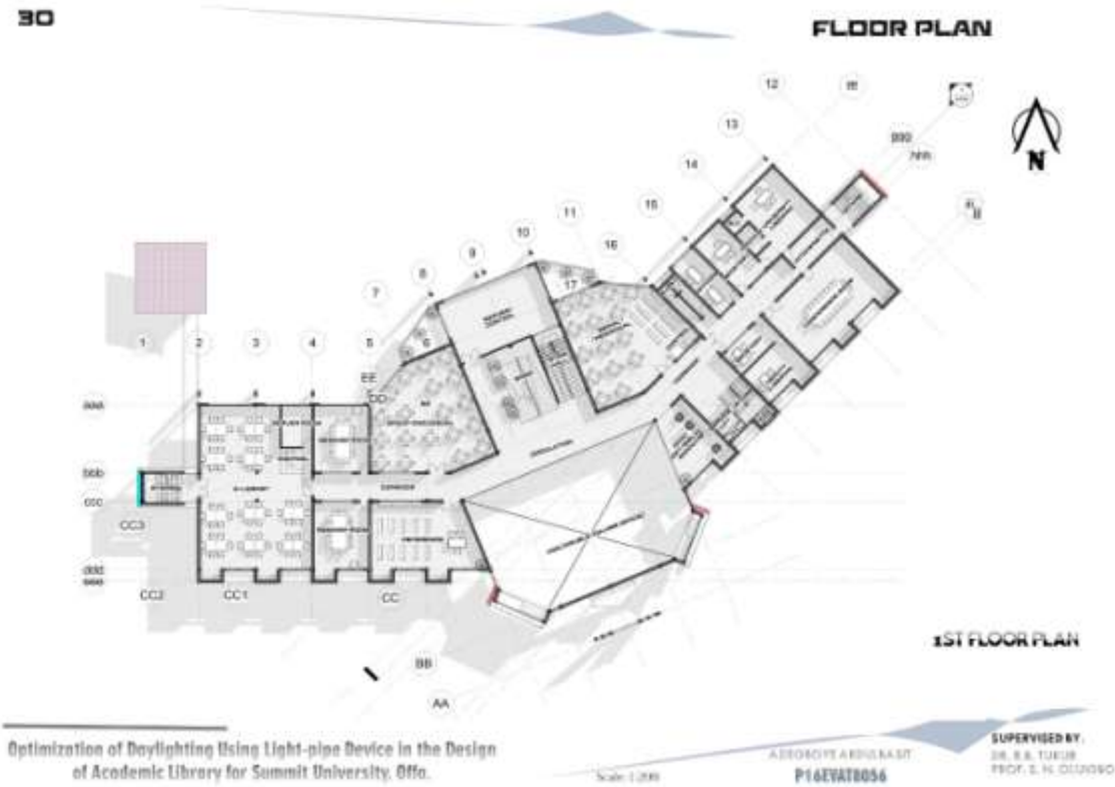
Total Area =2750.27 m²

Appendix 2: Site Plan

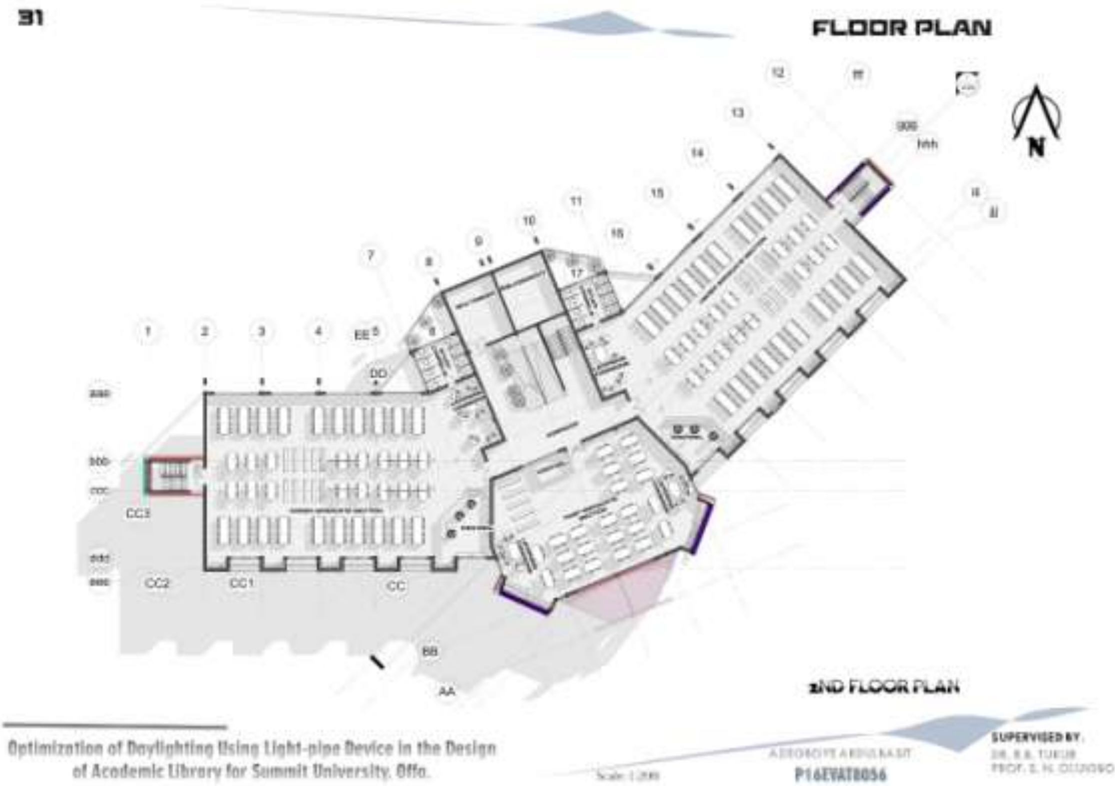
Appendix 3: Ground Floor Plan



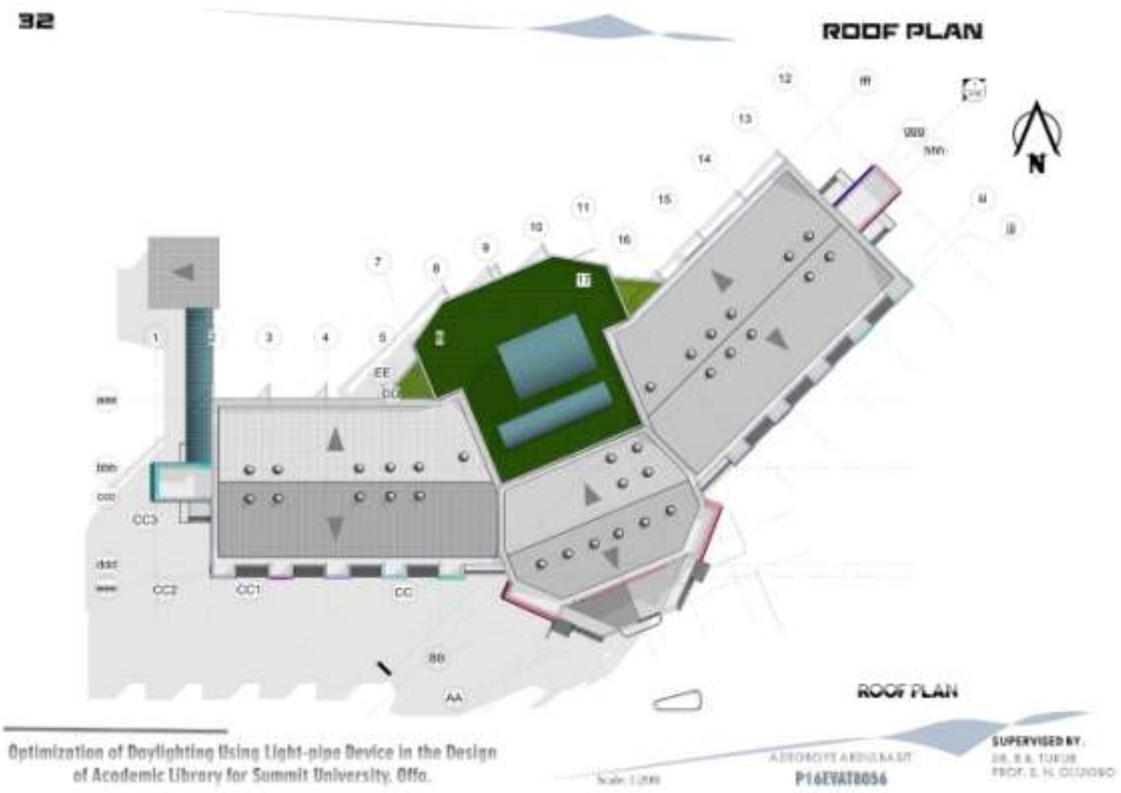
Appendix 4: First Floor Plan



Appendix 5: Second Floor Plan



Appendix 6: Roof Plan



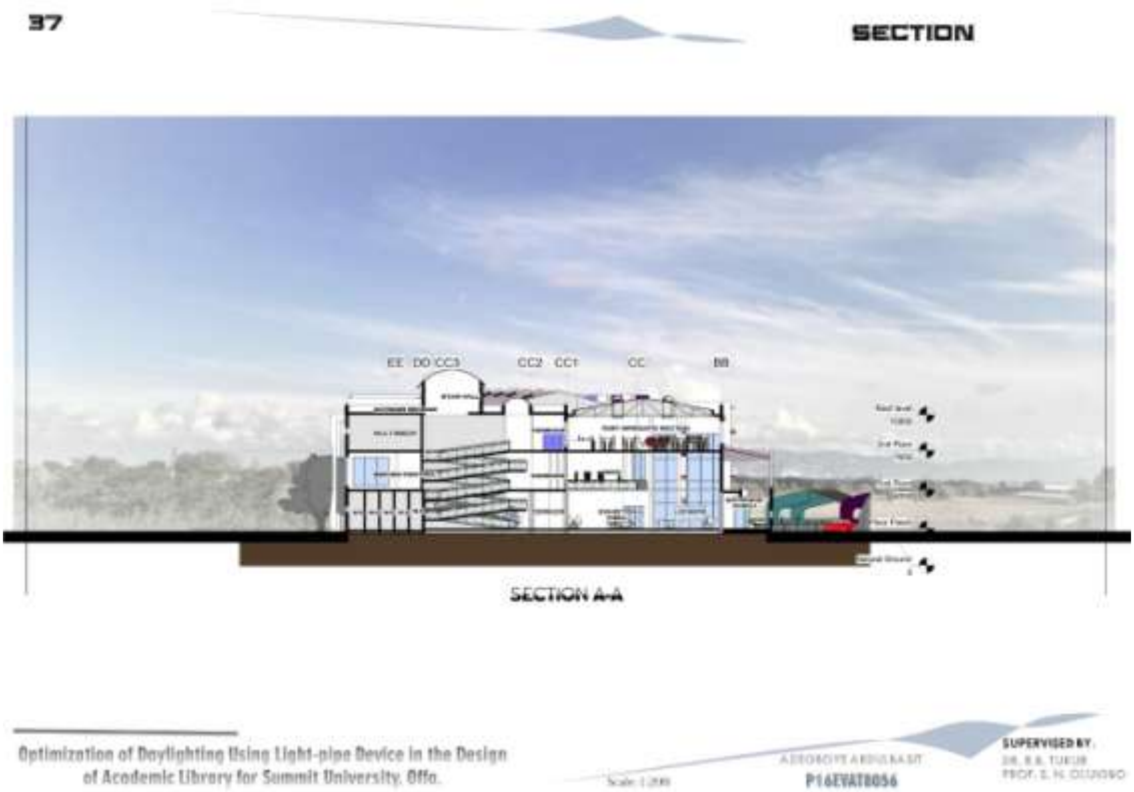
Appendix 7: Approach Elevation

Appendix 8: Rear Elevation

Appendix 9: Right-side Elevation

Appendix 10: Left-side Elevation

Appendix 11: Section A-A



Appendix 12: Section B-B