# Design Guidelines for Implementation of Daylighting Strategies in Buildings of Pakistan

**Seemin Aslam[1], Arsala Hashmi[2], Saira Naeem*[3]**

[1]Assistant Professor, School of Architecture and Planning, University of Management and Technology, Lahore, Punjab, Pakistan.

[2]Assistant Professor, School of Architecture and Planning, University of Management and Technology Lahore, Punjab, Pakistan.

[3*]Lecturer, School of Architecture and Planning, University of Management and Technology Lahore, Punjab, Pakistan.

**Corresponding Author:** saira.naeem@umt.edu.pk

***Keywords:*** *Daylighting, Energy Efficiency, Indoor Comfort, Building Design Standards.*

**DOI No:** https://doi.org/10.56976/rjsi.v6i2.243

*Turn on the lights please! Heard this many times? Because we like to see things lit properly and use artificial lights to do that, despite having natural light available for half the day. A well-daylit space connects to the outdoors, providing visual and thermal comfort while maximizing artificial lighting savings and reducing peak energy loads. Daylight offers pleasant indoor environments with better color rendering and alignment with human visual responses compared to artificial light sources. The benefits of daylight on occupant comfort, health, well-being, and productivity are well-documented. Despite these advantages, daylight is not widely integrated into building design due to a lack of information and evaluation tools regarding its suitability and energy-saving potential. This study conducts a systematic literature review to understand existing research and synthesize findings. Literature from large databases was reviewed, focusing on daylight integration. This research aims to present a review of metrics and standards for indoor daylight availability to aid decision-makers. The study concludes with recommendations for implementing and interpreting Daylighting Building Standards for successful daylighting architecture.*

## 1. Introduction

Daylighting, the use of natural light in interior spaces, offers numerous benefits for building occupants and energy efficiency. It positively impacts visual comfort, health, and performance (Al-Ashwal & Hassan, 2017) and can significantly reduce lighting energy consumption by 40-60% when properly implemented with lighting controls (Lawrence et al., 2008). Historically, daylighting was the primary illumination source in schools and workplaces until the widespread adoption of fluorescent lighting in the 1950s and 1960s (Heschong, 2002; Maleki et al., 2024) Despite concerns about increased heating and cooling loads, daylighting remains an energy-free and cost-efficient lighting source (Al-Ashwal & Hassan, 2017; Nazari & Matusiak, 2024).

Research has established links between natural light quality and human health, considering both psychological and physiological aspects (Boubekri, 2008; Liu et al., 2023) As global warming concerns grow, integrating daylighting strategies in building design becomes crucial for improving energy performance and occupant well-being (Al-Ashwal & Hassan, 2017; Boubekri, 2008; Li & Li, 2024).

The success of a daylighting strategy is closely related to how electric lighting and shading systems are controlled (manually, automatically, or with manual override). Effective daylighting techniques include configuring buildings properly, orienting them along an east-west axis while controlling daylight (Yu et al., 2020), placing critical visual tasks near the building's perimeter and positioning workstations and screens perpendicular to windows (Lee et al., 2022), admitting light from multiple sides (Onubogu et al., 2021), and using light-colored interior surfaces (Katunský et al., 2022). The variation in daylight within a space creates dynamic patterns of light and shadow, enhancing the aesthetic value and visual interest of the space (Edensor & Hughes, 2021; Li & Li, 2024). One of the primary purposes of daylighting is to reduce the reliance on artificial lighting, thereby decreasing electricity consumption for lighting.

In this study, we evaluate daylight performance in architectural design. We recognize the pivotal role of various standards in this evaluation, though few reviews have adequately addressed the relevant aspects and standards for daylight architecture (Liu et al., 2023). There is also a lack of information on the different aspects of daylight suitability and its energy-saving potential.

To address these gaps, this paper provides a comprehensive review of commonly used aspects and standards for potential energy savings from daylight. We begin by examining the gaps in our understanding of daylighting phenomena and proposing potential solutions. The study also focuses on presenting necessary definitions and summarizing existing literature and research findings related to daylighting, glare, and visual comfort.

Throughout the paper, we explore different standards and aspects relevant to daylight applications. This includes analyzing how various standards influence the effectiveness of daylighting in reducing energy consumption and improving occupant comfort. We also delve into the methods for measuring and evaluating daylight performance, considering factors such as light distribution, intensity, and the impact on indoor environments. This comprehensive review aims to provide insights and recommendations for better integrating daylighting strategies in architectural design.

## 2. Literature Review

Daylighting, the use of natural light in interior spaces, offers numerous benefits for building occupants and energy efficiency. It positively impacts visual comfort, health, and performance (Al-Ashwal & Hassan, 2017) and can reduce artificial lighting consumption by 50-80% in office buildings, leading to a global primary energy saving of up to 40% when considering the reduction in lighting internal loads(Bodart & De Herde, 2002). Historically, daylighting was the primary illumination source in schools and workplaces until the widespread adoption of fluorescent lighting in the 1950s and 1960s (Heschong, 2002; Maleki et al., 2024). Despite concerns about increased heating and cooling loads, daylighting remains an energy-free and cost-efficient lighting source (Al-Ashwal & Hassan, 2017; Nazari & Matusiak, 2024).

Research has established links between natural light quality and human health, considering both psychological and physiological aspects (Boubekri, 2008; Liu et al., 2023). As global warming becomes a growing concern, incorporating natural lighting strategies into building design is essential to improving energy performance and occupant well-being (Al-Ashwal & Hassan, 2017; Boubekri, 2008; Li & Li, 2024). The thermal-daylighting balance in architectural design can be achieved through proper base plan width-to-depth, facade window-wall-ratio, high transparency glazing, adjustable shading, and efficient lighting equipment, with optimal values varying based on location and climate. (Yu et al., 2020),

Daylighting systems can provide cost-effective, eco-friendly, and uniform illumination for buildings, but more research is needed to make them more affordable, eco-friendly, and easy to install for widespread deployment (Onubogu et al., 2021). Daylight impacts building interiors, affecting aesthetics, health, comfort, energy savings, and landscape (Katunský et al., 2022). The variation in daylight within a space creates dynamic patterns of light and shadow, enhancing the aesthetic value and visual interest of the space (Edensor & Hughes, 2021; Li & Li, 2024). One of the primary purposes of daylighting is to reduce the reliance on artificial lighting, thereby decreasing electricity consumption for lighting.

Daylighting standards should consider the health effects of sunlight on human health, as it is crucial for maintaining optimal health in homes and workplaces. A range of studies have contributed to the development of guidelines for daylighting analysis. (2011) emphasizes the importance of concentrating sunlight in daylight guidance systems, while Wymelenberg (2011) provides a practical resource in the form of the Daylighting Pattern Guide, which offers design patterns for well-day lit spaces. Tregenza (2018) highlights the need for more data to support definitive daylighting design criteria, particularly in the context of standards and regulations. Nazari (2024) offers a review of the origins of analysis methods used in daylighting simulation, providing a historical perspective on the development of these methods.

A range of studies have contributed to the development of guidelines for daylighting analysis. (2011)) emphasizes the importance of concentrating sunlight in daylight guidance systems, while Wymelenberg (2011) provides a practical resource in the form of the Daylighting Pattern Guide, which offers design patterns for well-day lit spaces. Tregenza (2018) highlights the need for more data to support definitive daylighting design criteria, particularly in the context of standards and regulations. Nazari (2024) offers a review of the origins of analysis methods used in daylighting simulation, providing a historical perspective on the development of these methods.

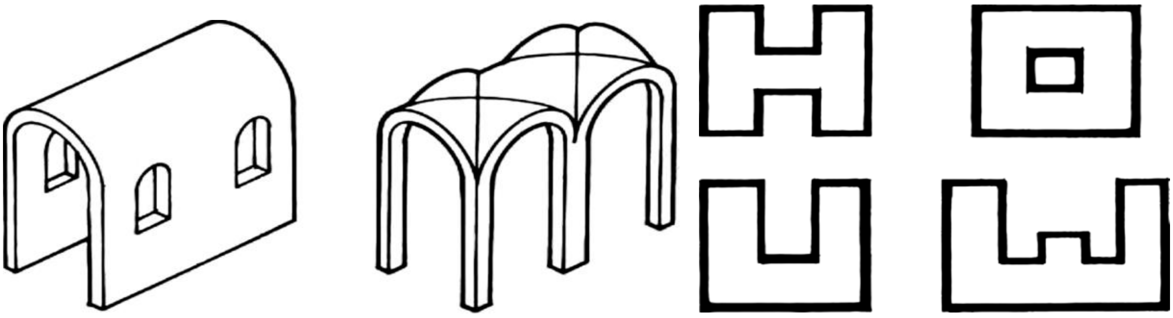
**2.1 Architectural History of Daylighting**

The history of architecture and history of window and of daylighting are same. The history begins with the initial crude openings for lighting and ventilation. Window was the tool for introducing daylight that was developed over centuries, to fill window opening different materials were used initially such as; thin marble slabs, mica sheets and oil paper until the development of glass (Jütte, 2023). In Egypt, around 3000 B.C, glass was used for decorative objects only, during Roman period small panes of handblown glass fitted in bronze frame were used in window openings whereas in 17th century large pane glass was developed in England and use of large windows was made possible (Di Pasquale, 2004). Window development ultimately led to the incredible interiors of the mediaeval cathedral, the Baroque churches or various private buildings of the 18th century.

Until the second half of the 20th century, the major structural changes that were made in buildings reflected the goal of how to enhance daylight collection in buildings; as till then artificial lighting was both expensive and poor so the main focus was on using daylight.

The evolution of Gothic architecture stemmed from a desire to maximize window areas (EASTLAKE, 2023). Since only a few openings were feasible in the massive bearing walls needed to support Romanesque barrel vaults, Gothic builders adopted the Roman groin vault (figure 1). In Renaissance architecture, building facades were dominated by large and numerous windows (Lechner, 2014). The building plans were of “E and H” shape that were mainly meant for daylighting and ventilation, no building wing in these plans was more than 60ft, high ceiling and high windows allow daylighting to reach to the interior spaces (Lechner, 2014) (figure 1).

**Figure No 1: Shifting from Barrel to Groin Vault Figure No: 1-Floor Plans of Large Buildings Prior to 20th Century**



Source: “Heating, Cooling, Lighting – Sustainable Methods for Architects” by Norbert Lechner

In the 19th century, the construction of all-glass buildings became possible due to the availability of glass and the development of new techniques using iron structures. Prominent architects of 20th century used daylighting not only for functional purposes but also as a tool to create dramatic spaces. Guggenheim Museum; an architectural masterpiece of Frank Lloyd Wright in which he incorporated ribbon windows and an atrium as a daylight source to illuminate the artwork at museum (Figures 2 and 3).

**Figure No 2 & 3: Guggenheim Museum; Ribbon Windows and Atrium as Daylight Sources to Illuminate Building Interiors**

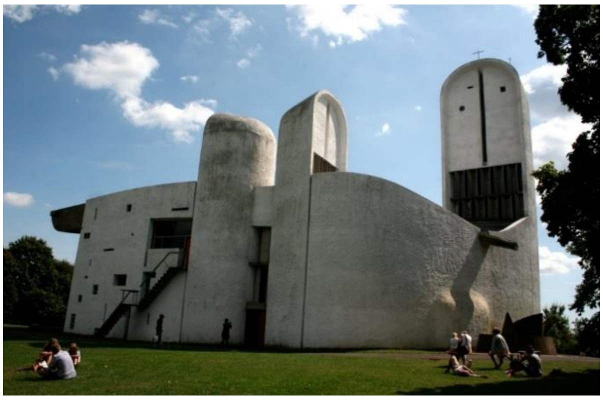
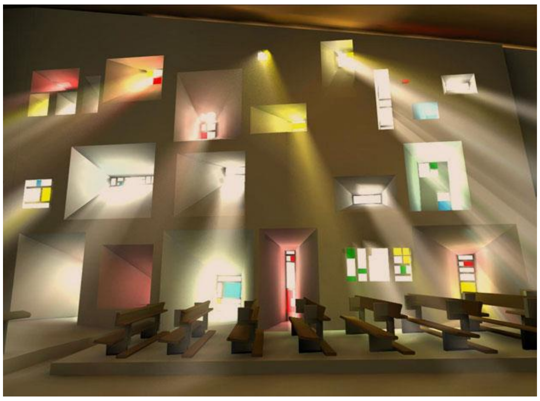
Source: http://michaelminn.net/newyork/museums/guggenheim_museum/

Another architectural masterpiece by Frank Lloyd Wright is the Johnson Wax Administration Building in Racine, Wisconsin. Wright allowed daylight to enter continuously along the upper walls, the edge of the roof, and through skylights around the mushroom-shaped columns (Figures 4 and 5). Le Corbusier created dramatic effects in the chapel at Ronchamp by using splayed windows and light towers (Figures 6 and 7).

**Figure No 4 & 5: Johnson Wax Administration Building in Racine, Wisconsin**


Source:http://www.archdaily.com/544911/ad-classics-sc-johnson-wax-research-tower-frank-lloyd-wright

**Figure No 6 & 7: Use of Splayed Windows and Light Towers in Chapel at Ronchamp by Le Corbusier**

*Source:http://energitismo.com/signorini-tells of-le-corbusier-and-the-chapel-of-ronchamp/*

## 3. Material and Methods

The research literature was carried out systematically as reference line data to explore different standards and aspects relevant to daylight applications. The gaps were identified regarding different aspects of daylight phenomenon and paper provides a comprehensive review of commonly used aspects and standards for potential energy savings from daylight. The methodological plan for this literature review is designed to ensure a thorough and systematic examination of existing research on daylight and glare in architectural design. The primary objectives are to understand the various definitions and structures related to daylight and glare, explore their impact on architectural design and occupant comfort, and identify and evaluate mitigation strategies for glare while optimizing daylight. The scope of the review includes a focus on peer-reviewed journals, conference papers, books, and reputable online sources, with an emphasis on studies from the last two decades to incorporate recent advancements.

The literature search strategy involves accessing multiple databases and sources, including academic databases as well as architectural and engineering journals.

Inclusion criteria focus on peer-reviewed articles and conference papers in English, addressing daylight and glare's impact on occupant comfort and building performance, alongside glare mitigation strategies. Exclusion criteria filter out irrelevant studies, non-peer-reviewed sources, and publications over 20 years old unless seminal. Data collection uses a standardized form for key details, managed with reference software. Thematic analysis identifies recurring themes, evaluates methodologies, and synthesizes findings to highlight gaps and propose future research directions.

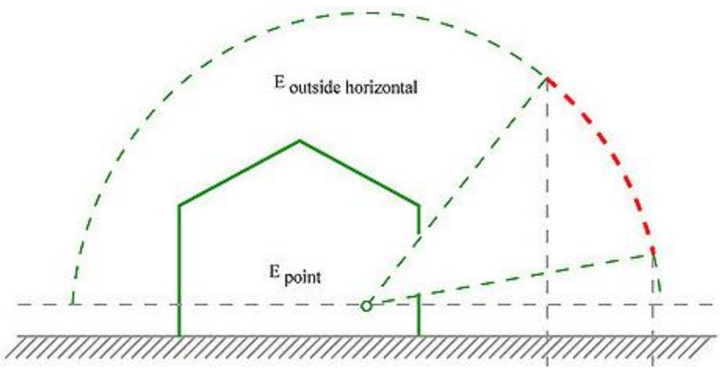
## 4. Discussion

Every building has its own daylight demand depending upon building typology and space utilization. So, to incorporate daylight into every building type is not desirable; daylight should be considered where appropriate. Daylight varies every moment either in intensity or quality; the desirability of these variations is highly dependent on the particular use of a space. There are some key aspects related to daylight that are crucial to be considered.

### 4.1 Daylight Factor

The %age of exterior illumination that is available inside the building is called daylight factor. Or daylight factor can be defined in other words as, "the proportion of interior horizontal illuminance (usually taken on a work plane) to exterior horizontal illuminance under unobstructed sky" (figure 8). DF = (E point / E outside horizontal) * 100%

**Figure No 8: Daylight Factor is the Proportion of Interior Horizontal Illuminance to Exterior Horizontal Illuminance**




It is the sum of sky component (SC) which is direct light from sky view, external reflected component (ERC) that is reflected light from the ground or other surfaces and the internal reflected component (IRC), figure 10.

**DLF = SC + ERC + IRC**

Daylight factor is a function of

- Window size and placement
- Sky obstructions
- Glazing transmission
- Interior reflectance

The total amount of exterior illumination available depends on weather conditions and latitude. Under clear skies, exterior illuminance varies with the season and orientation. In contrast, under overcast skies, orientation is comparatively insignificant.

**4.2 Design Considerations**

For designing a daylit building; there are some designing aspects to keep into consideration; some of the major aspects are discussed below.:

i. Understanding of the solar geometry
ii. Building orientation
iii. Room depth
iv. Colors of walls, floor and roof
v. Glazing properties

**4.3 Understanding of The Solar Geometry**

Building design requires a thorough understanding of orientation, which necessitates knowledge of solar geometry. Sun position is a key consideration in daylighting strategies, varying with latitude, time of day, and season. The sun's position in the sky is determined by two angles: the horizontal or azimuthal angle and the vertical or altitude angle. The azimuthal angle is measured clockwise from North (Fang & Cho, 2019). The altitude angle is the vertical angle at which the sun's rays strike the earth, depending on the latitude, time of year, and time of day.

**4.4 Building Orientation**

A key to energy efficient building design is to make it solar responsive. The amount of daylighting that a building receives vary from façade to façade, with season and time. For Northern hemisphere; the best building orientation is North-South facing. The North façade of the building receives the most consistent illumination (Livingston, 2021; Tregenza & Mardaljevic, 2018). To control diffuse illumination is easiest throughout the day and year. Thus, North façade permits large size windows for greater utilization of daylight without risks of great heat gains associated with direct sunlight(Lechner, 2014).

While the greatest daylight variations throughout the day and year are faced by the South façade of any building. In summer season altitude angle of sun is high. To block direct sun and allowing daylight into the space overhangs or blinds can be used. In winter altitude angle of sun is low that allows deepest penetration of light into the space and increase the hazard of discomfort glare so, proper shading or operable blinds can solve the problem of discomfort glare.

The East façade of the building faces the direct sun in morning time. With time, the sun got high in the sky and stops direct penetration in the space. And the light coming from the sky for the remaining time of the day is similar to the Northern light. The West façade of the building faces the direct sun in the evening at the time of sunset when the solar altitude angle is low. While receives North sky like light in the morning time.

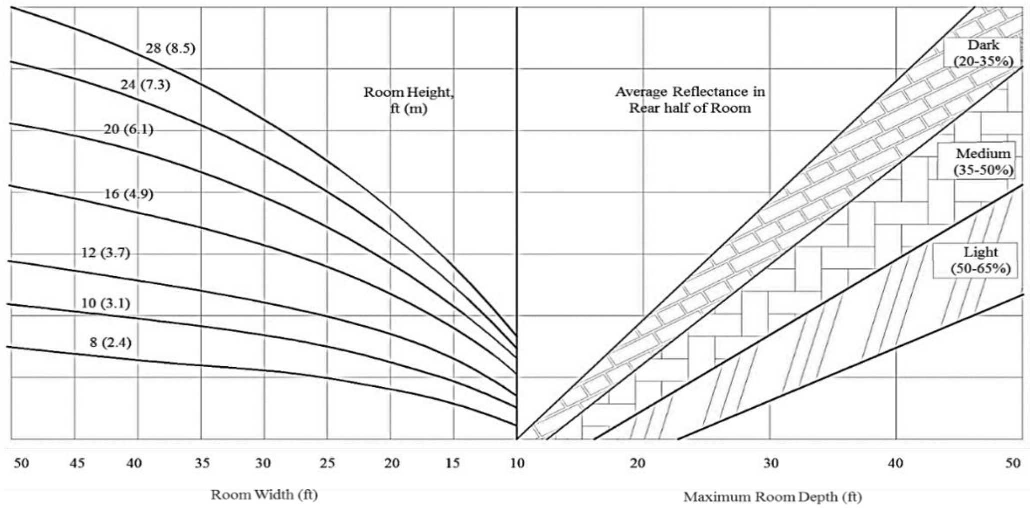
### 4.5 Room Depth

The building width is one of the key design considerations for a well daylit building. Thin building plans can have rooms with good daylighting. Rooms with sidelights have high illumination levels near the windows while illumination levels reduce rapidly as one moves farther from the windows. Deeper rooms have greater illumination contrast between near the window and rear spaces. In rear spaces illumination levels are highly affected by (Lechner, 2014):

i. Window height
ii. Distance from the window
iii. Window height above the floor
iv. Light reflectors or light shelves at window wall
v. Reflectivity of the interior surfaces
vi. Shading devices
vii. Non overcast sky conditions

To maintain a minimum illumination level and ensure even light distribution, the room depth should be less than 2.5 times the height of the window head. Light shelves can be used to improve daylight penetration, while roof overhangs can reduce it. Sunlight reflectors may help increase building width while maintaining effective daylighting. The graph attached below (figure 9) can be used to find out the maximum room depth. Move on the left side of the graph along the horizontal axis for a known room width then move vertically to intersect the curve for the room’s ceiling height, move on the right side of the graph to touch the diagonal line representing the average reflectance in the rear half of room. Finally move vertically to find the maximum allowable room depth. Where, average reflectance is an average value of all the surfaces in the rear half of the room.

**Figure No 9: Estimating Maximum Room Depth for Daylight Uniformity**




Source: "Sun, Wind and Light Architectural Design Strategies" by G.Z.Brown.

## 4.6 Walls, Roofs and Floors Color

Moving away from a daylight source reduces daylight penetration into the space while enhances the quantity of light provided by reflection of the interior surfaces. The light-colored surfaces have high reflectance values. The utilization of such surfaces helps in reflecting daylighting and hence enhances illumination level of a space (table 1) shows reflectance value of different colors(DeKay & Brown, 2013). The internally reflected component of daylight factor which is a significant part of the illumination level away from the window can be enhanced by reflectivity of the interior surfaces.

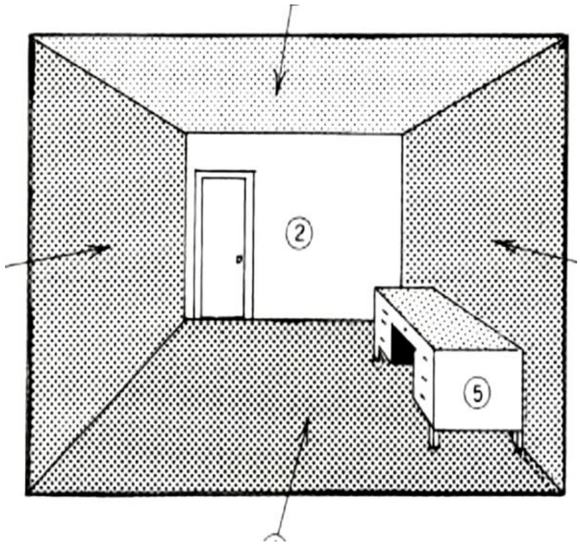
**Table No 1: Daylight Reflectance of Colors**

| Daylight Reflectance of Colors | | |
|---|---|---|
| **Sr. No.** | **Color** | **% Reflectance** |
| 1 | White | 80-90% |
| 2 | Pale yellow, rose | 80% |
| 3 | Pale beige, lilac | 70% |
| 4 | Pale blue, green | 70-75% |
| 5 | Mustard yellow | 35% |
| 6 | Medium brown | 25% |
| 7 | Medium blue, green | 20-30% |
| 8 | Black | 10% |

Table Source: Source: Sun, Wind, and Light; Architectural Design Strategies by G.Z.Brown

It is an important fact that the surface that first reflects the light should be light in color to enhance the reflected light. This surface may be floor if the light is directly coming from the sky or it may be ceiling if the light coming after reflections from the exterior ground surfaces. Light colors on surfaces near the daylight glazing and on window mullions can also reduce glare. Norbert Lechner in his book titled as, "Heating, Cooling, and Lighting" mentioned that for better distribution and penetration of daylight into a space, ceiling must have highest possible reflectance value, back wall should have second and side walls should have third highest reflectance values then floor and furniture pieces should have lowest reflectance. Figure 10, illustrates descending order of significance, for reflecting surfaces.

**Figure No 10: Illustrates Order of Significance, for Reflecting Surfaces.**




Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

Recommended reflectance values for structural components are shown below in table 2.

**Table No 2: Recommended Reflectance**

| Recommended Reflectance | | |
|---|---|---|
| **Sr. No.** | **Structural Component** | **% Reflectance** |
| 1 | Ceilings | 70-80% |
| 2 | Walls | 40-80% |
| 3 | Floors | 20-40% |

Table Source: Sun, Wind, and Light; Architectural Design Strategies by G.Z.Brown

### 4.7 Glazing

Use of any light admitting material such as glass in the building structure refers to glazing. There is a range of glazing material that are available in the market with varying light transmitting properties, with low U-Values. These available materials are frequently improving with technological advancements, so there is a need to get up to date of these new developments.

Whereas, the tables 3 & 4 shows recommended lux level for different functional spaces according to European and U.K standards respectively.

**Table No 3: Recommended Daylight Factor % for Building Types**

| Recommended Daylight Factor % For Building Types | | |
|---|---|---|
| **Sr. No.** | **Building Type** | **Recommended Daylight Factor %** |
| 1 | Kitchen | 1 |
| 2 | Schools | 1 |
| 3 | Offices | 2 |
| 4 | General | 2 |
| 5 | Drawing Offices (on drawing boards) | 6 |
| 6 | Typing and computing | 4 |
| 7 | Laboratories | 3-6 |
| 8 | Art Galleries | 6 |

Table Source: Sun, Wind, and Light; Architectural Design Strategies by G.Z.Brown

**Table No 4: European Standards**

| European Standards | | |
|---|---|---|
| **Sr. No.** | **Task/Use** | **Lux** |
| **1** | Corridor | 100 |
| **2** | Stairs | 150 |
| **3** | Technical Drawing Room | 750 |
| **4** | Trade fairs, Exhibition Halls - General lighting | 300 |
| **5** | Lecture Halls | 500 |
| **6** | Entrance Halls | 200 |
| **7** | Library bookshelves | 200 |
| **8** | Library reading areas | 500 |
| **9** | Classroom, tutorial room | 300 |
| **10** | Offices (reading, writing, CAD work) | 500 |
| **11** | Conference and meeting room | 500 |
| **12** | Computer practice room | 300 |
| **13** | Kitchen | 500 |
| **14** | Toilets | 200 |

Source: “Lighting of indoor workplaces”, EN 12464-1 (June 2011)

**Table No 5: CIBSE Standards**

| CIBSE Standards | | |
|---|---|---|
| **Sr. No.** | **Task/Use** | **Lux** |
| 1 | Corridor | 100 |
| 2 | Stairs | 100 |
| 3 | Drawing Offices | 750 |
| 4 | Museum & Art Galleries | 300 |
| 5 | Lecture Theatre | 300 |
| 6 | Foyers and Entrances | 200 |
| 7 | Libraries | 300 |
| 8 | Teaching Spaces | 300 |
| 9 | General Offices | 500 |
| 10 | Conference room | 300-500 |
| 11 | Computer practice room | 300-500 |
| 13 | Kitchen | 500 |
| 14 | Toilets | 100 |

Source: CIBSE Code for lighting http://www.kellwood.co.uk/led-lighting/technical/CIBSE/recommended lux levels

### 4.8 Daylighting Strategies

There are a number of daylighting strategies that can be used depending upon the requirement for the particular case. Some of these strategies are discussed below in detail.

### 4.9 Unilateral Lighting

Windows on one side/wall of a room, is the only daylight source for that space and is known as unilateral lighting (figure 11). When possible, unilateral lighting should be avoided.

### 4.10 Design Consideration

In case, unilateral lighting will be the only possible option for a space; then windows should be placed near interior walls. In this case, interior walls adjacent to

Vol 6 No 2 (2024): 495-522

windows will act as reflectors that reflect the light to other walls of the room and will also cause glare to reduce (figure 11).

**Figure No 11: Unilateral Lighting (left plan) Bilateral Lighting (right side plans)**

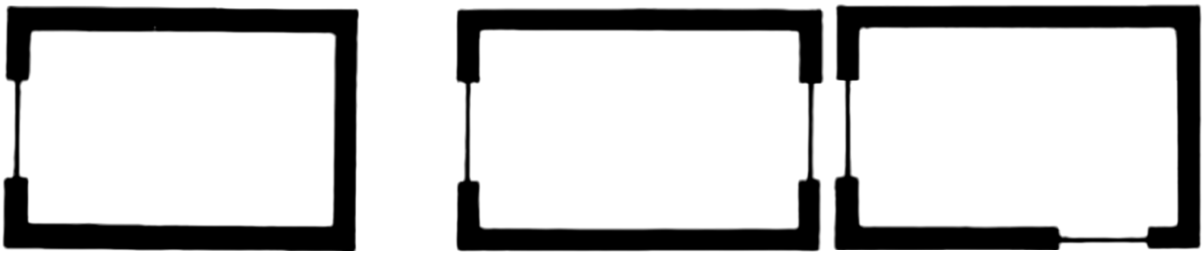
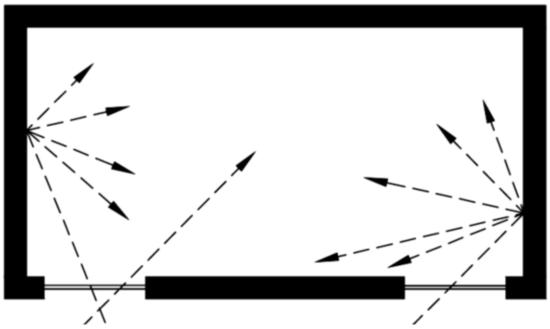


**Figure No 12: Both Daylight Distribution and Quality are Improved by the Reflections of Adjacent Walls.**



Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

### 4.11 Bilateral Lighting

Windows on two sides/walls are two daylight sources for that space, and is known as bilateral lighting (figure 11; right plans). Bilateral lighting is generally preferred over unilateral lighting; as bilateral lighting allows better light distribution while reducing the glare effects in comparison to unilateral lighting.

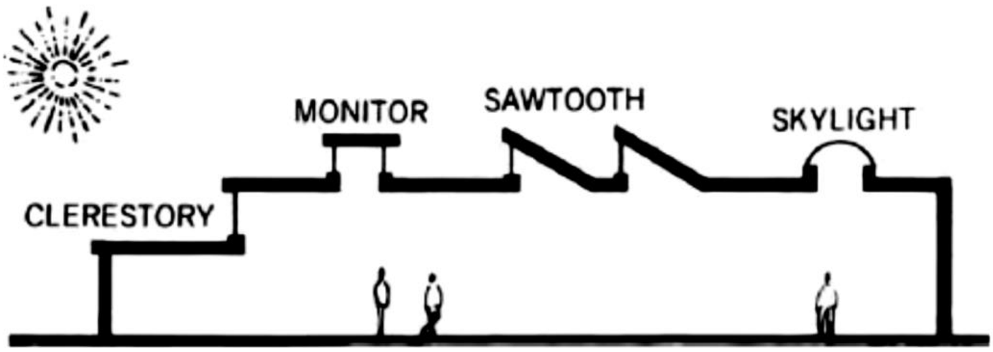
If the windows are placed on two adjacent walls, they will be effective in reducing glare. Windows on each wall will illuminate the adjacent wall that will reduce contrast between each window and its adjacent wall (figure 12).

### 4.12 Top Lighting

Clerestory, monitor, saw-tooth and skylights all are the approaches for implementing top lighting into a building and all of these are raised above the main roof level to bring natural light to the center of a space (figure 13).

The chief advantage of top lighting is it has potential for high quality as well as high quantity illumination over a large area. But unluckily because of some major drawbacks; orientation issues etc., top lighting is not a feasible approach for multi-story buildings and it should complement but not a substitute of windows. Each of the top lighting strategy will be individually discussed in detail.

**Figure No 13: Various Possibilities of Top Lighting**




Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

## 4.13 Skylight

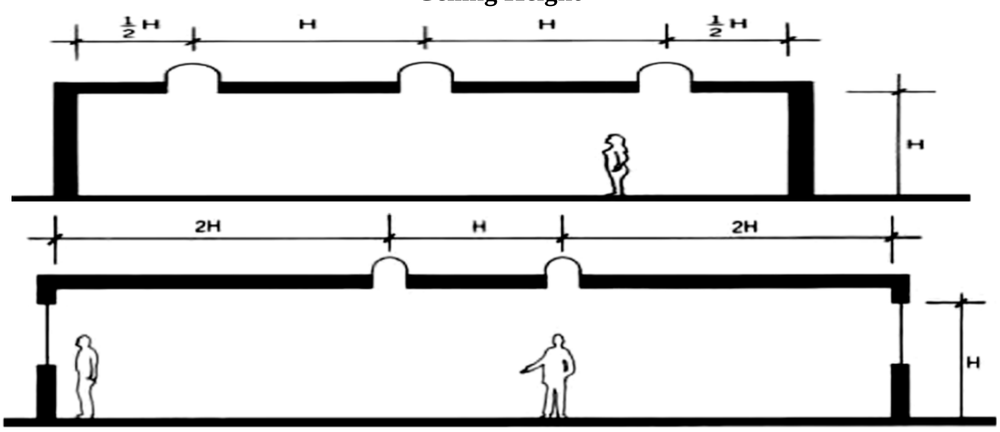
"Skylights are horizontal or slightly sloped glazed openings in the roof." Skylights are a good source of daylighting; provide uniform illumination levels within large interior spaces. Skylights as horizontal openings receive more daylight as compared to vertical openings in form of windows. But unfortunately, the associated issues of shading and heat gain with skylights restricted their use to some extent and vertical glazing on the roof in other forms such as clerestory, monitors, saw-tooth etc. are preferred. Translucent glazing can be used in skylights unlike in vertical glazing, as there are no views to be blocked by translucent glazing, so use of such glazing in skylights can help in avoiding direct glare.

## 4.14 Guidelines

Because of certain advantages of skylights i.e. inexpensive and popularity etc., there are some guidelines for skylight utilization which are given below.

1) For uniform lighting, skylights should be placed at a given distance. Figure 14 shows recommended skylight spacing without windows and with window respectively.

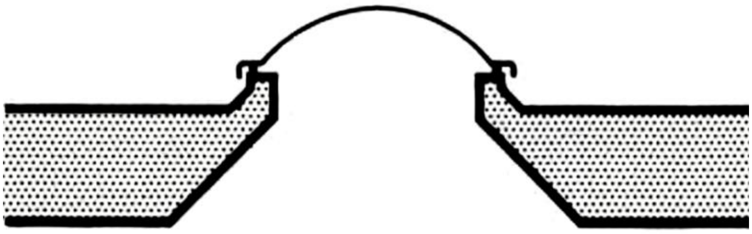
**Figure No 14: Recommended Skylight Spacing Without Windows and with windows as a Function of Ceiling Height**




Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

2- Use of splayed openings increase the size of skylight that consequently enhance both the quantity and quality of daylighting entering the building interiors (Fig 15).

**Figure No 15: Splayed Openings Offer Better Daylight Distribution & Reduces Glare as Compared to Square Openings**



Source: "“Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner”

3- Skylights should be placed near walls. Anyone of the walls, particularly the north wall can be used as a diffuse reflector for a skylight. Skylight placed before north wall provide more uniform daylight, will balance the light coming from the south window and avoid puddles of sunlight on the lower parts of the walls (figure 16).

**Figure No 16: Skylight Placed Before North Wall Provide Uniform Daylight and Less Glare.**

Source: "“Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner””

4- Use of internal reflectors below skylight can diffuse sunlight, can provide very uniform sunlight by bouncing light up to the ceiling and reduces glare (figure 17).
5- External shades over skylights can be used to shade the skylight from the summer sun and use of external reflectors can enhance the winter sun collection (figure 18).

**Figure No 17: Use of Reflectors Under Skylight to Diffuse Sunlight**

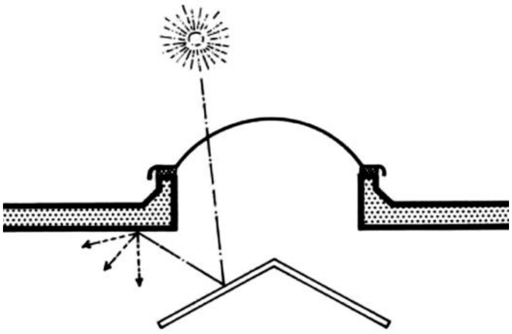
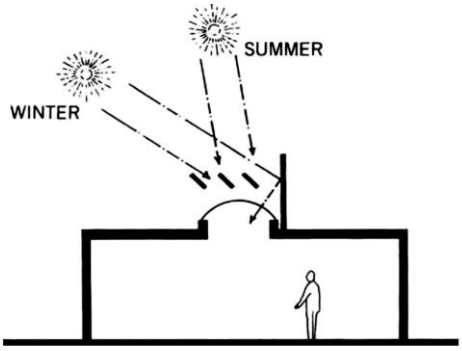


**Figure No 18: Shade the Skylight from Summer Sun and Use Reflector to Allow Winter Sun**




Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner

6- Use of steeply sloped skylights over horizontal ones, can improve summer/winter balance by allowing the winter sun and restricting the summer sun (figure 19).
7- Skylights can also be used for dramatic purposes only, in areas such as lobbies, lounges and some other spaces which don't require visual tasks (figure 20).

**Figure 19: Operable louvers below Skylight to Adjust Light Levels**

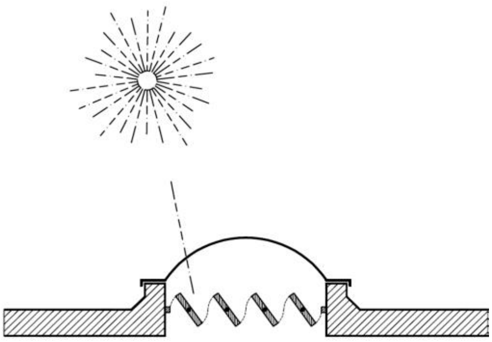
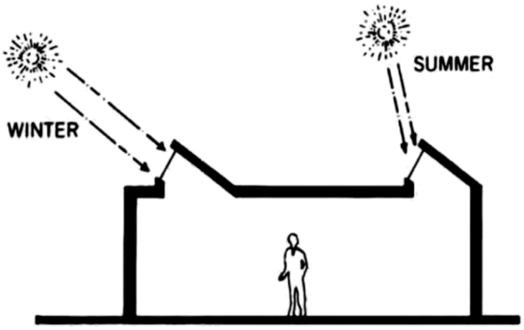


**Figure 20: Steeply Sloped Skylight Have Better Performance than Horizontal Ones**

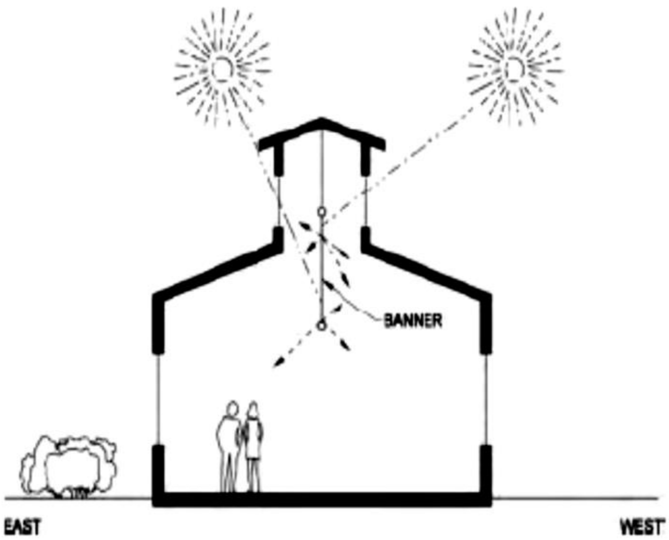



Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

## 4.15 Monitors

The word "monitor" is normally used wherever windows face more than one direction and are operable. Monitors not only used to provide daylighting but to ventilate the center of large spaces. A banner is an effective technique for diffusing sunlight (figure 21).

**Figure No 21: A Banner is an Effective Technique for Diffusing the Sunlight**

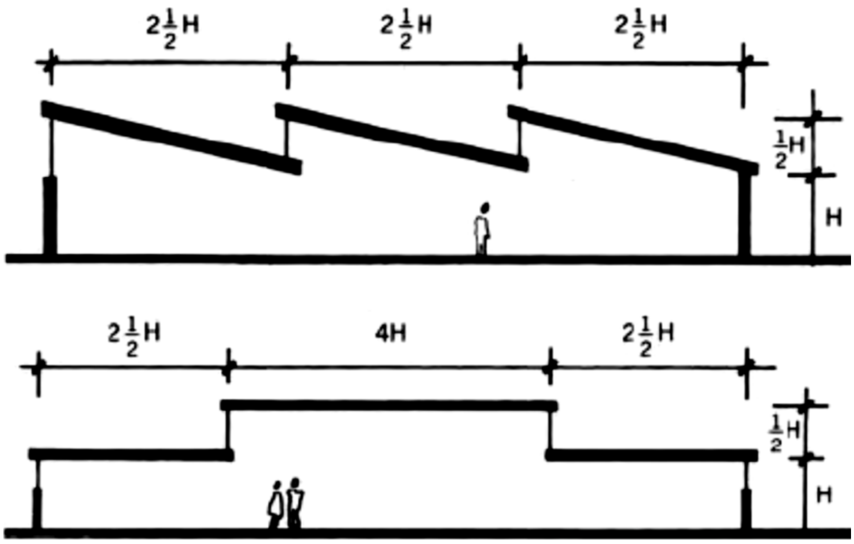



Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

## 4.16 Clerestory

Vertical or nearly vertical glazing of clerestories has similar characteristics to windows and can be easily shaded depending on their orientation. Clerestories should face north or south, depending on the climate, while east and west-facing clerestories are generally to be avoided. In hot climates with short winters, a combination of north and south-facing glazing might be a good option. Figure 22 illustrates the spacing for typical clerestories as a function of ceiling height.

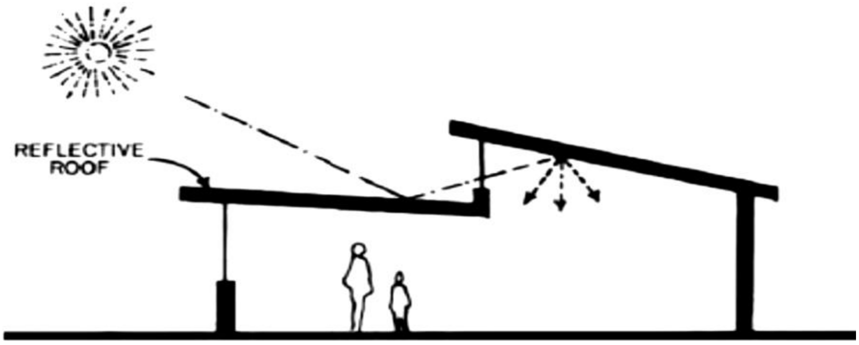
**Figure No 22: Typical Spacing of Clerestories is Given as A Function of Ceiling Height**



Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

1- Light entering through clerestories is diffused because it reflects off the roof, especially when the roof is painted white or a light color. (figure 23).

**Figure No 23: Use of Reflective Roof to Maximize the Diffused Light Entering Through a Clerestory**




*Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"*

2. Walls can act as brightness diffusers. When a clerestory is placed just before an interior wall, sunlight entering through the clerestory glazing reflects off the interior wall, allowing light to penetrate deeper into the space and reducing direct glare (Figure 24). South-facing clerestories are particularly effective in this regard.

3. Diffusing baffles can be used to prevent puddles of sunlight on work surfaces, distribute sunlight more evenly over workspaces, and eliminate glare from the clerestory. The spacing between baffles should be designed to block direct sunlight and avoid direct glare within the field of view below 45° (Figure 25). The finishes of the baffles should be matte, highly reflective, or highly translucent.

**Figure No 24: Clerestory Reflect Light Off the Interior Wall**

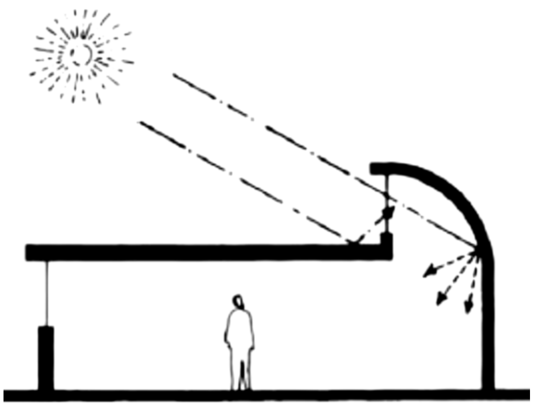
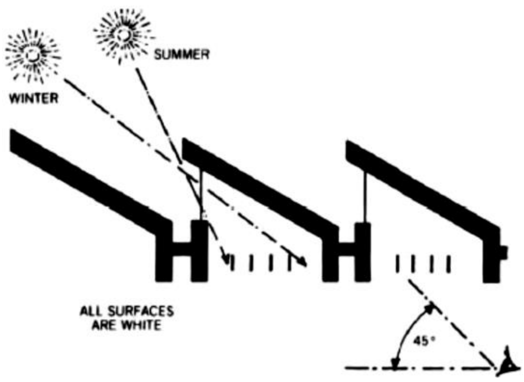


**Figure No 25: Diffusing Baffles Avoid Direct Sun & Glare in The Field of View**



Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

### 4.17 Light Scoop

Light scoop is a terminology used when clerestory windows are oriented to one direction only then the opposite side is made curved in order to reflect daylight down (figure 26).

**Figure No 26: Light Scoop in a Roof**

Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

### 4.18 Light Shelf

A light shelf is a horizontal structure installed above a window that reflects light onto the ceiling to enhance daylight penetration into a space. When placed above eye level, the window glazing below the light shelf serves primarily for viewing. The light shelf acts like an overhang for the lower window glazing, preventing direct sunlight from entering the space, eliminating sunlight puddles, and reducing glare by blocking the view of the bright sky through the lower window glazing.

Glare from the upper window glazing can be managed using louvers or by adding an interior light shelf (Figures 27 and 28). An interior light shelf is particularly effective as it captures and distributes daylight further into the space compared to a light shelf with louvers. It can be very delicate, such as a white film or a piece of fabric stretched over a light metal frame.

**Figure No 27: Light Shelf at Eye Level with Louvers on Glazing Above Light shelve**

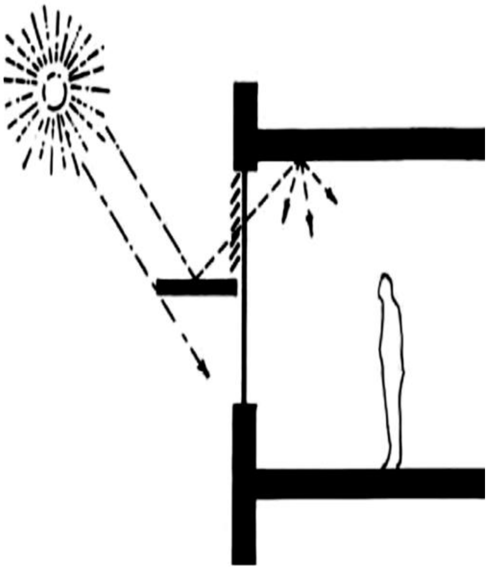
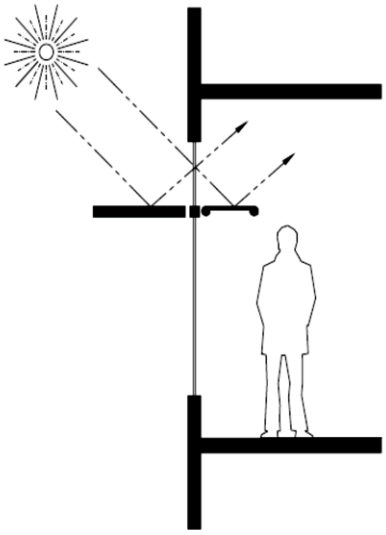


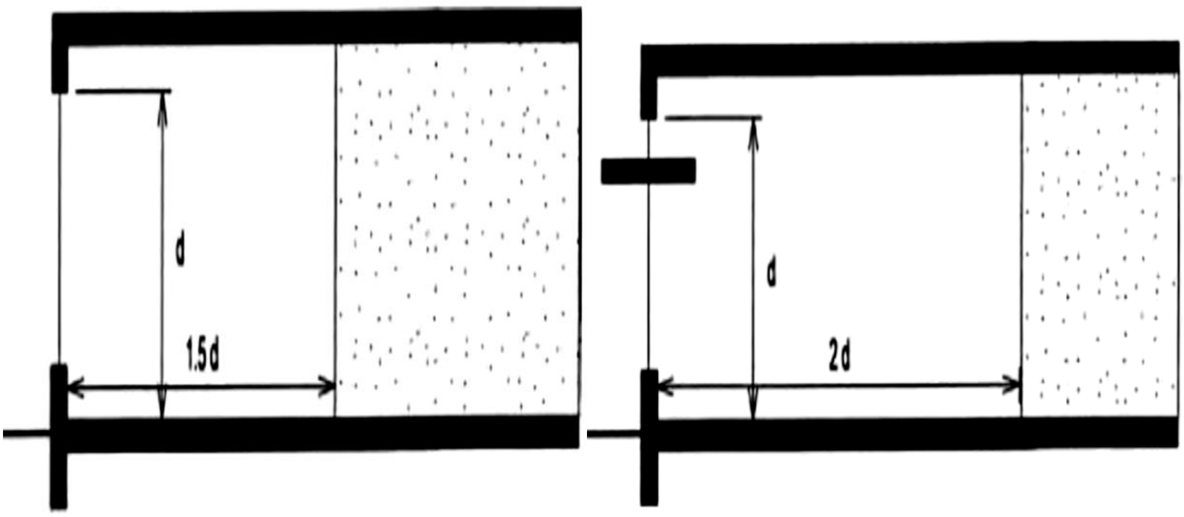
**Figure 28: - A 2nd Light Shelf on Interior**



*Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"*

Light shelves not only improve the daylighting quality but also increase the depth of daylighting zone from 1½ times the height of the standard window to 2 times the height of the window with light shelve for south facing windows in direct daylight (figure 29).

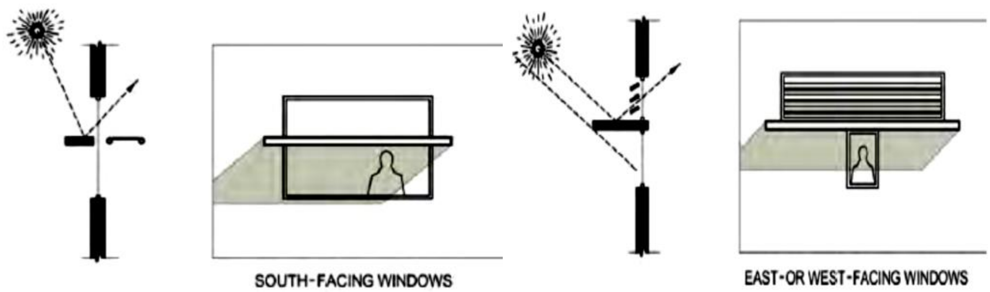
**Figure No 29: Adding Light Shelf Increases Daylighting Zone from 1½ to 2 Times The Height of the Window**




Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

Light shelve work well on south glazing. North glazing doesn't require any light shelve. In comparison to south glazing, east and west glazing require longer light shelve to block the lower summer sun. On east or west glazing, louvers are designed above the light shelve (figure - 30).

**Figure No 30: Light Shelf w.r.t Different Orientation**




Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

## 4.19 Courtyard

Courtyards are open to the sky so are exposed to the weather. As compared to glazed atrium courtyards have more daylight available to them. Because of open to sky; courtyards may cause in excessive glare levels in sunny sky conditions if finishes with high reflectance values are used. Courtyards may also be shaded.

External finishes used in courtyards are generally preferred to be darker in color in comparison to internal surface finishes. It is common practice to provide verandas/cloister in the adjacent rooms of a courtyard building. So, these verandas/cloisters provide shade to the glazing of the adjacent rooms from the direct sun and rain but also reduce the sky view. So, in achieving reasonable daylighting levels in adjacent rooms ground reflected light will have to make a major contribution. Use of light-colored courtyard floor finishes along with cloister configuration contribute in achieving significant daylight levels in sunny climatic conditions. In cloudy climatic conditions low illuminance available from the diffused sky along with the use of darker courtyard floor finishes may cause reduced daylighting levels so projecting cloister with clerestory window above might be one possible solution to well daylit the adjacent rooms.

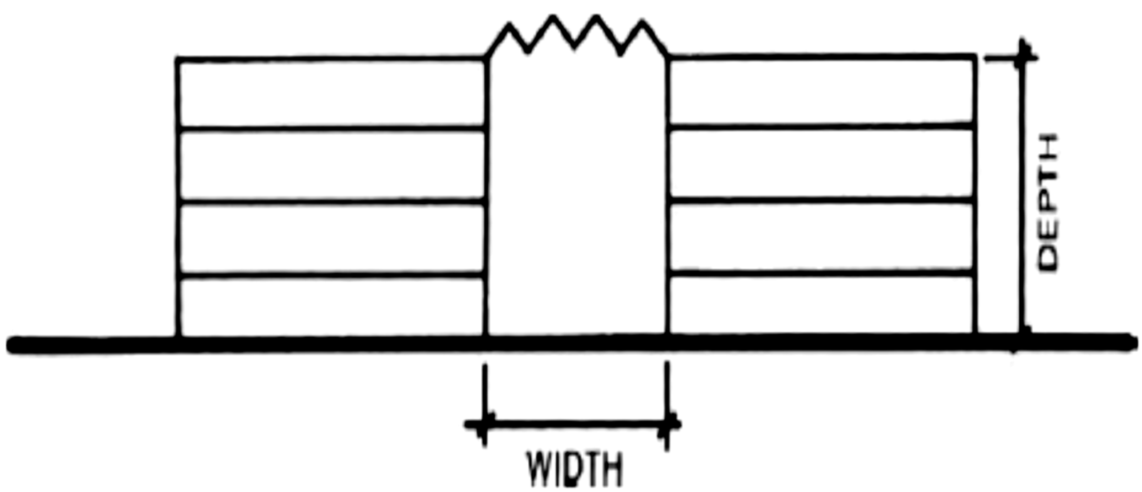
## 4.20 Atrium

Atriums play a crucial role in maximizing daylight within building interiors by enclosing a space on two or more sides and utilizing transparent or translucent materials in the roof, which also illuminates connected interior spaces. This daylighting strategy is employed to illuminate adjacent rooms, support plant growth, and facilitate activities within a centrally located, climate-controlled environment.

Modern atriums are enclosed spaces that maintain indoor temperatures similar to the surrounding building, ensuring thermal efficiency while maximizing exposure to natural light. The amount of daylight reaching the base of an atrium depends on several factors, including the translucency of the atrium roof, reflectance values of atrium walls, and the spatial geometry (depth versus width) as illustrated in Figure 31.

Daylight reaching adjacent rooms from an atrium is influenced by the width and height of the atrium, reflectivity of interior surfaces, translucency of the atrium roof, and the size and positioning of windows facing the atrium, as well as the transmittance properties of the glazing. Other daylighting strategies such as skylights, clerestories, or window walls can be integrated with atriums to enhance their illumination capabilities, as depicted in Figure 32.

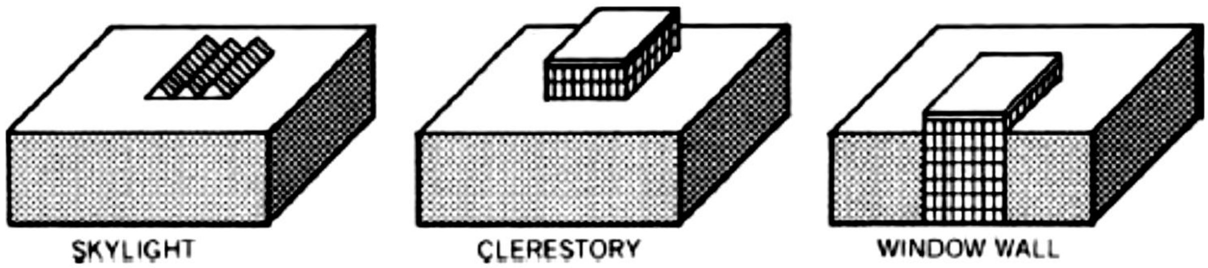
**Figure No 31: The Actual Values of Depth or Width is Not Important but Their Ratio is Significant in Determining the Amount of Daylighting That Reaches at The Base of the Atrium**




Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

Other daylighting strategies such as a skylight, clerestory or a window wall etc. can be combined with atriums to make atriums well illuminated (figure 32). Atriums that are too small to be useful spaces, they are known as "light wells".

**Figure No 32: Common Types of Daylit Atriums**




Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

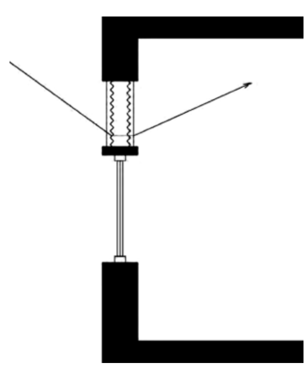
### 4.21 Light Wells or Shafts

Light wells or light shafts are compact spaces that, while often too small for practical use, can be optimized for efficiency. Increasing the width-to-depth ratio and using reflective materials on the walls of light wells can enhance the quantity of transmitted light. This approach improves the effectiveness of light wells in bringing natural light into interior spaces, despite their limited size and functional utility.

### 4.22 Prismatic Systems

In early 20$^{th}$ century, prismatic glass floor tiles were popular as daylighting product. They were used above windows to refract daylight. The interior surfaces of these tiles have triangulated grooves that act like prisms and their outside surfaces have different decorative patterns (figure 33).

**Figure No 33: Prismatic Glass Tiles Refract Light Farther Indoors**



Source: "Heating, Cooling, Lighting – Sustainable Methods for Architects by Norbert Lechner"

### 4.23 Glass Floors

Other than aesthetic reasons, glass paving blocks are a wonderful source of providing lighting from a floor to another floor. Glass's brittle nature had restricted its use but today, with technological advancements availability of laminated glass has solved the problem. Laminated glass is now used to cover large spans but requires careful design calculations i.e., calculate the required thickness of glass and no. of laminated sheets to be used for a specific glass floor size and its loading.

## 5. Conclusion

Daylighting is a critical aspect of sustainable architectural design, offering significant benefits in energy efficiency, occupant comfort, and overall well-being. To achieve optimal daylighting in building design, it is crucial to conduct a thorough analysis of solar geometry during the design phase to understand the sun's path and optimize window placement and shading devices. Buildings should be oriented to maximize north-south exposure, ensuring consistent daylight distribution and easier management of direct sunlight and heat gain. Appropriate window design, including strategic placement and sizing, should balance daylight penetration with glare control, utilizing light shelves, overhangs, and louvers to enhance daylight distribution while minimizing direct sunlight. The use of light-colored and reflective interior surfaces can further enhance daylight penetration and distribution, particularly in deeper rooms. High reflectance colors such as white (80-90%) and pale-yellow rose (80%) significantly enhance daylight distribution within a space. Recommended reflectance for ceilings is 70-80%, for walls 40-80%, and for floors 20-40% to optimize light reflection and uniformity. Incorporating advanced glazing materials that provide optimal light transmission while minimizing heat gain and glare is essential.

European and CIBSE daylighting standards are available but no daylighting standards were found specifically for Pakistan. European standards for lux levels range from 100 lux for corridors to 750 lux for technical drawing rooms. CIBSE standards similarly recommend 100 lux for corridors and stairs, with 750 lux for drawing offices and 500 lux for general offices and computer practice rooms. Adhering to recommended lux levels and daylight factors as per European and CIBSE standards ensures that lighting conditions meet the necessary criteria for different tasks and uses, promoting both energy efficiency and occupant well-being.

Several strategies can be employed to optimize daylighting in buildings. Each of these strategies has unique benefits and can be selected based on the specific requirements of the building and its location. For instance, skylights provide uniform illumination in large spaces, while clerestories allow for effective light distribution in smaller, more controlled areas, ideal for spaces requiring specific light levels without direct sun exposure. Light-shelves can enhance daylight penetration into deeper spaces, reflecting light onto ceilings for better distribution, and atriums can bring natural light into the core of a building, creating pleasant central spaces while enhancing overall light levels.

In summary, effective daylighting design requires a careful balance of color selection, reflectance optimization, and adherence to established standards. By implementing these strategies, architects and designers can create well-lit, energy-efficient, and comfortable indoor environments.

### 5.1 Recommendations

Consider the building's geographical location and orientation to maximize natural light while minimizing heat gain and glare. Use building orientation to take advantage of seasonal sun angles, ensuring optimal light penetration and energy efficiency. Utilize light-colored interior surfaces to enhance the reflection of natural light, improving overall illumination levels. Employ external and internal shading devices, such as overhangs, louvers, and blinds, to manage glare and heat gain effectively. Use operable shading devices to allow for seasonal adjustments, optimizing comfort and energy efficiency throughout the year. Design a hybrid lighting system that integrates daylighting with artificial lighting, ensuring consistent light levels during varying weather conditions and times of day. Use sensors and controls to adjust artificial lighting based on available daylight, further enhancing energy savings.

## 6. References

Al-Ashwal, N. T., & Hassan, A. S. (2017). The integration of daylighting with artificial lighting to enhance building energy performance. *AIP Conference Proceedings*, *1892*. https://doi.org/10.1063/1.5005777

Bodart, M., & De Herde, A. (2002). Global energy savings in offices buildings by the use of daylighting. *Energy and Buildings*, *34*(5), 421–429. https://doi.org/10.1016/S0378-7788(01)00117-7

Boubekri, M. (2008). Daylighting, Architecture And Health. *Daylighting, Architecture and Health*, 1–144. https://doi.org/10.4324/9780080940717

DeKay, M., & Brown, G. Z. (2013). *Sun, Wind, and Light*. https://books.google.com/books/about/Sun_Wind_and_Light_Architectural_Design.html?id=vMVFp_7zlaIC

Di Pasquale, G. (2004). Scientific and technological use of Glass in Graeco-Roman Antiquity. *When Glass Matters : Studies in the History of Science of Art from Graeco-Roman Antiquity to Early Modern Era. - ( Biblioteca Di Nuncius. Studi e Testi / Istituto e Museo Di Storia Della Scienza, Firenze ; 53)*, 1000–1048. https://doi.org/10.1400/47879

Djunaedy, E., Van Den Wymelenberg, K., Acker, B., & Thimmana, H. (2011). Oversizing of HVAC system: Signatures and penalties. *Energy and Buildings*, *43*(2–3), 468–475. https://doi.org/10.1016/j.enbuild.2010.10.011

EASTLAKE, CHARLES. (2023). *HISTORY OF THE GOTHIC REVIVAL*. https://books.google.com/books/about/A_History_of_the_Gothic_Revival.html?id=BPirEAAAQBAJ

Edensor, T., & Hughes, R. (2021). Moving through a dappled world: the aesthetics of shade and shadow in place. *Social & Cultural Geography*, *22*(9), 1307–1325. https://doi.org/10.1080/14649365.2019.1705994

Fang, Y., & Cho, S. (2019). Design optimization of building geometry and fenestration for daylighting and energy performance. *Solar Energy*, *191*, 7–18. https://doi.org/10.1016/J.SOLENER.2019.08.039

Heschong, L. (2002). Daylighting and Human Performance. *Ashrae Journal*.

Jütte, D. (2023). Transparency: THE MATERIAL HISTORY OF AN IDEA. *Transparency: The Material History of an Idea*, 1–502. https://books.google.com/books/about/Transparency.html?id=aNGwEAAAQBAJ

Katunský, D., Dolníková, E., Dolník, B., & Krajníková, K. (2022). Influence of Light Reflection from the Wall and Ceiling Due to Color Changes in the Indoor Environment of the Selected Hall. *Applied Sciences 2022, Vol. 12, Page 5154*, *12*(10), 5154. https://doi.org/10.3390/APP12105154

Lawrence, T., Roth, K., Crawley, D., & Brodrick, J. (2008). *Toplighting & Lighting Controls For Commercial Buildings*.

Lechner, N. (2014). *Heating, cooling, lighting: Sustainable design methods for architects*. https://books.google.com/books?hl=en&lr=&id=WjetCwAAQBAJ&oi=fnd&pg=PR11&dq=2.%09Lechner,+Norbert.+Heating,+Cooling,+Lighting+Sustainable+Methods+for+Architects.+4th.+New+Jersey:+John+Wiley+%26+Sons,+2015.&ots=YPJ8yRKH86&sig=YaJrVHC2ImfLK9b1fWwQ4QzETd8

Lee, E. S., Matusiak, B. S., Geisler-Moroder, D., Selkowitz, S. E., & Heschong, L. (2022). Advocating for view and daylight in buildings: Next steps. *Energy and Buildings*, *265*, 112079. https://doi.org/10.1016/J.ENBUILD.2022.112079

Li, P., & Li, B. (2024). *Generating Daylight-driven Architectural Design via Diffusion Models*. http://arxiv.org/abs/2404.13353

Liu, L., Sun, C., Liu, Y., Leng, H., and, Y. Y.-A. M., & 2024, undefined. (2023). Optimized design research on daylighting performance of cold land buildings based on improved neural network. *Sciendo.Com*, *9*(1). https://doi.org/10.2478/amns-2024-0730

Livingston, J. (2021). *Designing with light: The art, science, and practice of architectural lighting design*. https://books.google.com/books?hl=en&lr=&id=Ic9JEAAAQBAJ&oi=fnd&pg=PR1&dq=1.%09Jason+Livingston,+IALD,LC.+Designing+with+Light+The+Art,Science+and+Practice+of+Architectural+Lighting+Design.+New+Jersey:+John+Wiley+%26+Sons,+2014&ots=E0JDff4h7u&sig=HN3SZjlPesREwyeGxq7qVOgC7rE

Maleki, M., Gheitaran, N., El-Sayed, S., Cloutier, S., & Gaelle Giraud, E. (2024). The development and application of a localised metric for estimating daylighting potential in floor plate. *International Journal of Ambient Energy*, *45*(1). https://doi.org/10.1080/01430750.2023.2277310

Mayhoub, M. S., & Carter, D. J. (2011). Hybrid lighting systems: Performance and design. *Http://Dx.Doi.Org/10.1177/1477153511416324*, *44*(3), 261–276. https://doi.org/10.1177/1477153511416324

Nazari, M., & Matusiak, B. (2024). Daylighting simulation and visualisation: Navigating challenges in accuracy and validation. *Energy and Buildings*, *312*, 114188. https://doi.org/10.1016/J.ENBUILD.2024.114188

Onubogu, N. O., Chong, K. K., & Tan, M. H. (2021). Review of Active and Passive Daylighting Technologies for Sustainable Building. *International Journal of Photoenergy*, *2021*(1), 8802691. https://doi.org/10.1155/2021/8802691

Tregenza, P., & Mardaljevic, J. (2018). Daylighting buildings: Standards and the needs of the designer. *Lighting Research and Technology*, *50*(1), 63–79. https://doi.org/10.1177/1477153517740611/ASSET/IMAGES/LARGE/10.1177_1477153517740611-FIG1.JPEG

Yu, F., Wennersten, R., & Leng, J. (2020). A state-of-art review on concepts, criteria, methods and factors for reaching 'thermal-daylighting balance.' *Building and Environment*, *186*, 107330. https://doi.org/10.1016/J.BUILDENV.2020.107330