# Dynamics of Windows for Effective Daylighting Design Strategies in Academic Library

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## Abstract
Libraries are attached to universities as resource centers for students to study and get access to facilities and environment that will lead to better performance. However, the increasing demand for healthier as well as a more energy saving buildings have placed greater emphasis on the supply of daylight for task performance in libraries. This paper evaluates the dynamics of windows for effective daylighting design strategies in the library. A mix method approach was used for this study using interview, case studies and observational checklists. Twelve institutional library buildings were examined in order to gain insight on the subject matter as it is already applied to life situations. Interviews were also conducted for proper investigation of the topic. Findings reveal that for there to be effective daylighting through the use of windows in the library, the placement, orientation, shading devices, material size, height and the surrounding environment must be given adequate consideration. Also, the courtyard was found to be the most effective means of increasing the number of windows. The study concluded that effective daylighting strategies in libraries require the designers to consider daylighting right from the conceptual development of the design stage so that they can effectively harness as much natural light as required into the building as it is the most preferred light for task performance and means of reducing energy consumption in buildings.

**Keywords:** Daylighting, design strategies, dynamic, energy consumption, library, windows

## Introduction
The increasing demand for healthful and more energy saving buildings have laid greater emphasis to the supply of daylight in libraries. Libraries have existed for as long as anyone can remember and are commonly seen as collections of information and services. Historically, libraries were places for easy book borrowing and study, but have now turned into places for communication, learning and socializing. The learning areas in libraries remain the most important places for student thinking, discovering and innovating (Sternheim, 2016). In these spaces, learners prepare their minds to receive, translate, analyze, and process information. Therefore, daylighting in these areas must be designed to accommodate these modern library functions and enhance interior comfort to achieve users' satisfaction.

Daylight in buildings plays a pivotal role in the indoor climate. Good daylight design contributes to the aesthetics and physical properties of learning spaces. It also plays a significant role in the visual comfort of buildings (Bian and Luo, 2017). According to the European Union studies, lighting is responsible for 14% of final energy consumption (Halonen et al., 2010). Controlled daylight in buildings can replace up to 80% of the electricity consumption for lighting during the day. Pniewska, & Brotas, (2013) noted that since there is no substitute for electric lighting during the hours of darkness, it is imperative to conserve

electricity during daylight hours by incorporating daylight into buildings.

Daylighting is the normal routine of having fenestration in walls open to incident sunlight to allow natural light into the space during daytime (Muneer, 1997). It is one of the main features of Windows. Other features of windows include natural ventilation and visual appearance in buildings. The window design is a major determinant factor for daylight distribution in the room. Windows as key elements of building openings are therefore architecturally, socially, psychologically and ecologically indispensable (Munner 2000). However, the dimensions and placement of windows, prefabricated window units and other components of the facade must be cautiously examined to reference to the eye level of building residents, as they play a crucial role in determining the brightness and dissemination of indoor daylight (Carmody, 1996). Therefore, this study aims to examine the dynamics of windows as effective strategies for daylight design in libraries. Daylighting is one of the main functions of windows. The window design determines the distribution of daylight to a space.

### *Library as a Space for Learning*

Ogbebor (2011), defines library as an orderly group of books (printed and unprinted) and audiovisual materials needed to meet explanatory research, academic and recreational needs of its users which are supplied and explained with the help of staff. Libraries are called knowledge repositories because they contain information that is accessible in different recorded forms such as academic and technical papers, conference papers, patents, thesis, data, articles and so on. According to the class of information obtainable in the library, it is classified as a primary and secondary source. The primary sources are information in its original and evolving form, while the secondary sources direct users to the primary documents such as indexes, bibliographies and summaries, dictionaries, encyclopedias, and handbooks. In this digital age, alongside the conventional forms of resources, recent forms of resources are being developed into libraries, namely CD-ROM, online journals, optical discs, DVD and the Internet.

Libraries have endlessly played an important role in facilitating people to engage with all classes of information and knowledge resources. Conventionally, the library is a place where people go to and read books, magazines, newspapers or maybe to find geographical maps. Today's library is a powerhouse where information are kept, generated, and transferred to meet user needs. However, scientific advancement in libraries has influenced both the information space and information application, as the development of integrated library systems and online catalogs permit access to information about libraries from places with Internet connection (Curran et al., 2006).

In the university, the library is a place in which exchange of reasoning and knowledge occurs. An affluent education system depends solely on the availability and usage of information sources and services. In this context, libraries make available the knowledge and information resources needed for teaching, learning and research. Academic libraries are fast in supporting and revitalizing the remodeling of new forms of teaching and learning practices. For example group projects, group studies, teamwork and activity-based learning and assignments (Edward and Fisher, 2002). Efficient and effective delivery of library resources can have a positive influence on academic performance (Williams, et. al., 2001). However, the libraries' designers must have a detailed knowledge of the end users' needs. Without the knowledge, it will be very difficult to provide an effective and structured services**.**

### *The Importance of Daylighting*

Daylight is a vital resource and one of the unchanging fundamental forces of nature (Nováková, & Vajkay, 2019). It is a fundamental feature that creates significant and effective architectural experiences by improving moods and quality of space. People like natural light and always crave for it in the house. Daylight can affect

reading, task engagement, productivity (Kilic and Hasirci 2011, Othman and Mazli, 2012), wellbeing, mood and health, comfort, spatial perception and emotions (Sufar et al., 2012). The use of daylight proffers countless opportunities to shape the space and enhance the aesthetics of the building. It is widely believed that bright lighting makes people more vigilant, and well illuminated rooms are basically recognized by occupants as 'better' than dimly lit ones (Mardaljevic et al., 2012). The natural light physiologically revive the human visual system and the human circadian system, which benefits people's comfort and well-being (Boyce et al., 2003). In healthcare facilities, natural light improves the recovery rate of patients and enables the elderly in assisted living facilities a good view (Edwards and Torcellini, 2002). Studies also show that natural light environments enhance productive learning. It was equally found that students in classrooms with adequate daylight performed 7% to 18% better than those with ~~the~~ inadequate daylight (Heschong, 2002). Daylight is also recognized to increase safety by better lighting conditions in buildings (Edwards and Torcellini, 2002).

Veitch et al., (2008), opined good and proper lighting conditions (both daylight and electric lighting) contributed to environmental satisfaction, which in turn led to greater job satisfaction. The most noticeable means for energy saving in buildings is in utilizing the most opulent source of light available to humans (Philips, 2004). Daylight is a section of passive design strategies that is most considered by building designers and architects (Lim et al., 2012). Natural light is an important source of energy savings in buildings (Li, Lam & Wong, 2005) signifying a passive energy efficiency strategy. Natural lighting has other advantages such as, increased visual comfort in interior design, enhance better interaction with nature (Sharmin, 2011), effective strategy to eye health and depletion of time, and enhance mood performance, awareness, logical performance, physical activity, sleep quality, and attentiveness in students and workers (Shishegar and Boubekri, 2016).

In contrast, fuzzy lighting can influence workers' health, while lack of maintenance of good lighting can result into fatigue and different fashions of ailments such as: eye pain, itchy eyes, neuralgia, discomfort, and other symptoms, often known as sick building syndrome (Phillips, 2004). Furthermore, an environment with uncomfortable thermal and visual conditions reduces the well-being and jeopardies the health of employees (Teixeira, et. al., 2020). Heerwagen and Orians (1986), submitted that it was logical to envisage that windowless environments can be more worrying and psychologically unbearable than rooms with windows. Sufficient daylighting is required as it has a direct influence on individual performance, psychology, health, energy conservation and performance. It also has indirect influences on ventilation and good views (Pulay and Williamson, 2019; Nicklas and Bailey, 2020).

### *Application of Day Lighting*

The sun is the primary source of daylight and the effect of daylight on the shape of buildings is very important. Daylight is the use of sunlight and skylight to supplement or replace electric light. It can also be explained as the full spectrum of light best suited for human visual response (İnan, 2013) and regarded as the finest light source for better color rendering (Li et al., 1999). Daylight is a sustainable source of highly energy saving light, making daylighting in building a pleasant energy strategy compared to the common practice of steady electric lighting.

The aggregate of daylight that is received by a given building is continually changing because the light source, the sun, is continually changing its location in relation to the building, shining directly and indirectly on both the inner and outer part of the building. However, the factors affecting the design of daylight are analyzed in three categories: In the first category the day, the hour, the state of the sky (the rate at which

the air is closed), the location of the sun and the location of the building, affect the brightness and amount of daylight. The second category includes the openings (windows) which are imperative for daylight to enter the building, while in the third category include the dimensions of the windows, the shape and the structural characteristics of the surfaces which influence light distribution (Kazanasmaz, 2009). In addition, there are three customary sky states: clear sky, overcast sky, and partly cloudy sky. The clear sky contains sunshine and is more intense and brighter at the horizon than at the zenith, except around the Sun. Daylight direction on cloudy days varies, although the light is spread out more than on a clear day. On overcast days, daylight is consistent but varies in absolute brightness from sunrise to sunset (Edward, 2018).

It is paramount for every architect and builder to know the application of light and use daylight to a greater extent when designing spaces (Atamaz et. al., 2017). Natural light should be taken into consideration from the onset of the design to ensure effective use (Javadnia, 2016). In general, to control the quantity and diffusion of natural light infiltrating a space and to ensure a comfortable and healthy lighting environment, a good daylighting approach should incorporate more than a simple opening in the window or roof. Custom solutions or devices may need to be implemented depending on the climate, functions and requirements (Altomonte, 2008).

Daylight normally gets into the building in two ways; side and top. While the size, direction and position of the light hinge on the purpose of the room and the atmosphere to be fashioned (Ruck, et. al., 2000). The light coming from above can be more advantageous than the light from other directions because the quality of light in the room remains constant as there is no significant change in the direction and angle of the light all through the day. This light is extremely desired in libraries, galleries and art workshops because it uniformly spreads out and does not glare (Piana, and Merli, Francesca. 2020).The light from the side windows conveys the irregularities of the room during the day and the light quality in the morning differs from the light quality at sunset. This shows that users can discern the space differently at different hours of the day (Kaya et. al., 2018).

In addition buildings are also supplied with daylight through techniques such as light shelves, light tubes, light guides, and different categories of glass that have been developed to provide visual comfort and energy savings (Ruck et. al., 2018). Daylighting systems range from simple static (louvers, light shelves, fixed overhangs, laser cut panels, prismatic elements, etc.) to customizable dynamic elements (blinds, advanced glazing, holographic optical elements, etc.) and/or combinations of these (IEA Task 21, 2000). The utilization of these systems, which can be categorized as modern methods of utilizing daylight in buildings, is now becoming more universal (Yener, 2007). The use of these approaches focus on capturing and distributing uttermost natural daylight to circumvent visual discomfort and thus help lessen lighting energy consumption while supplying adequate lighting.

## Research Methodology

A mix methods approach was adopted for the study with the use of case studies, interview guides and observation checklist. Twelve libraries were selected in the south-western part of Nigeria for appraisal; two were selected from each state of the south western zone as shown in table 1 below. Both private and public university libraries were chosen from each state of the south western zone so as to formulate generalizations that extend across all the cases. The appraisal of existing library development was carried out to evaluate by practical visitation to the site. This is done in order to gain insight of the subject matter as already applied to life situations and in order to examine the merits and shortcomings of the library, especially on technical issues relating to the dynamic of

windows for effective daylighting in the library. The research identified a number of variables which were ineptly studied to yield data that expresses the dynamics of window openings for effective daylighting design strategies in academic libraries. This variable includes; nature of building window sizes, window type, window material as well as the placement and available shading devices. The summary of studying these variables was used to judge the sufficiency and insufficiency of daylighting within a building. A structured interview was also conducted with users of the building. The interview method was adopted to ensure that all the interviewees were provided with the same questions; this allowed for proper investigation of the topic and provided opportunities for both interviewer and interviewee to discuss the area of interest in detail. There were 36 respondents; three from each case study were selected for the interview from each location.

## Results and Discussion

### *Nature of Building*

The height and depth of the building are key major variables that relate to window opening. Likewise, most institutional buildings often adopt multiple floor structures except in a few cases where the available resources seem not sufficient. For the libraries examined, the building structure was quarried in regard to the number of floors and the depth of the spaces as most academic libraries have multiple floor building structure while the shape of the buildings may exist as regular (square, rectangle, circle, and oval, hexagonal) or irregular shapes. Irrespective of what form a library building is, this investigation observed that a building's shape has little or no impact on the day lighting capacity of the building. Rather, what affects the amount of luminance in a building is the depth of the space. With increasing distance from the building's opening, the magnitude of sunlight that infiltrates the space diminishes. While the brightness of the environment increases with the number of floors. These can be fairly noted in plate I and II.

**Table 1: List of library**

| S/N | Institution | Library Name | Location |
|---|---|---|---|
| 1 | Ajayi Crowther University | T.Y Danjuma Library | Oyo State, Nigeria |
| 2 | University of Ibadan | Kenneth dike library | Ibadan, Oyo State |
| 3 | Babcock University | Laz-Ottis Library | Ileshan-Remo, Osun State, Nigeria |
| 4 | Joseph Ayo Babalola University | Joseph Ayo Babalola University library | Ikeji Arakeji, Osun state |
| 5 | Lagos State University | Fatiu Ademola Akesode library | Ojo, Lagos State |
| 6 | Celeb University Lagos | | Imota, Lagos |
| 7 | Covenant University | Knowledge Hub | Ota, Ogun sSate |
| 8 | Federal University of Agriculture | Nimbe Adedipe Library | Abeokuta, Ogun State |
| 9 | Federal University of Technology Akure | Albert Ilemobade Library | Akure, Ondo State |
| 10 | Achiever University Owo | Achiever University Library | Owo , Ondo State |
| 11 | Afe Babalola University | Afe Babalola Library | Ado Ekiti, Ekiti State |
| 12 | Federal University Oye-Ekiti | | Oye Ekiti, Ekiti State |

Plate I: A three storey building (library)

Plate II: The interior of a 3 storey library exploiting full intensity of the sunlight through window openings and skylight.

### *Window Placement and Orientation*

Windows bring in natural light and also give view of the outdoors. However, the placement of the window determines how effective the building will maximize natural light. For ultimate maximization of natural light that infiltrates a space there is a need for proper positioning of windows. The right placement of windows will allow for properly distributed daylight throughout the rooms. It was noted from the cases visited that focus was given to the reading area of the library through the provision of adequate windows on at least two sides of the wall in order to have a well-lit space. Thus, the shadow created by one window is balanced with the light coming from the other, thereby reducing the contrast in the space. This was agreed to by most respondents as it was opined that a refined steady light can be generated by positioning windows in at least two directions of different walls.

The placement of openings in at least two sides of the wall is important as it allows for proper distribution of light within the space. This was achieved in most of the libraries while others introduced the courtyard to achieve this. The utilization of the courtyard helps to increase the number of windows available. This gave the opinion that courtyards are the most affordable architectural means of throwing light into a building as it gives allowance for window openings. Figure 1 illustrates the frequency of application of courtyards in the cases studied. It was recorded that 40% of the cases studied have courtyards.

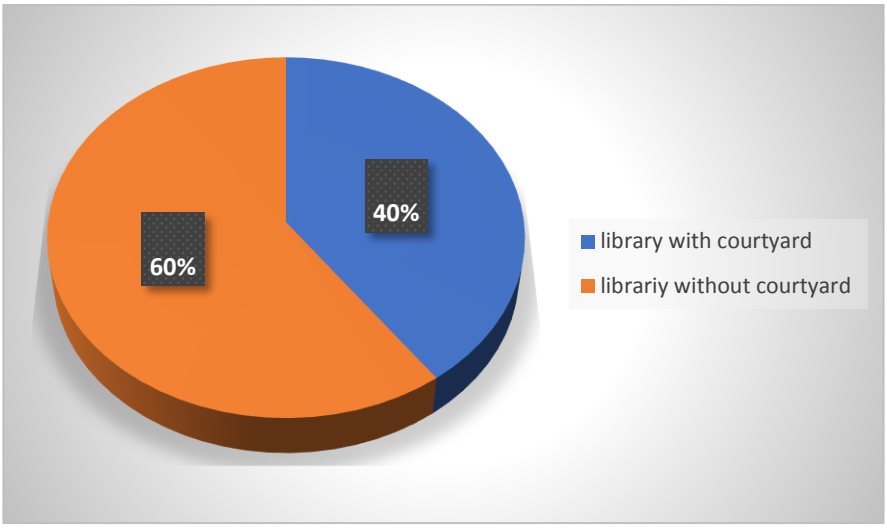


Figure 1: Chart showing percentage of library with/without courtyard

Window placement determines the intensity of lights exploited by a building. Hence, the building orientation is a very important factor to be considered when investigating the dynamics of windows in a building in order to achieve visual comfort. The orientation of windows determines the adequacy and standard of natural light on the inside. While to a large extent the light from the north is to diffuse skylight and supply the inside of the building with an effective and enjoyable light that is reasonably steady throughout the day. While the light from south, east and west orientations supply the inside of the building with direct sunlight with different light levels throughout the day as the sun pursues its course around earth. This was noted from the case studies have most (eight) of the libraries pay more attention to the provision of adequate daylighting for task performance through proper orientation of the building especially for the reading while the others with insufficient daylight for reading was due to poor orientation of the openings. In addition, most institutions agree that the right locations of windows while taking advantage of the orientation will enable the building to maximize the amount of sunlight that gets into the interior of the building. While respondents from most of the public universities opined that the proper placement of windows will affect the supply of daylight in the interior space and determine the amount of 'useful' daylight.

However, in placement of the window the environment should also be a considering factor as obstruction in the environment reduces the amount of natural light entering into the building. The positioning of windows should also take cognizance of the relationships between the view to the outside and the eye level of the inhabitants.

### *Shading Devices*

Shading is important for good daylighting performance as it can be utilized to modify the amount of daylight infiltrating into the spaces and also aid to control glare. The shading device varies from awnings, blinds, and canopies shutters, horizontal and vertical projectors. The blinds, horizontal, vertical and combined shading device were the various types of shading devices considered in this research. The location of these devices has also not been omitted in others to ensure that they protect the interior space from glare and direct heat from sunlight. Figure 2 shows that 10% used blinds, while the majority used horizontal or vertical or combined (horizontal and vertical) style of shading device.

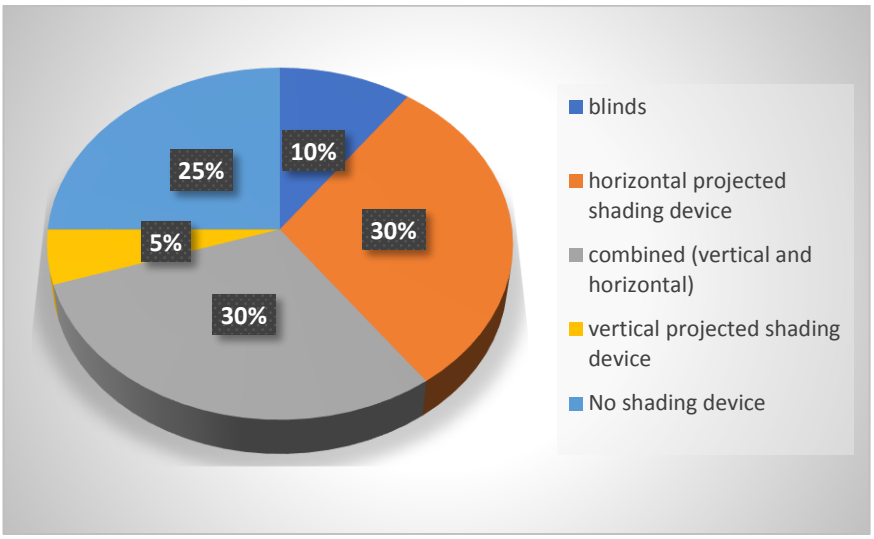


**Figure 2:** Percentage of the various types of shading devices in use

Most of the shading devices admit adequate lighting into the building in libraries; the venetian blinds are often kept open all day long as observed during this study. This explains the reason why there is a low percentage of its application. The venetian blinds are often used to control glare and heat gained from the sunlight into the building, but in this survey, most libraries adopt vertical and horizontal shading devices as a structural component of the libraries. Plate III shows the use of artificial lighting used in a library whose window was covered with venetian blinds.

Plate III: Showing venetian blinds

The results indicates that direct light and high intensity of diffuse light only illuminate the area near the window and external shading devices have little impact on the distribution of daylight. Shading devices permit minimum solar radiation, adequate daylighting and provide thermal comfort. Shading devices are mostly presumed to fend off for glare, heat gain, and simultaneously allow for view out. In order to shun against the negative effect of daylight, external and internal devices were designed to mitigate the excessive ray of sun into internal spaces when the external air temperature is above the suitable temperature for human comfort. It was also stated by respondents from Adekunle Ajasin University, Federal University of Technology Akure, University of Ibadan, Lagos State University, Joseph Ayo Babalola University and Afe Babalola University that shading device incorporated into library design helps reduces the amount of solar radiation infiltrating into the building which reduces the heat generated in the space. The shading devices prevents direct sunlight that can cause excessive heat in the interior space of the building.

For some of the case studies direct light and high intensity of diffuse light only illuminate the area near the window and external shading devices have little impact on the distribution of daylight. While the presence of external shading devices in some of the cases studied reduces the light distribution which affects the amount of daylight for interior lighting. This was supported by the claims of some of the respondents as they noted that the shading devices also reduce the amount of day lighting entering into the spaces. It was said that the shading device is a good way of reducing heat gain into the building but it also reduces the amount of daylight that enters the building. Respondents from Lagos State University and University of Ibadan noted that most shading devices in place reduces the daylighting gained by the building. However, respondents noted that the shading device must be properly designed if not it will serve as a barrier to light and ventilation. It reduces the amount of solar radiation entering into the buildings. However, this will affect the availability of daylight for interior lighting.

Also, the shading system is used on the window to limit glare discomfort. External shading devices were mostly used to allow for diffusion of daylight in the room and they prevent direct sunlight penetration, they can also be used to prevent the solar radiation before it gets to the indoor; however, external shading devices can influence the amount of daylighting received. Respondents from Afe Babalola University noted that the use of high-performance glass can help in controlling the amount of excess heat in the room. While respondents from university of Ibadan opined that uncontrolled fenestration in buildings especially where tasks are being performed could lead to overheating, thereby causing poor thermal performance and leading to discomfort of the users/occupant. However, for windows that face the sun, overhangs that will let in low-

angle sun, while blocking high-angle sun that may overheat buildings should be used. External shading devices can be utilized to block the solar radiation before it reaches the indoor environment, and are hence more effective than internal shading devices. However, external shading devices can affect daylighting.

### *Available Window Type and Size*

The most readily available source of passive luminance in a building is the fenestration; this established fact led the attention of the researcher to major on the window style, size and material, the observed window sizes range from small to medium to large/long windows. All window types observed were summarized into projected, casement, louvers, tilt-turn, sliding and clerestories. Louvers were found in a few ancient library buildings, but the new generation buildings now use casement, clerestories and sliding windows. Tilt-turn and projected windows were found in a few high budget-built libraries. Nonetheless, clerestories are a very effective means of obtaining good quality daylight in buildings. It was observed during the process of this study that libraries with an array of windows above the eye-level provide more visual comfort in their reading space. Table 2 shows the summary of window types used in the case studies

**Table 2: Window types in case studies**

| | Window types | Frequency(number of occurrence) |
|---|---|---|
| 1 | Clerestory | 5 |
| 3 | Projected | 2 |
| 3. | Sliding | 1 |
| 4. | Casement | 3 |
| 5. | Louvers | 1 |

Here, the descriptive analysis established that most academic libraries employ high level windows otherwise referred to as clerestories to exploit sunlight into the building. This analysis as interpreted in figure 3 shows that 42% of case studies adopted this window type which offers average daylight luminance compared to the others with no fixed glass above eye-level. 17% of the university libraries adopted the use of a projected window as presented in figure 3, this may be due to its inability to supply sufficient light needed in a reading space. The researcher observed that libraries with these types of windows have less luminance within its interior spaces, except in cases where it was combined with clerestory; hence, there was need for constant electrical supply to enhance the available daylight.

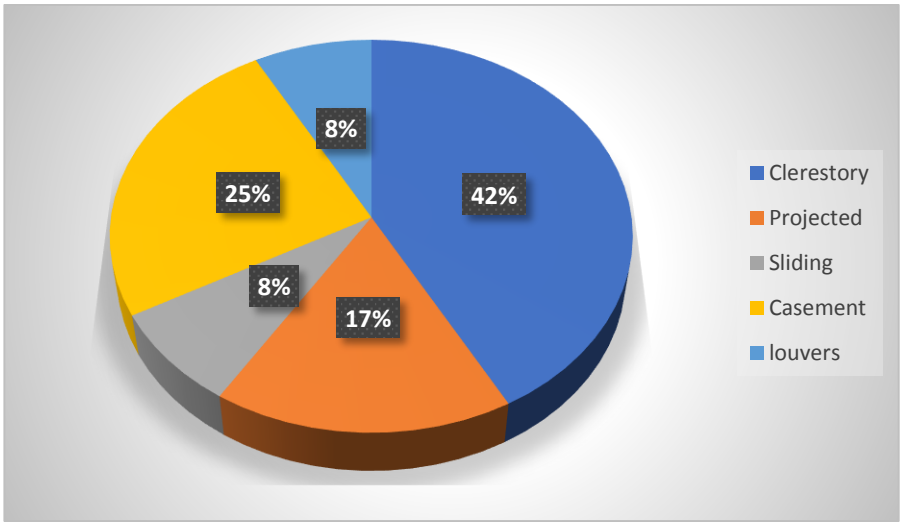


**Figure 3:** Window types used in the case studies

The casement window whose shutter swings to 90 or 180 degrees were seen being used in some libraries, the researcher went ahead to study the inner reading space of such library and observed, using human visual eyes that, to an extent there was sufficient lighting in cases where casement Windows of required size and material were used in combination with fixed glass. Figure 3 shows that 25% of libraries studied adopted this system of window opening. Only 8%of the occurrences used the sliding window in the reading areas. This study found that clear glass sliding windows provide adequate lighting in a building when used appropriately and placed in an efficient location.

Although some of the fenestration was not properly placed leading to reflections/glare. Figure 4 depicts that 33 % of academic libraries enjoy sufficient daylighting while 67% struggle through electrical and mechanical means and yet encounter insufficiency in the amount of illumination.

In addition, the interview conducted shows that the type of windows used were used to improve the aesthetic value of the building. Apart from old buildings where the louvers were used as fenestration, other buildings considered the appearance of the building before selecting the type of windows to be used. The window type~~s~~ was used to improve the aesthetic value of the building without proper consideration of the amount of light needed in the spaces. Again, most of the respondents considered the amount of light in the indoor spaces especially the library to be fairly good as there was a presence of light in this space even though some were not adequate. It was equally noted by most of the respondents that the size of the window determines the amount of daylighting that will be absorbed into the building. However the size of the window should not be oversize, the important of which is to reduce heating, prevent glare and fading of furniture.

### *Available Window Material*

Window materials were classed in two, these includes; frame and shutter. The materials used for either of the classes given required attention during this study. From findings most windows used for the libraries are made of aluminum or steel frame with glass shutters. Figure 5 illustrates the percentages of each window material and percentage of frequency. This clearly analyzes that most libraries, just as commonly seen in all other types of buildings, use glass as material for window shutter, while ~~the~~ aluminum is the major material mostly used for window frames. The glass is one of the versatile and oldest building materials that effectively throws light into the building. Apart from it throwing light into the building, glass adds aesthetic value to the building and helps in creating elegance in space. This function of glass cannot be replicated by any other material.

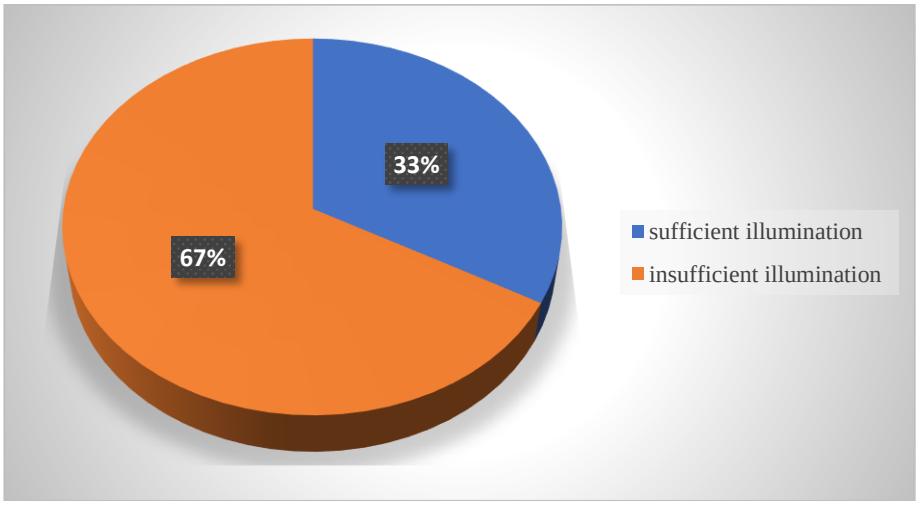


Figure 4: Buildings with/without sufficient illumination

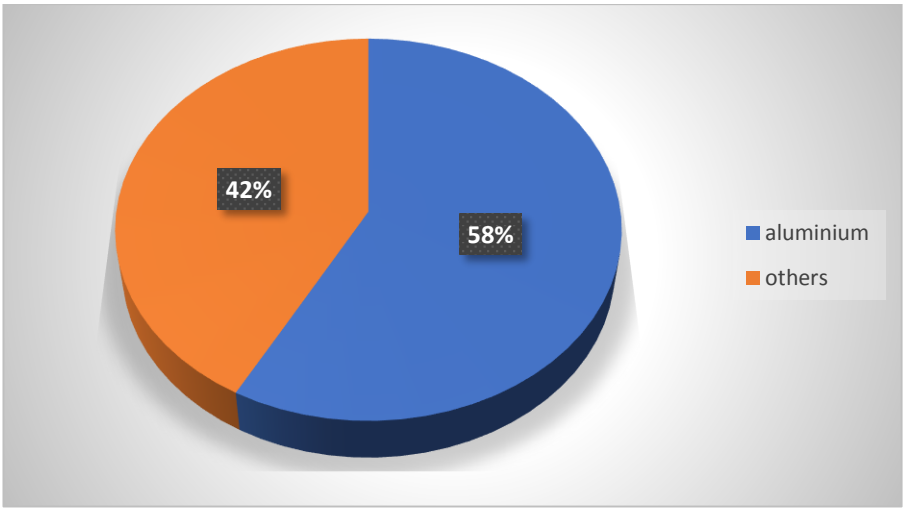


Figure 5: Types of window material

## Conclusion

It is obvious that the importance of daylighting in the library cannot be over emphasized. Daylighting is extremely important for reading activities in the library, not only that the use of daylighting also helps in energy saving in buildings. It was this assumption that underpinned this study and it was established by the study that effective use of window can deliver a great amount of daylighting into the library for task performance however daylighting provided through the window could be affected by several variables such as the placement of the window, the height, size and glazing material of the window, the orientation, type of window, and the surrounding environment. The study revealed that placing windows on at least two sides of the wall allows for effective illumination of the space while the height and size of the window must be considered in relation to the depth of the building. It was also revealed from the study that the courtyard is one of the most efficient architectural means of increasing the number of windows. The study concluded that there is need for designers to address the issue of daylighting from the beginning of the design so that they can effectively harness as much natural light as they need into the building

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