Studies on the Contribution of Daylight at Indoor Environment within a Stand-alone Building Throughout a Year, A Software-based Approach

A Thesis Submitted Towards Partial Fulfilment of the Requirements forthe Degree Of

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This is to certify that the thesis entitled "Studies on Contribution of Daylight at Indoor Environment within a Stand-alone Building Throughout a Year, A Software-based Approach" is a bonafide work carried out by **Arghadip Dian** under my supervision and guidance for partial fulfillment of the requirement of ***MASTER OF TECHNOLOGY IN ILLUMINATION TECHNOLOGY & DESIGN***, during the academic session 2020 - 2021.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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Abstract:

The building design incorporates lighting design in a significant way. Energy consumption in a building can be decreased with the use of natural lighting. The foundation of the planning concept is aesthetic levels. However, in order to achieve an energy-efficient building design, the idea of natural illumination must be taken into account. Understanding how lighting intensity affects a building's opening size, depth of space, and height was the goal of this study. Analyzing statistical information about space illumination levels from DIALux is the quantitative research method. The amount of openings in a building's exterior has an impact on how bright a space is. The depth of the space and the floor height of the building are both impacted by the dispersion of natural light. Based on this finding, it is anticipated that when constructing a structure, attention must be paid to the building facade in order to ensure that natural light penetration into the building is not excessive and to prevent undesirable effects like glare, extreme brightness, and contrast.

1. Introduction

Daylight is a valuable resource that is constantly present and unlikely to become scarce in the near future. It also has the extremely unique power to change an interior environment from one of uninspired monotony into one that is psychologically uplifting. One of the key reasons architects aim to allow daylight to enter a structure wherever possible is that it has the capacity to both enlighten an area and make it more fascinating.

Depending on the specific use of a room, the amount of change in daylight that is desirable or tolerable fluctuates from moment to moment in intensity and quality. For some usage, including in rooms, lighting regulations might be fairly rigorous, but many other applications allow for more flexibility. The quantity, quality, and distribution of light are the three elements that must constantly be taken into account in order to produce good lighting. Intense light sources, such as sunshine or electric light, can cause considerable glare, which can be both inconvenient and detrimental to a user's ability to perform their activity. This is the reason that carefully planning the design of openings in a building's fabric is necessary to manage the admission of sunlight into an area.

Section 2 describes the many ways in which daylight and sunlight can be brought into a building and how well the different options perform.

Section 3 examines the ways of controlling daylight and electric light so that internal conditions are maintained within design limits, and energy use reduced.

Section 4 reviews the tools available to help incorporate daylight into building design and predict itsperformance.

Section 5 gives an Analysis of studies of daylight systems that have been demonstrated.

2. Introducing Daylight into a Building

There are numerous texts that outline the fundamentals of daylighting, thus only a quick overview is given here. The design elements related to cutting-edge lighting systems that refocus light are given more attention.

2.1. Principles

Daylight needs to be considered at the outset of designing a building as daylighting strategies and architectural design strategies are inseparable. Daylight can not only replace artificial lighting, reducing lighting energy use but also influence both heating and cooling loads [3]. Planning for daylight therefore involves integrating the perspectives and requirements of various specialties andprofessionals.

Daylighting tactics are dependent on the availability of natural light, which is influenced by the building's latitude and the surroundings, such as any barriers that may be present. Climate has an impact on lighting techniques as well, thus it's critical to understand seasonal variations, current climate conditions, especially ambient temperatures, and sunshine probability. The first step in planning for daylight is to understand the environment and the amount of sunlight that is available at each façade of a proposed structure.

Designers typically seek to maximize daylight penetration in a structure during the winter months when sunshine levels are low due to the differing summer and winter conditions found at high latitudes. At these latitudes, it makes sense to direct sunlight from the sky's brightest areas towards buildings. In contrast, in tropical regions with high levels of year-round daylight, the design focus is typically on reducing overheating by limiting the amount of daylight entering a building. This can be accomplished either directly by using light reflected from the ground or indirectly by blocking large portions of the sky, particularly those close to the zenith, and allowing only lower portions of the sky to receive daylight [2].

2.2. Strategies for Different Light Conditions

An essential quality of daylighting systems is their ability to be tailored to particular sources of skylight [4].

2.2.1 Skylight

Strategies for diffuse skylight can be designed for either clear or cloudy skies. However, the most significant characteristic of these strategies is how they deal with direct sunlight. Solar shading always is an issue for daylighting except on facades facing the North/South pole (in the northern/southern hemisphere respectively). If solar shading is only of minor importance as a result of orientation and obstructions, a system to protect from glare can be used for solar shading as well. Solar shading and glare protection are different functions that require individual design consideration. Solar shading is a thermal function that primarily protects from direct sunlight, and glare protection is a visual function that moderates high luminance in the visual field. Systems to protect from glare address not only direct sunlight but skylight and reflected sunlight as well. Thus, systems that provide solar shading sufficient to prevent overheating may not be adequate for glare control [4].

2.2.2 Cloudy Skies

Daylighting strategies designed for diffuse skylight in predominantly cloudy conditions aim to distribute skylight to interior spaces when the direct sun is not present. In this case, windows and roof lights are designed to bring daylight into rooms under cloudy sky conditions, so windows will be relatively large and located high on the walls. Under sunny conditions, these large openings are a weak point, causing overheating and glare. Systems that provide sun shading and glare

protection are therefore an indispensable part of this strategy. Depending on the design strategy, various shading systems that transmit either diffuse skylight or direct sunlight may be applicable in this case. To avoid decreasing daylight levels under overcast sky conditions, moveable systems are usually applied. Some innovative daylighting systems are designed to enhance daylight penetration under cloudy sky conditions. Some of these systems, such as anabolic systems or light shelves, can control sunlight to some extent. The application of simple architectural measures, such as reflective sills, is another opportunity to enhance daylight penetration, but the design of the window itself is the main influence on the performance of this type of strategy under cloudy conditions [7].

2.2.3 Clear Skies

In contrast to daylighting strategies for cloudy skies, strategies that diffuse skylight in climates where clear skies predominate must address direct sunlight at all times. Shading of direct sunlightis therefore part of the continuous operating mode of this strategy. Openings for clear sky strategies do not need to be sized for the low daylight levels of overcast skies. Shading systems that allow the window to depend primarily on diffuse skylight are applicable in this case [13].

2.2.4 Direct Sunlight

The approaches to diffuse skylight and sunshine are very different. Because direct sunshine is so intense, it only takes a modest amount of incident light to fill a big interior space with enough light to be comfortable. If the likelihood of sunshine is high, beam daylighting solutions are appropriate. Direct sunlight can be easily steered and piped because it is a parallel source. In this situation, optical light transport systems and systems for direct light guiding are both appropriate. Since beam daylighting apertures typically don't offer a view of the outdoors, they should be coupled with other view windows. Beam daylighting can be used as an additional tactic in an approach that would ordinarily concentrate on cloudy sky

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2.3. Daylighting Systems Overview

Simple glazing and another component that improves the distribution or control of light in space are combined to create a daylighting system. While regular windows can meet some of a room's needs for daylighting, there are new technologies and solutions that perform better than the traditional ones:

- Providing usable daylight at greater depths from the window wall than is possible with conventional designs
- Increasing usable daylight for climates with predominantly overcast skies
- Increasing usable daylight for very sunny climates where control of direct sun is required
- Increasing usable daylight for windows that are blocked by exterior obstructions and therefore have a restricted view of the sky
- Transporting usable daylight to windowless spaces

These work by introducing reflective or refractive components into the glazing system. In addition, they may or may not combine this with shading the interior from sunlight or daylight to reduce glare or solar gain [2].

2.3.1 Daylighting Systems with Shading

Two types of daylighting systems with shading have been reviewed: systems that rely primarily on diffuse skylight and reject direct sunlight, and systems that use primarily direct sunlight, sending it onto the ceiling or to locations above eye height.

Conventional solar shading systems, such as pull-down shades, often significantly reduce the admission of daylight to a room. To increase daylight while providing shading, advanced systems have been developed that both protect the area near the window from direct sunlight and send direct and/or diffuse daylight into the interior.

2.3.2 Daylighting Systems Without Shading

Daylighting systems without shading are designed primarily to redirect daylight to areas away from a window or skylight opening. They may or may not block direct sunlight. These systems can be divided into four categories:

- **Diffuse light-guiding systems** redirect daylight from specific areas of the sky vault to the interior of the room. Under overcast sky conditions, the area around the sky zenith is much brighter (around three times) than the area close to the horizon. For sites with tall external obstructions (typical in dense urban environments), the upper portion of the sky may be the only source of daylight. Light-guiding systems can improve daylight utilization in these situations.
- **Direct light-guiding systems** send direct sunlight to the interior of the room without the secondary effects of glare and overheating.
- **Light-scattering or diffusing systems** are used in skylit or top-lit apertures to produce even daylight distribution. If these systems are used in vertical window apertures, serious glare will result.
- **Light transport systems** collect and transport sunlight over long distances to the core of a building via fiber optics or light pipes

Table 1 lists the different types of window systems, and shows which climate they are suitable for, and where they are normally placed in a building. It also gives information on:

- Their ability to protect against glare
- If they allow a view outside
- can guide light into the depth of a room
- can provide homogeneous illumination
- can save energy use by artificial lighting
- whether they need tracking, i.e. to move with the sun’s position and their availability

Some systems included can fulfill multiple functions and are therefore shown in more than one category. Light shelves, for instance, redirect both diffuse skylight and beam sunlight.

2.4. Daylighting System Details

There is a wide choice of daylighting systems and often many alternatives within each choice. Themain characteristics of each system are described in the following sections.

2.4.1. Light Shelves

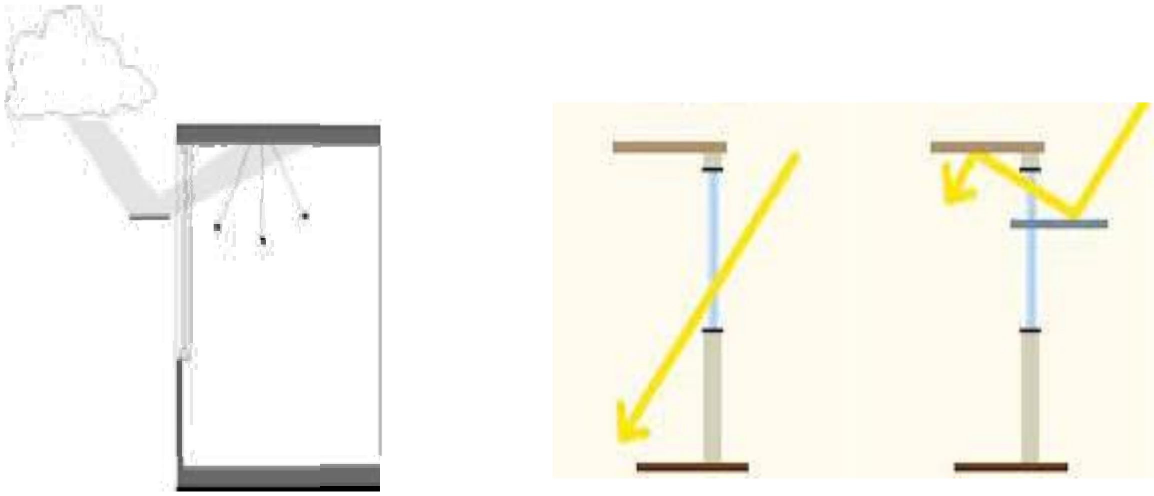


Figure 1.1: Light shelves [17]

A light shelf is a classic daylighting system, known to the Egyptian Pharaohs, which is designed to shade and reflect light on its top surface and to shield direct glare from the sky. It is mounted approximately horizontally either inside or outside a window (or both) and usually above eye height, dividing a window into a lower part with a vi w, and an upper clerestory above. The lower the height of a light shelf, the greater the light reflected onto a ceiling, but also the incidence of glareis likely to increase.

Light shelves inside a window decrease the total light in a room, but distribute it more evenly. External light shelves can increase the total light because they can increase the proportion of light that comes from high angles in the sky, where the sky luminance is greater.

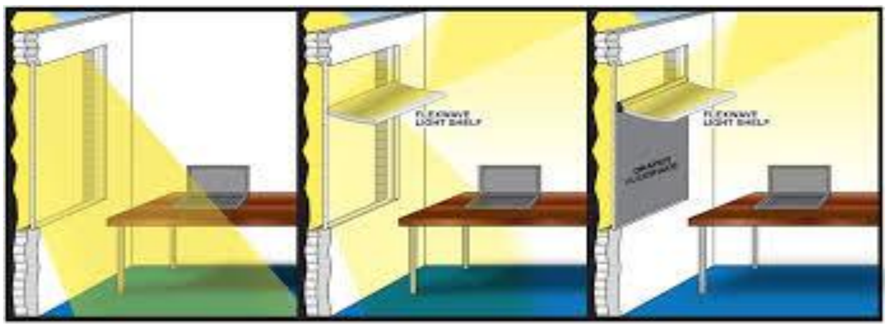


Figure 1.2: Light shelves [12]

2.4.2 Prismatic Panels

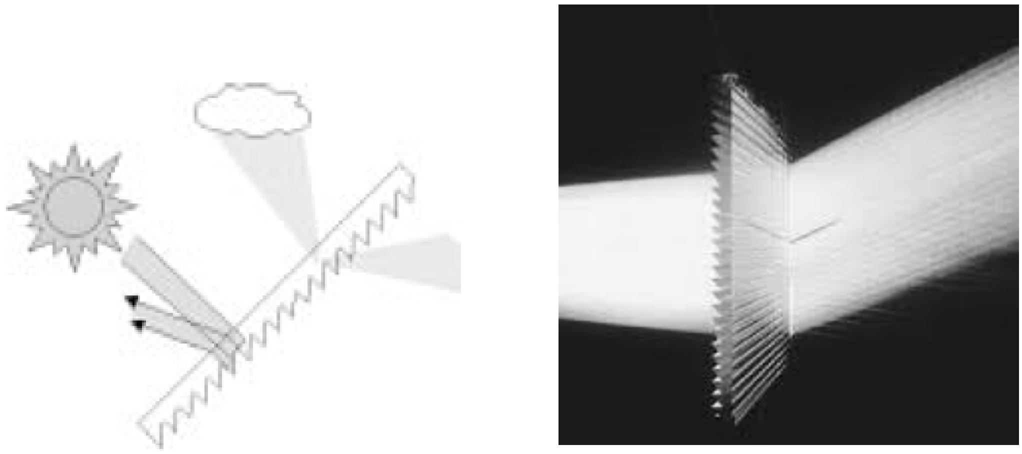


Figure 2: Prismatic Panels

Prismatic panels are thin, planar, sawtooth devices made of clear acrylic that are used in temperate climates to redirect or refract daylight. When used as a shading system, they refract direct sunlight but transmit diffuse skylight. They can be applied in many different ways, in fixed or sun-tracking arrangements, to façades and skylights, and used to guide diffuse daylight or sunlight [8].

If used for redirecting sunlight, prismatic panel designs may redirect some sunlight downwards, causing glare. However, with a correct profile and seasonal tilting, these downward beams can be avoided.

2.4.3 Laser-Cut Panels

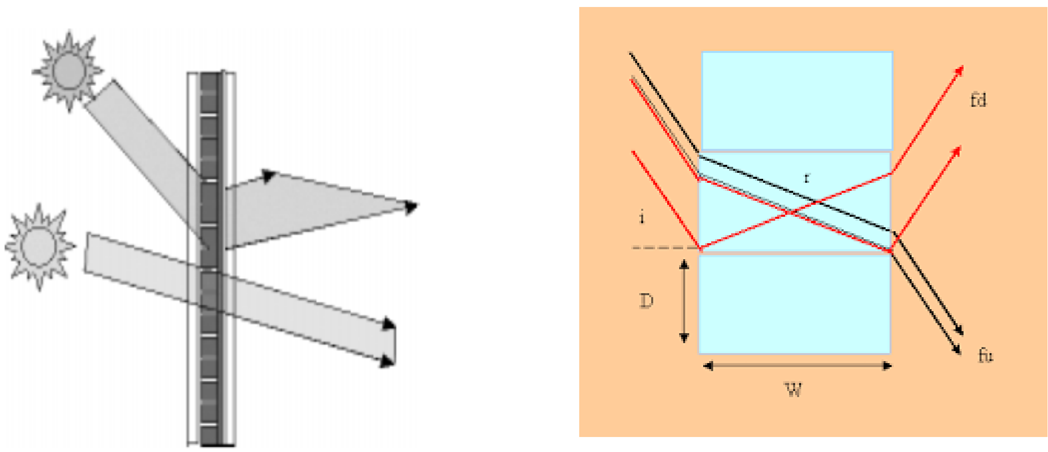


Figure 3: Lase-Cut Panels[16]

A daylight-redirecting system known as a laser-cut panel is created by cutting thin panels of clear acrylic material using a laser. The panel is divided into a variety of rectangular components by the laser cutting. The sliced surfaces then transform into tiny internal mirrors that reflect light into the panel. The panel has the benefit of maintaining a somewhat distorted view of the outside of the window in between the incisions.

2.4.4 Angular Selective Skylight (Laser-Cut Panel)

An angular selective skylight is a conventional clear pyramid or triangular type of skylight. Laser-cut light-deflecting panels are incorporated inside the clear outer cover forming double glazing. This system transmits more low-elevation light and less high-elevation light. Normally, a diffusing panel is used at the ceiling aperture.
The primary function of an angular selective skylight is to provide relatively constant irradiance to the interior during the day and to reduce the tendency to overheat a building on summer days. The skylights are especially suited for natural lighting of ventilated or air-conditioned buildings with extensive floor area and low-angle roofs, such as supermarkets and schools [8].

2.4.5 Light-Guiding Shades

Figure 4: Light Guiding Shades [6]

External shading devices called light-guiding shades are used to direct sunlight and skylight onto the ceiling. They are made to increase the amount of natural light that enters subtropical buildings' interior spaces, which are sometimes heavily externally shaded by big eaves that cut down on radiant heat gain from windows. They are more intricate and accurately defined than standard shades, and their interior surfaces must be made of highly reflecting material.
A diffusing glass aperture and two reflectors make up the shading system, which is intended to guide diffuse light from the aperture into a building at angles that fall within a given angular range (often 0-60°). The window is shielded from direct sunlight by the light-guiding shade, which is fastened over the window in the same manner as an external shade. The light-guiding shade greatly enhances the illuminance and its homogeneity in the interior of the space when compared to shading from an opaque overhang.

2.4.6 Sun-Directing Glass

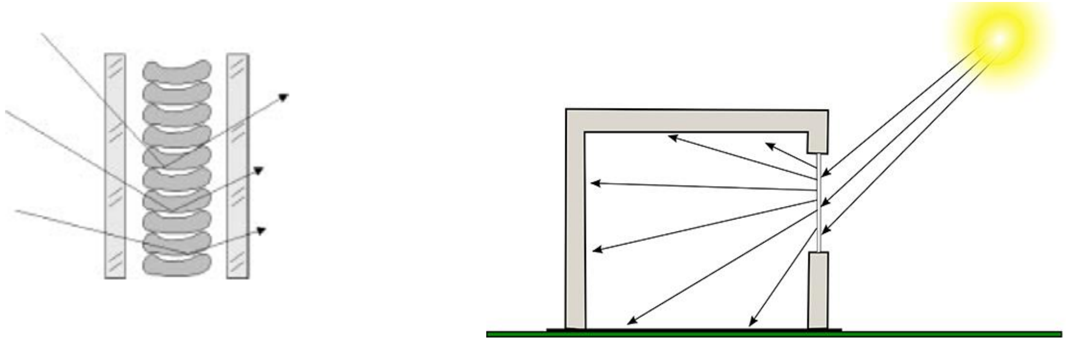


Figure 5: Sun directing Glass [17]

A double-glazed sealed unit holding concave acrylic pieces serves as the major part of a sun-directing glass system. Direct sunlight is deflected onto the ceiling by these elements, which are placed vertically inside a double-glazed unit. Typically, the sealed unit is positioned above the view window. To diffuse outgoing light within a constrained horizontal, azimuthal angle, the inside surface of the window unit can be patterned in a sinusoidal pattern. It is also possible to focus the incoming sunlight into a small horizontal angle by applying a holographic coating to the external glass pane.

The device is made to be used in bright sunlight. In regions with temperate climates (in the northern hemisphere), facing south is the best direction for a façade. It only works in the morning or late afternoon on facades facing the west or east. Although the system also deflects diffuse light, it does so at a far lower brightness level than does direct sunlight. Therefore, the pieces must be larger for north facades.

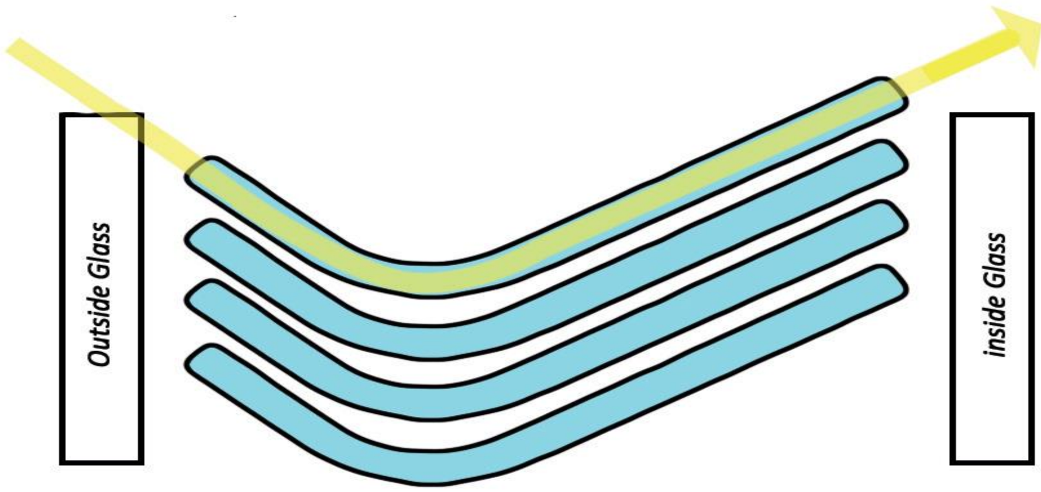


Fig 5.2: Glass through which sun light directed [13]

2.4.7 Zenithal Light-Guiding Glass with Holographic Optical Elements

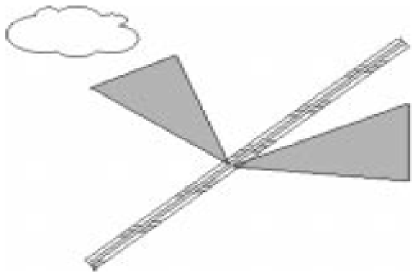


Figure 6: Zenithal light guiding [13]

Diffuse skylight is redirected through zenithal light-guiding glass into the depth of space. The main element is a polymeric sheet laminated between two glass panes that has holographic diffraction gratings. The holographic component reflects diffuse light from the zenithal region of the sky that enters the structure. Only façades that do not receive direct sunlight should use the technology because it may result in colour dispersion when exposed to sunshine.

The glass can be integrated in a vertical window system or attached to the façade in front of the upper part of a window at a sloping angle of approximately 45° [9]. Because zenithal light-guiding glass slightly distorts the view, it should only be applied to the upper portion of a window.

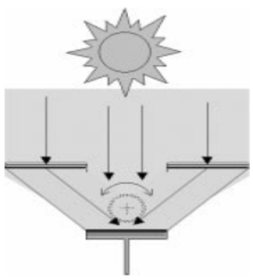


Figure 7: Holographic Optical element [11]

2.4.8 Directional Selective Shading Systems using Holographic Optical Elements

Directional selective shading systems reject incident light from a small angular area of the sky vault. They can therefore redirect or reflect incident beam sunlight while transmitting diffuse light from other directions. This selective shading provides daylight to building interiors without seriously altering view from windows.

In this system, holographic diffraction gratings are embedded in a glass laminate and the optically selected direct radiation can either be directed out again (rejected) or directed to a secondary area (for conversion to electricity or thermal energy). In either case, the whole shading assembly has to track the sun's path (on a single axis) to achieve optimal shading. Normally the assembly would be attached in front of the main vertical glass façade or roof as a shading system. Internal mounting is possible if the solar gain can be adequately rejected, e.g. into the roof.

2.4.9 Anidolic Ceilings

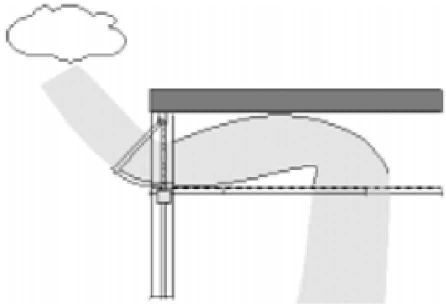


Figure 8: Anidolic Ceilings[9]

Anidolic ceiling systems use the optical properties of compound parabolic concentrators to collect diffuse daylight from the sky. The concentrator is coupled to a specular light duct above the ceiling plane, which transports the light to the back of a room. The primary objective is to provide adequate daylight to rooms under predominantly overcast sky conditions and is designed for side lighting of non-residential buildings [5].

On the outside of a building, an anidolic (non-imaging) optical concentrator captures and concentrates diffuse light from the upper (brighter) area of an overcast sky, and efficiently introduces the rays into a light duct. At the duct's exit aperture in the back of the room, a parabolic reflector distributes the light downward, avoiding any back reflection. The daylight is transported deeper into the room by multiple specular reflectors lining the light duct, which occupies most of thearea above the ceiling.

Anidolic ceilings can be used in densely built-up urban as well as rural areas. Their relative effect is more impressive in an urban environment because obstructions around a building increase the importance of collecting diffuse light from the upper sky.

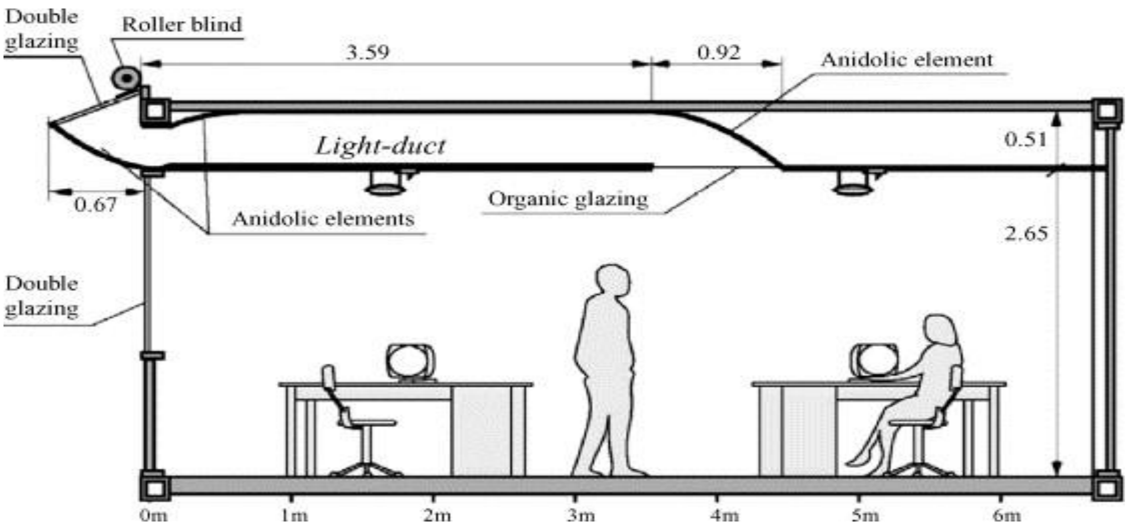


Figure 9: Annidolic ceiling [12]

2.4.10 Anidolic Zenithal Openings

The anidolic zenithal opening is a daylighting system used to collect diffuse daylight from a large portion of the sky vault without allowing direct sun to penetrate. This form of sky lighting system is best utilized to provide daylight to single-storey buildings, atrium spaces, or the upper floor of multi-storey buildings.

The roof collector is based on a linear, non-imaging, compound parabolic concentrator whose long axis is oriented east-west. The opening is tilted northward for locations in the northern hemisphere and designed so that the sector where it admits light includes the whole sky between the northern horizon and the highest position of the sun in the southern sky during the year. A compound parabolic deconcentrate, similar to the compound parabolic concentrator but reversed, is placed atthe emitting end of the opening to guide the daylight flux towards the bottom of the room.

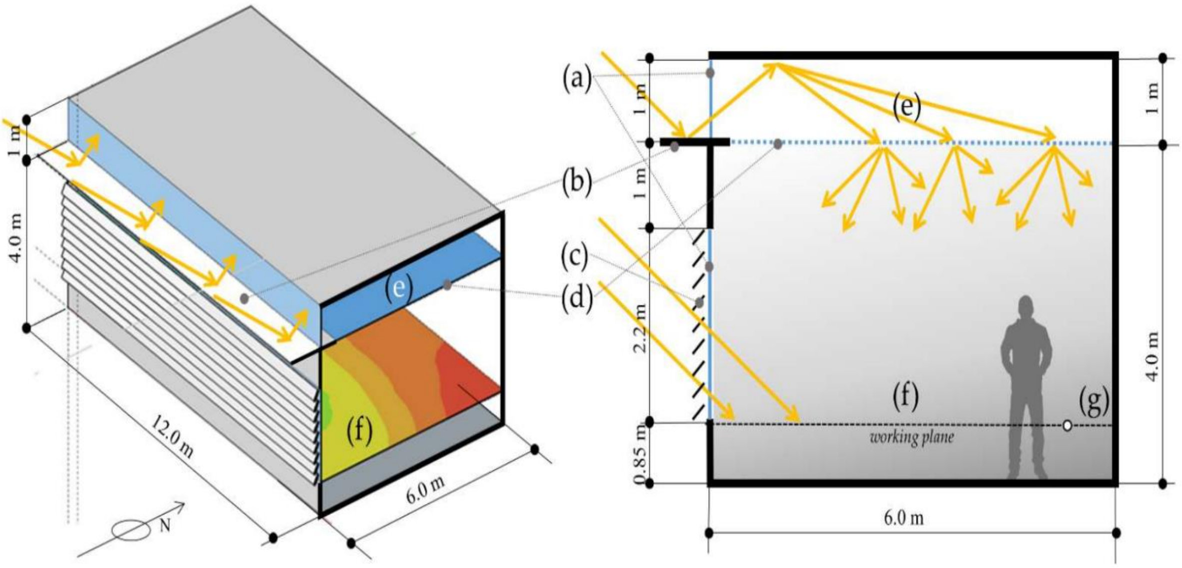
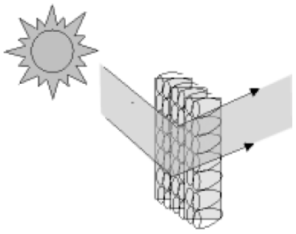


Figure 10: Anidolic Zenithal Openings [11]

2.4.11 Anidolic Solar Blinds



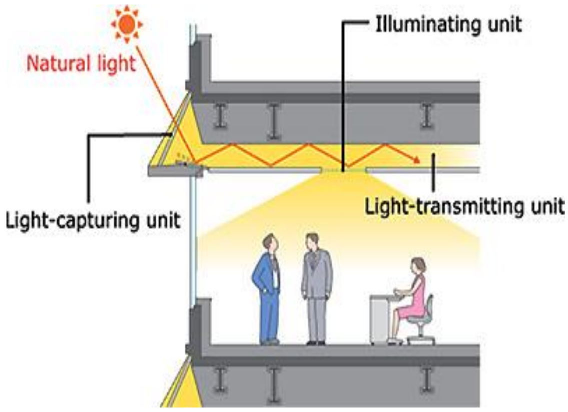


Figure 11: Anidolic solar blinds

Anidolic solar blinds consist of a grid of hollow reflective elements, each of which is composed of two three-dimensional compound parabolic concentrators. The blinds are designed for side lighting and provide angular-selective light transmission to control sunlight and glare. The innovative feature of anidolic solar blinds compared to other anidolic systems (anidolic ceilings, anidolic zenithal openings) is their use of three-dimensional reflective elements and their small scale. The optics of the admitting portion of the blinds are designed to reject most high-solar-altitude rays from direct sun but to transmit lower altitude diffuse light or winter sunlight.

The anidolic solar blind system can be applied either as a fixed louvre to window openings that were principally designed to collect daylight (i.e., the view through them is blurred), or can be placed in the upper part of a normal window if the view to the outside must be maintained through a lower portion of the window. In either application, anidolic solar blinds would typically be placed between two panes of glass for protection against dust.

Anidolic blinds are a fixed system to control daylight and thermal gains in south-facing or other façades that receive extensive sunlight. The blinds are intended to increase daylight penetration under a wide range of conditions while preventing the interior space from overheating. Although the system is mainly designed to control daylight in sunny climates, it may be used under predominantly cloudy skies.

2.5. Performance

The different types of daylighting systems were tested using models, full-scale test rooms, in real buildings, or by computer simulation. From these tests, some conclusions can be made about the performance of the different systems in terms of their ability to block, or redirect daylight. When combined with a daylight responsive control system for electric lighting, energy savings can be made.

2.5.1 Shading Systems Using Diffuse Light

Louvres

Fixed, mirrored louvres are designed principally for direct sun control. High-altitude sun and skylight reflected off the louvres increase interior daylight levels. Daylight levels from low-altitude skies (i.e. from approximately 10° to 40° above the horizon) are reduced [7]. Fixed, mirrored louvres can control glare but reduce daylight levels. They are a design option for shallow rooms in temperate climates.

Blinds

Standard venetian blinds provide moderate illuminance distribution. The optimum amount of slat closure is dictated by glare, direct sun control, and illumination requirements. Inverted, silvered blinds increase daylight levels if the slats are horizontal.

Automated Blinds

When an automated venetian blind is used to block direct sunlight and is operated in synchronization with dimmable fluorescent lighting, energy savings are substantial compared to the energy used when a static blind is paired with the same electric lighting control system.

Holographic Optical Element (HOE) Shading Systems

These systems provide efficient solar shading while maintaining daylight illumination. The current high cost imposed by the required tracking system may limit the applicability of HOE shading systems.

Fig 12: Louvres

2.5.2 Shading Systems Using Direct Sunlight

Light Shelves

Optically treated light shelves are an improvement over conventional internal light shelves, and can introduce adequate ambient light for office tasks under most sunny conditions.

Light-Guiding Shades

Light-guiding shades increase daylight illumination in the center of space as compared with the illumination provided by conventional shades. Light-guiding shades are suitable for hot, sunny climates.

Angular Selective Skylights

Angular selective skylights are best used in low latitudes because these systems reject direct sunlight at high altitude and redirect low-altitude daylight into a room, controlling heat gains and at the same time providing additional illumination from the sky [3].

2.5.3 Non-Shading Systems Using Diffuse Light

Light Shelves

External light shelves use not only diffuse light but also distribute (diffused) direct sunlight. An external, upward-tilted (30°) light shelf can increase daylight levels at the back of a room. An internal light shelf will decrease light levels.

Anidolic Ceiling

This system, which has an exterior, sky-oriented collection device, has been shown to increase the daylight factor below the light-emitting aperture of the system at a five-meter room depth. It requires a blind on the collection device to control sunlight on very sunny days.

Zenithal Light-Guiding System with HOEs

This system increases illumination in the depth of a room and reduces it near the window at orientations where there is no direct sunlight [5].

2.5.4 Non-shading systems using Direct Sunlight

Laser-Cut Panel

Similar to the prismatic panel, the laser-cut panel increases light levels by 10% to 20% in the depth of a room, particularly in sunny climates. When the panel is tilted, substantially higher levels are achieved. Tilting can also reduce the glare factor.

Sun-Directing Glass

Sun-directing glass increases illuminance levels in the depth of a room in sunny climates. The system depends on the incident angles of the sun and is best used in temperate climates.

3. Controlling Lighting in Response to Daylight

It is desirable to be able to control both the daylight entering a space and the electric lighting within it. In this way, the benefit of receiving daylight can be achieved whilst minimizing the electricity used for artificial lighting, and maintaining the illuminance within the required limits. Excess solar gain can be avoided and occupants remain comfortable. To achieve this level of control and for it to be successfully accepted by users are two of the main goals of good daylighting.

3.1. Controlling the daylight contribution

The primary control of daylight should be made by the choice of window size and position. The daylight transmittance of the glazing then determines the maximum light that can be received in the room.

Manual control over the quantity and quality of daylight in the rooms can be provided either by simple, but widely-used diffusing curtains or venetian blinds, or by the more sophisticated light re- directing systems, as described in the previous section. The latter aim to optimize the quantity, and quality of the incident natural light, i.e. avoiding glare.

Automatic systems can perform a wide range of control actions. They can tilt or turn horizontal/vertical lamellae, lower or raise curtains, rotate sun-tracking systems, etc. However, many of these systems do not respond to the overall daylight availability, rather their actions may depend on the direct sunlight or solar position alone. Examples are shading controlled on the basis of direct sunlight, using a roof-based sensor measuring total radiation on a tilted surface; controls for tilting blinds based on astronomical data for solar position; and controls of heliostats based on solar position.

Daylight responsive daylight control systems consist of a sensor, measuring incident flux, and a control system acting according to the sensor’s signal. For all control systems, the best functioning ones are preferably unnoticeable to a room’s occupants.

3.2. Controlling Electric Lighting

In recent years, the use of electric lighting controls has shown potential to significantly reduce lighting energy use and to moderate peak demand in commercial buildings compared to conventional systems without controls [7]. Lighting control strategies have included automatically dimming the lights in response to daylight, dimming and switching luminaires on or off according to occupancy, and performing lumen maintenance, i.e., automatic compensation for long-term lumen losses. However, these systems have proved in some instances difficult to calibrate and commission in actual practice.

Lighting controls that are now becoming available offer potential solutions to these difficulties: lighting energy monitoring and diagnostics, easily accessible dimming capabilities, and the ability to respond to real-time utility pricing signals. Research using an advanced electric lighting control system has found that daylight-linked control systems can bring about sustainable reductions of 30–41% in electrical energy for an outermost row of lights in a perimeter zone, and 16–22% for the second row of lights.

With the advent of inexpensive handheld remote controls, occupant-controlled dimming is becoming an affordable option and has received a high occupant satisfaction rating. In a study comparing the energy savings and effectiveness of various control techniques in offices during a period of seven months in a building in San Francisco, controls yielded between 23 and 44% savings, depending on the control technique used.

Energy savings from occupant sensing versus dimming depend to a large extent on the behavior of occupants. In offices where occupants remain at desks during the day, dimming controls will save more energy. An occupant's immediate lighting requirements will also vary with the type of work being undertaken.

3.3. Components of an Electric Lighting System

Various systems for electric lighting control are available; these systems are either centrally or locally controlled. It is possible to control each luminaire or an entire building or floor area by a connected centralized system. Centrally controlled systems usually rely on a single daylight sensor that is often located on the ceiling (or sometimes the wall) of a large area in the center of a circuit (or with a luminaire) and is calibrated on site within the sensor itself or within the controller to maintain a constant illuminance level. Controls can be adjustable in their preset levels, i.e., the range of light levels, with stepped or continuous ranges of lighting. Different types of controls can be used with different space functions; e.g., in circulation spaces, a simple on/off control may be all that is necessary, whereas in a large office, dimming controls may be more appropriate.

In locally controlled systems, a light sensor estimates the luminance on the work surface and adjusts the light output of the lamp to maintain a preset level. In general, localized systems perform better than centralized systems. However, one of the shortcomings of using these sensors is the problem of reflectance factors, e.g., when a large white sheet of paper is spread out on the work surface. This problem can be overcome by proper placement of sensors or can be reduced byusing sensors With a large view angle [1].

3.3.1 Photoelectric Sensors

A key element of all types of photoelectric control is the sensor, which detects the presence or absence of daylight and sends a signal to a controller that will adjust the lighting accordingly. The location of the sensor is important because it influences the type of control algorithm used.

The photoelectric cell or sensor is often located on the ceiling and is calibrated on site to maintain a constant illuminance level. A single sensor that dims large areas can cause problems if some parts of the interior space are overshadowed by buildings or trees. It has been found that with innovative daylighting systems such as light shelves, a partially shielded sensor (shielded from the window only) is not susceptible to sky conditions and direct light from the window.

3.3.2 Controllers

A controller is located at the beginning of a circuit (normally the distribution board or the ceiling space) and incorporates an algorithm to process the signal from the photosensor and convert it into a command signal that is received by the dimming or switching unit.

3.3.3 Dimming and Switching Units

A dimming unit smoothly varies the light output of electric lights by altering the amount of power flowing to the lamps. If daylight is less than the target illuminance, the control tops up the lighting to provide the right amount on the work plane. Dimming controls can save more energy than switching if they are linked to daylight and if lamps are dimmed at the start of their lifetimes to compensate for their increased output [13]. Dimming controls are also less obtrusive to occupants than switching, but a manual override is recommended in areas where occupants expect to have control. Switches can also be used instead of dimmers, but this is not recommended except for limited applications because they are more obtrusive and may use more energy than dimming switches. High frequency dimming produces the greatest savings in all but the most well daylit rooms.

A problem with photoelectric switches is rapid switching on and off when daylight levels fluctuate around the switching illuminance. This can annoy occupants and reduce lamp life. Various techniques have been developed to reduce the amount of switching. Differential switching control uses two switching illuminances, one at which the lights are switched off and another, lower illuminance level at which the lights are switched on. Photoelectric switching with a time delay can also introduce a delay in the switching process.

3.3.4 Occupancy Sensors

Studies have shown that many workers are out of their offices 30% – 70% of the time during working hours. A conservative estimate of savings possible from controls is about 30%, once time delays on occupancy control systems are taken into account. The actual savings will depend on the nature of the organization using the space and the number of occupants in an office. Occupancy sensors are well suited to buildings where people are often away from their offices for a longer time than a few minutes. A weak point in this system is that the switching off of a certain zone, in a room where other people remain working, is generally experienced as disturbing. There are systems that allow a very smooth dimming down (or up after the return of the occupant) instead of sudden switching, which can help overcome this problem in group offices and thus increase user acceptance [9].

3.3.5 Types of Control Strategies

A control system may use a photosensor located so that it is able to detect both the electric light that the system controls and the available daylight (a “closed loop” system). In this case, the sensor needs to allow for the output of the lighting system that it controls. In contrast, an “open loop control” system’s photosensor is designed and located so that it detects only daylight and is insensitive to the electric light that it controls. Although a lighting control system focuses on sensor placement and zoning, both of which are critical, other factors should be considered, including occupant override of controls, integration of controls with task and ambient systems, and design of the control system to accommodate skylights or light shelves.

3.3.6 Shading Controls

Shading can be used to control glare caused by the sun and/or high sky luminance’s as well as to control heat gain. Some shading systems can operate independently of a daylighting system; others, such as the transparent sun-excluding system (see section 2.4.9), can be included in the daylighting system. In Section 2, daylighting systems are described as either shading systems (i.e., they are designed to provide both shading and daylighting) or as unshaded systems. For the latter, shading systems may need to be added, particularly in the tropics and in the summer season, to restrict solar heat gain and glare from direct sunlight [11].

A variety of strategies can be used to control a shading system automatically. Most current shading devices are manually controlled. However, when occupants are given only manual control of shading systems, the systems are often left closed, which eliminates all potential benefits from daylighting. External shading systems can be automatically controlled through a centrally controlled master switch that opens, tilts, or closes all shading devices at once. It is also possible to gauge the amount of light available to determine when shading is required.

3.3.7 Occupant Behavior

Experience has shown that manual controls are not used effectively. Many occupants leave electric lighting on once it is switched on even if the illumination from daylight is at a level that would be considered adequate if the occupant were entering the space. Although most case studies of lighting controls have focused on energy savings, a major factor in choosing lighting controls should be the improvement of visual comfort.

Satisfaction with lighting controls can increase if users can alter settings using a remote-control device. User-controlled systems enable occupants to set workplace conditions according to performance, activity, and location. A range of devices is available to allow users to control their lighting levels.

Occupancy-linked controls can switch off or dim lighting, reactivating them on a manual signal, and leaving the judgement of lighting adequacy to the user. This type of combination is directed at providing quality daylight and encouraging the occupant to assess the need for supplementary lighting when entering an interior space.

A lighting control system is better accepted if it reacts in a predictable way, for example when the sun shines on the façade and the electric lighting level is dimmed. Changes in illuminance are mostly accepted when the control system reacts quickly when an action is needed, e.g. sudden dark clouds reducing the daylight, and slowly when the user should not notice, e.g. increasing daylight in the morning allowing electric lighting to be dimmed.

3.3.8 Electricity Savings

Energy savings from daylight design in buildings cannot be realized unless the electric lights are dimmed or switched in response to the amount of available daylight. The energy savings achieved with daylight-responsive lighting controls will depend on the daylight climate, the sophistication of the controls, and the size of the control zones [10].

Some of the daylighting systems that have been tested, such as the selective shading systems that reconcile solar shading and daylighting, can save significant energy. Non-shading daylighting systems that are located above eye level and redirect sunlight to the room ceiling, such as laser-cut and prismatic panels, can also save considerable electrical energy but require detailed design consideration, e.g., specific tilting to avoid glare. Under overcast or cloudy sky conditions, anidolic systems perform well.

Automatically controlled blinds and louvres have proved to be efficient shading systems with much greater energy savings potential than static systems. Systems with holographic optical elements are promising but require further development to reduce cost and improve performance.

Overall, daylight-responsive systems have used up to 40% less than non-controlled systems, and additional electricity is saved through cooling load reductions, especially in hot climates.

4. Tools to Design for Using Daylight

Design tools are intended to help designers with the qualitative and quantitative elements of daylighting design through features that commonly include:

- visualization of the luminous environment of a given daylighting design
- prediction of daylight factors in a space lit by diffuse daylight
- identification of potential glare sources and evaluation of visual comfort indices
- prediction of potential energy savings achievable through daylighting
- control of the penetration of the sun's rays and visualization of the dynamic behavior of sunlight

By providing this range of information, design tools play a significant role in the decision-making process that characterizes daylighting design. These tools support designers throughout the sequence of decisions, from formulation of the daylighting concepts to final implementation of daylighting strategies and innovative techniques in real buildings.

Design tools need to fit in with the main phases of architectural projects during which important decisions regarding daylighting strategies are made. These tools must suggest appropriate architectural solutions that meet the architectural objectives of the project. The capability of design tools to analyze a given daylighting scenario, based on a detailed physical description of the project, is especially significant when advanced daylighting systems are considered.

This section gives an overview of the state of the art of daylighting design tools at the time of IEA Task 21 work. Special emphasis is placed on tools that address advanced daylighting systems.

4.1 Ray-Tracing Techniques

The ray-tracing technique determines the visibility of surfaces by tracing imaginary rays of light from a viewer's eye to the objects of a rendered scene. A centre of projection (the viewer's eye) and an arbitrary view plane are selected to render the scene on a picture plane. Thanks to the power of novel computer algorithms and processors, millions of light rays can be traced to achieve a high-resolution rendered picture. Originally developed for imaging purposes, some ray-tracing programmes (e.g., RADIANCE, GENELUX, and PASSPORT) were adapted and optimized for calculation of daylighting within building spaces. In this case, light rays are traced until they reach the main daylight source, which is usually the sun position (clear and intermediate skies) or the sky vault (cloudy skies).

Most daylighting and electric lighting calculation programmes currently use this backward ray- tracing technique (from the viewpoint to the source). A slightly different technique is used by some software to improve daylighting calculations, especially for clear sky conditions (with sun). A forward rather than backward ray-tracing technique is used by the GENELUX programme to follow rays from the light source to a scene.

For all types of light calculations, the ray-tracing technique can:

- account for every optical phenomenon that can be analytically expressed by physicalequations.
- take into account specular materials, like window panes and glossy surfaces.
- effectively simulate non-homogeneous textures and surface points.

Thanks to their large range of applications, ray-tracing techniques play a significant role in the design and simulation of advanced daylighting systems. Figure 1 shows the numerical simulation ofa room equipped with two different daylighting systems (a conventional window and a zenithal anidolic collector (see section 2.4.11)) created by the programme RADIANCE using a backward ray-tracing technique. This simulation allows a designer to compare the luminous performance of the two daylighting systems.

Several validations of ray-tracing programmes have demonstrated their reliability for daylighting performance assessment and advanced systems design.

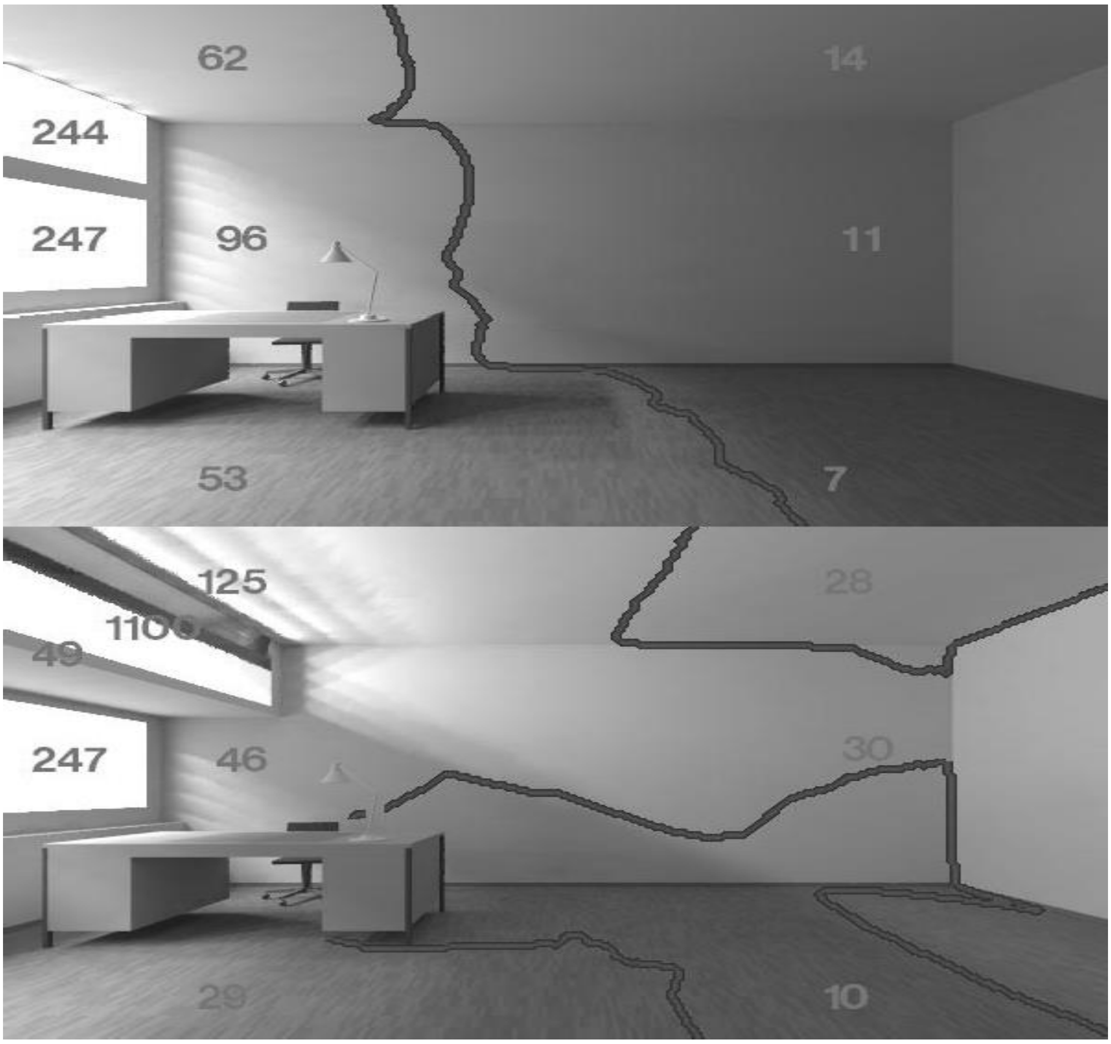


Figure 13. Simulated light distribution in a room: TOP: with simple double-glazed windows; BOTTOM: with an anidolic zenithal collector. Output from the ray-tracing programme radiance.

4.2 Velux:

A verified simulation and visualisation tool for daylighting design and analysis is the VELUX Daylight Visualizer. By anticipating and documenting daylight levels and a space's appearance before the building design is implemented, it aims to promote the use of daylight in buildings and help experts.

The Daylight Visualizer's user-friendly modelling tool enables speedy creation of 3D models with windows on the facade and roof that may be freely placed. In order to improve productivity and give the model geometrical flexibility, the programme also enables users to import 3D models created by CAD programmes.

For any of the 16 sky types listed in the CIE Standard General Sky, brightness, illuminance, and daylight factors can be calculated using the Daylight Visualizer. Images are included in Daylight Visualizer's output.

4.3 Radiance:

Radiance is a suite of programs for the analysis and visualisation of lighting in design. Input files specify the scene geometry, materials, luminaires, time, date and sky conditions. Calculated values include spectral radiance (i.e., luminance + colour), irradiance (illuminance + colour) and glare indices. Simulation results may be displayed as colour images, numerical values and contour plots. The primary advantage of Radiance over simpler lighting calculation and rendering tools is that there are no limitations on the geometry or the materials that may be simulated. Radiance is used by architects and engineers to predict illumination, visual quality and appearance of innovative design spaces, and by researchers to evaluate new lighting and daylighting technologies." The program is continuously being updated.

4.4 DIALux:

DIALux can calculate electric light, daylight and the energy performance of electric light. The program is oriented towards the European market, and is widely used for calculation of indoor and outdoor electric lighting systems. It follows different national standard lighting calculations, and can import photometric databases directly from manufacturers. The daylight calculation capabilities within DIALux make use of German standard DIN 5043 and CIE Publication 110. Geometric input is limited to certain shapes. Sky choices are somewhat limited but acceptable for diverse ranges of weather conditions. There is an external radiosity and ray-tracing model, POV-Ray (Persistence of Vision 2010). It is used to produce images from calculation results and for presentation renderings. DIALux is available free of charge but is not open source.

5. Methodology :

5.1 Overview

Considering a G+4 building in Kolkata's Newtown in order to analysis daylighting. This plot targets the MIG (Middle Income Group). In this structure, there is a designated parking space, and there are two apartments with two flats on each floor.

According to NKDA (New Town Kolkata Development Authority West Bengal) all the building should maintain below mentioned rule and regulation as follows[34]:

Open space -

- Open Space means an area forming an integral part of the plot, open to the sky and no cornice or weather shade more than 75 mm. widths shall overhang or project thereon. The total area of open spaces in a plot shall be as follows: -

The area of Open Space in a Plot = (Total area of the Plot) – (Area of the plot covered by Building when vertically projected on the ground level).

- Every building shall have marginal open spaces comprising front open space, rear open space and side open spaces. The minimum width prescribed for front open space, rear open space and side open spaces shall be provided along the entire front face, rear face and side faces of the building respectively. For this purpose, the front face of the building shall be that face of the building that faces the means of access and the rear face of a building shall be deemed to be that face of the building, which is farthest from the means of access.

- In the marginal open space one or more “Gate Goomti” for security purpose may be allowed. The covered area of each “Goomti” shall not exceed 3.00 square meters and the height of such “Goomti” shall not exceed 3.00 meters, provided that in case of land area of two hectares or more, such area of gate goomti may be increased upto twelve square meters[34].

(i)The minimum front open space shall be as follows: —

Table-1: The minimum front open space

<table>
<tr><td rowspan="2">Type of building</td><td colspan="2">Minimum front open space for building height in meter</td></tr>
<tr><td>Up to 15.1 .</td><td>Above 15.1 m.</td></tr>
<tr><td>Residential</td><td>1.2 meter</td><td rowspan="2">15% of building height or 3.5 meter is more;</td></tr>
<tr><td>Educational, Institutional, Mercantile (Retail), Business including IT and ITES, Assembly,</td><td>3.0 meter</td></tr>
<tr><td>Industrial, Mercantile (Wholesale), Storage, Hazardous,</td><td colspan="2">Minimum 15% of building height or 5 meterwhichever is more.</td></tr>
</table>

If type of building is residential and the height of build is up to 15.1-meter, minimum front open space between two buildings must be 1.2 meter. In case beyond 15.1-meter residential building, the minimum front open space between two buildings must be 15% of building height or 3.5 meter whichever is more.

(ii) The minimum rear open space shall be as follows: —

Table-2: The minimum rear open space

<table>
<tr><td colspan="2" rowspan="2">Type of building</td><td colspan="2">Minimum rear open space for building height in meter</td></tr>
<tr><td>Up to 15.1 m.</td><td>Above 15.1 m.</td></tr>
<tr><td rowspan="2">Residential</td><td>Plot area up to 300 sq m</td><td>2.0 meters</td><td rowspan="2">25% of building height or 4 meterwhichever is more</td></tr>
<tr><td>Plot area above 300 sq m</td><td>3.5 meters</td></tr>
<tr><td colspan="2">Educational, Institutional, Mercantile (Retail), Business including IT/ ITES,Assembly,</td><td colspan="2">25% of building height or 4 meter whichever is more</td></tr>
<tr><td colspan="2">Industrial, Mercantile (Wholesale), Storage, Hazardous,</td><td colspan="2">25% of building height or 5 meter whichever is more</td></tr>
</table>

If type of building is residential and the height of build is up to 15.1-meter, minimum rear open space between two buildings must be 2.0 meter. In case beyond 15.1-meter residential building, the minimum front rear space between two buildings must be 25% of building height or 4 meter whichever is more[34].

(iii) Minimum side open spaces for building height in meter:

Table-3: Minimum side open spaces

Type of building		Minimum side open spaces for building height in meter			
		Side 1 Open Space		Side 2 Open Space	
		up to 15.1 m.	Above 15.1 m.	up to 15.1 m.	Above 15.1 m.
Residential	Plot area up to 300 sq m	0.8 meters	15% of building height or 3.5 meters whichever is more,	2.4 meters,	15% of building height or 3.5 meters whichever is more,
	Plot area above 300 sq m	1.2 meters,			
Other building		15% of building height or 3.5 meters whichever is more		15% of the building height or 3.5 meters whichever is more	

If type of building is residential and the height of build is up to 15.1-meter, minimum side 1 open space between two buildings must be 0.8 meter. In case beyond 15.1-meter residential building, the minimum side 1 space between two buildings must be 15% of building height or 3.5 meter whichever is more.

Note:

(a) Side 1 of any plot shall always be adjacent to narrower side 2 of adjoining plot;

(b) Facing a plot from the means of access, the left-hand side of the plot shall be treated as side 1 and the right-hand side of the plot shall be treated as side 2.

(iv) Structural design. –

The structural design shall be in accordance with IS: 1893 – 1984, IS: 13920 – 1993, IS: 13828 – 1993, IS: 13827– 1993, IS: 13935 – 1993, IS 4326: 1993 and IS 1893 (Part – I) 2002 given in Annexure – A including the Indian Standards for earthquake protection of buildings.

Note: Whenever an Indian Standard or National Building Code is referred to, the latest provision in the Standard should be adhered to.

(b) All materials and workmanship shall be of good quality conforming to the accepted standards of the Public Works Department of the Government of West Bengal or Indian Standard Specifications as included in the National Building Code of India.

(V) Inner Courtyard and Outer Courtyard and Ventilation Shaft

Every room intended for human habitation or kitchen shall abut an inner courtyard or outer courtyard or marginal open space or an open verandah which is open along its length onto the courtyard or marginal open space.

(vi)For Inner Courtyard

In case any room, excepting bath, water-closets and store-room, is not abutting any marginal open spaces, it shall abut on inner courtyard whose minimum width shall be 30% of the height of the building or 3.20 meters, whichever is more, if an inner courtyard is formed by a composite block of higher and lower blocks, the minimum width of courtyard shall be determined by the maximum height of lower block;

(vii)For Outer Courtyard

(a) the minimum width of such courtyard shall not be less than 20% of the height of the lower building or 3.2 meter whichever is more, up to a maximum limit of 10.0 m

(b) the maximum depth of that courtyard shall not be more than 1.5 times the width;

(c) outer courtyard having depth up to 1.2 meters shall be treated as a “Recess” not a courtyard [34].

5.2 Simulation design

5.2.1 Location:

The latitude and longitude of considered is roughly 22.577173, 88.465772 as per Google map. In the figure 14 picture the building has marked with blue sign.

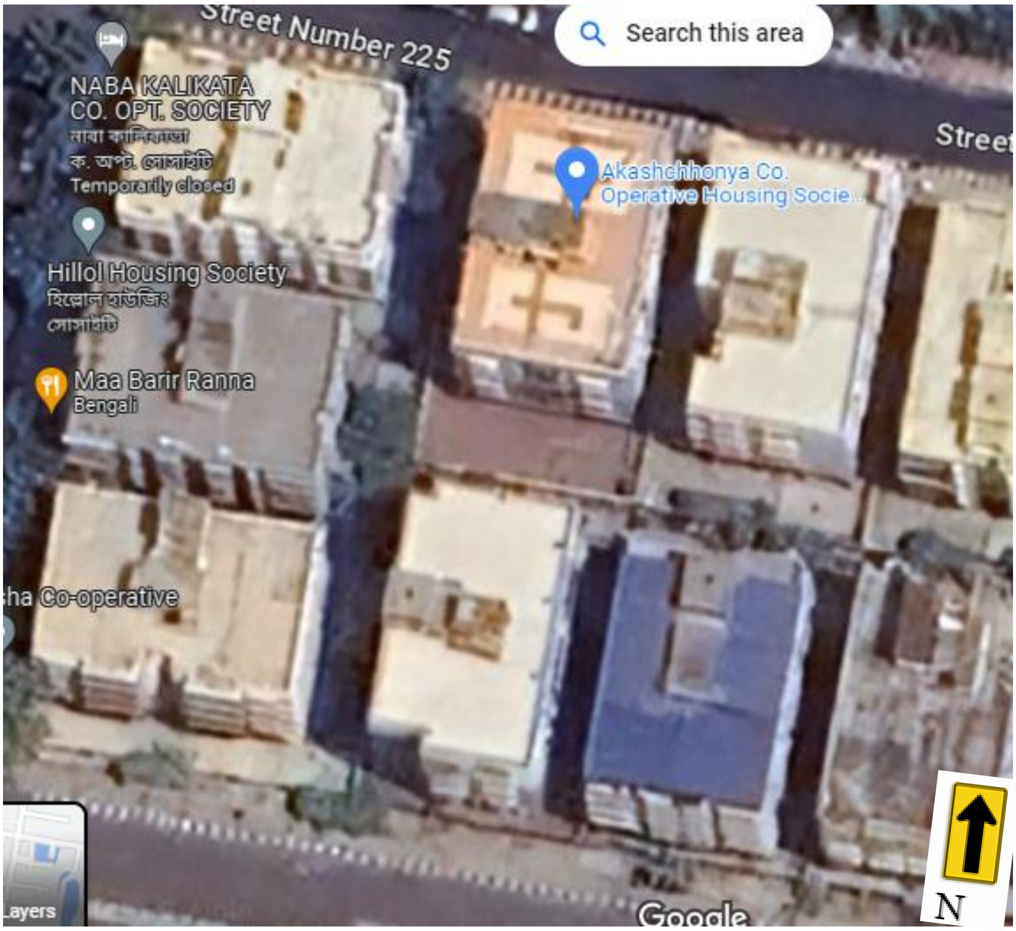


Figure 14. Google earth view of considered building's location

The building has a road in front and is surrounded by buildings on three sides.
If I stand facing to this picture, my right side will be east, my left will be west, my front will be north and my back will be south.

5.2.2 Building Structure:

The building is four storeys with a parking plot below, the total building is five storeys. Each floor has two flats. Each apartment includes a dining area, a kitchen, two bathrooms and three rooms.

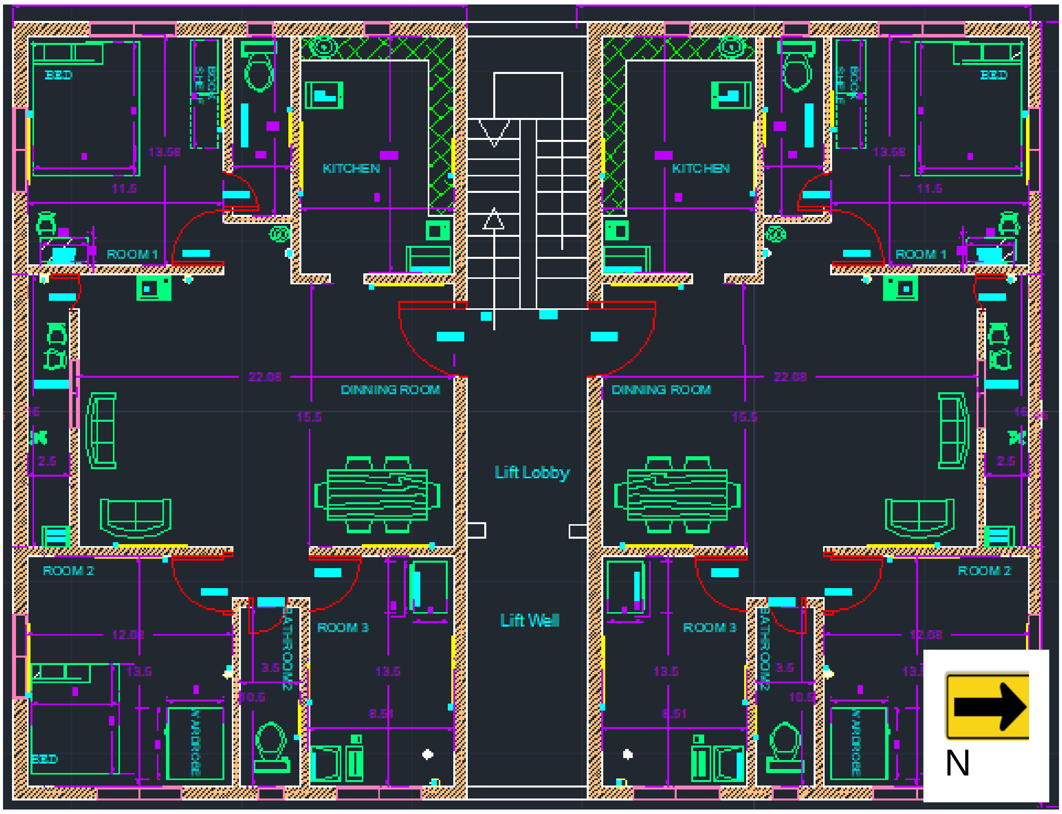


Figure 15. Plan View of the each flat (in the picture two flats plan view are shown)

Figure 15 depicts the location of two apartments on a single floor. One of the flats has a southern face, the other a northern face. In between two flats there are one space is allocated for lift lobby as well as staircase.

5.2.3 Distance with other buildings:

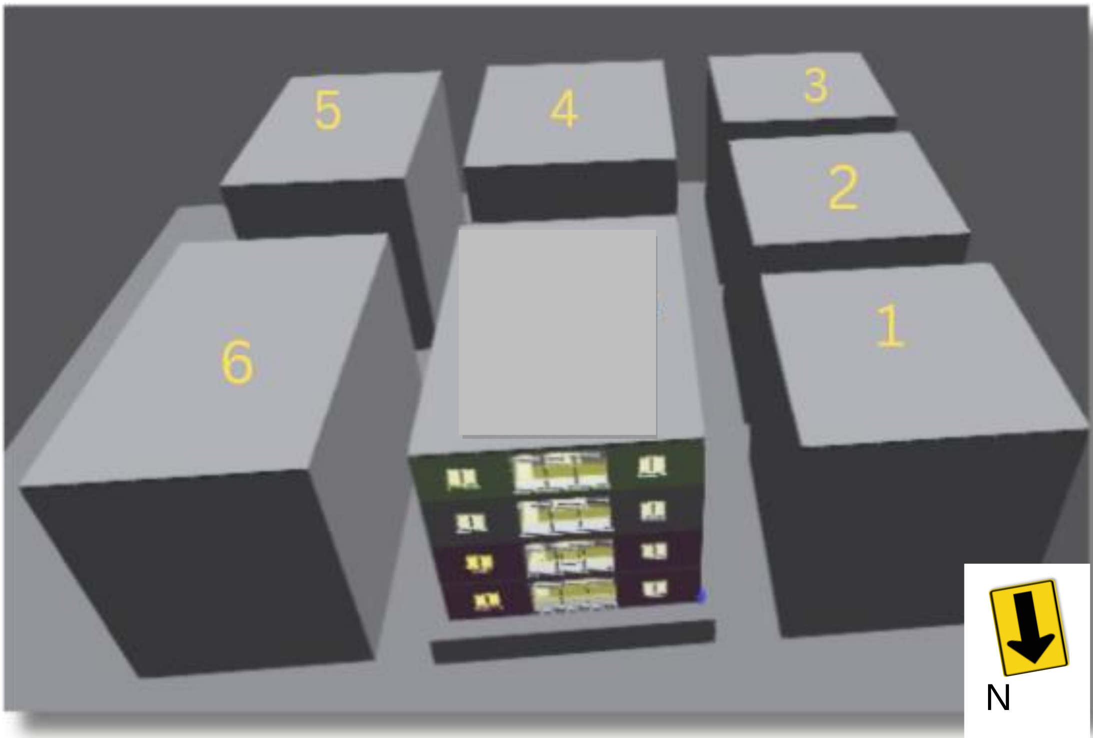


Figure 16. Location of surrounding building with respect to considered building.

From figure 16 it is clearly observed that there are six buildings are present with same height as per NKDA rule. It is the top view of considered building taken for analysis. There are two buildings on the west side of the structure as well as there is only one building on the north side. Three buildings are also present further east side.

Table-4: Distances with surround building

Building no	Distance with other buildings (meter)
1	5.4
2	5.4
3	7
4	6.7
5	4.5
6	5.1

Distance between surrounding buildings with respect to considered building taken for analysis shown in the above table. In the front of the building i.e., north side there is a road. In the east side there are two building presents. On that side the distance between considered building and building 6 is 5.1 meter and the distance with building 5 is 4.5 meter. In case of west side there are also three building presents. The distance between building 1,2,3 with respect to considered building taken for analysis is 5.4 meter,5.4 meter and 7 meters respectively.

The height of surround buildings is same as per NKDA rule i.e., 15.1 meter. All surrounding buildings are G+4 that means all are four storeys with a parking plot.

5.2.4 Flow chart Simulation design of proposed building:

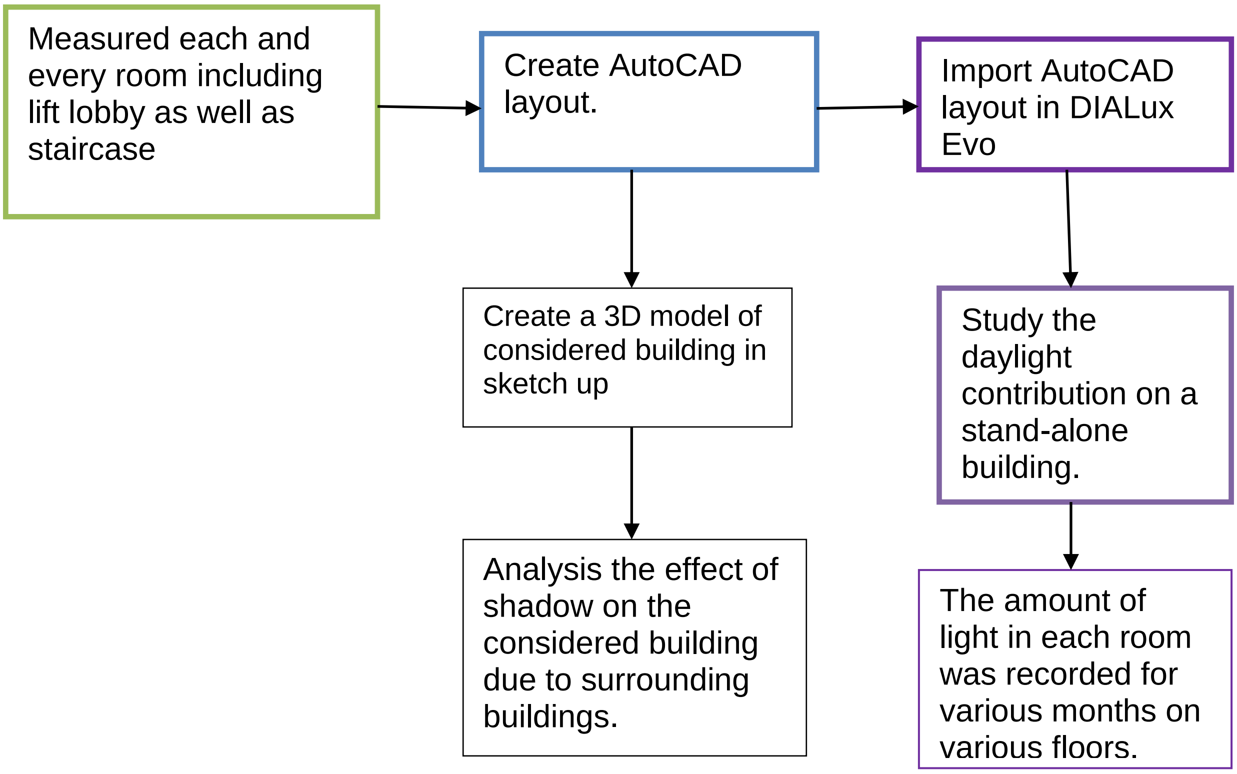


Fig 17: Flow chart Simulation design of proposed building

Measured each and every space, including the elevator lobby and stairwell. Make an AutoCAD layout based on the measurements. Sketch up a 3D model of the potential building. Analyze how the neighbouring buildings' shadows affect the building under consideration. Using a 3D model created in Sketch Up, the effect of shadow on the proposed building was examined. The months of January, March, May, July, September, and November were taken into account while analyzing the shadow direction and how the shadow of neighbouring buildings would affect the proposed project.

Use the AutoCAD layout that was built in DIALux, however, to examine how much daylight a standalone building receives. four distinct times during the day—9 am, noon, 3 pm, and 8 pm—were taken into account, and the amount of light in each room was recorded for various months on various floors.

5.3 Variation of shadow on various months:

5.3.1 What is Shadow Analysis:

Shadow studies are a crucial tool in building design that allows architects and engineers to evaluate the movement of the sun across a site and understand how shadows cast by nearby buildings, trees, or other objects will impact solar access, natural lighting, occupants' comfort and energy performance of a building. By comprehending how sunlight and shadows interact with the built environment, designers optimize the building orientation and shape, identify the ideal shading devices to manage glare and direct sunlight, maximize natural light utilization, minimize the need for artificial lighting, and enhance energy efficiency.

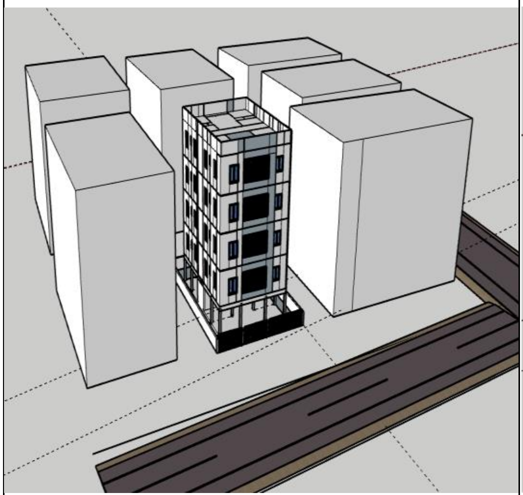
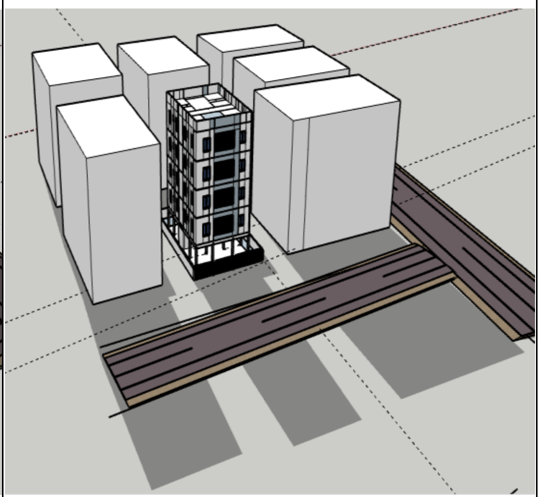
5.3.2 Tool used:

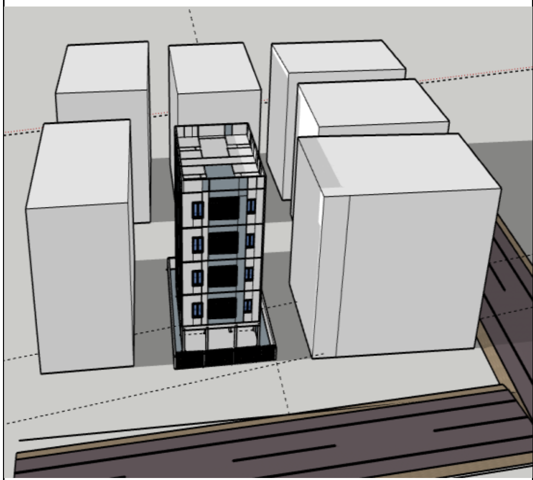
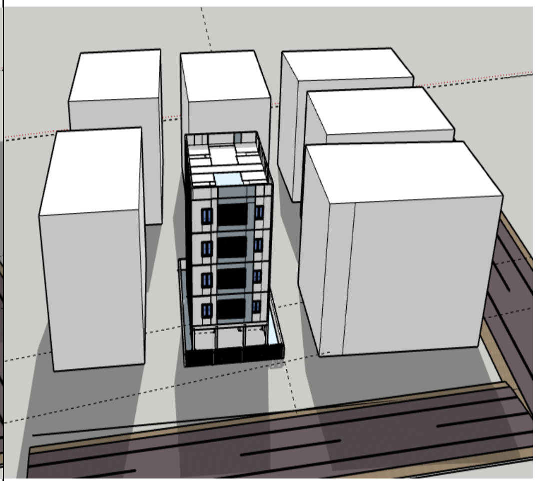
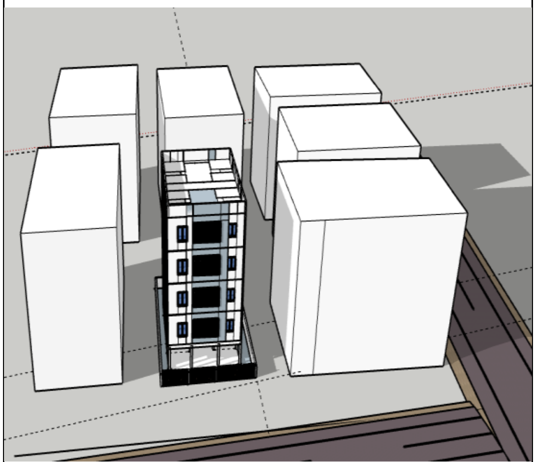
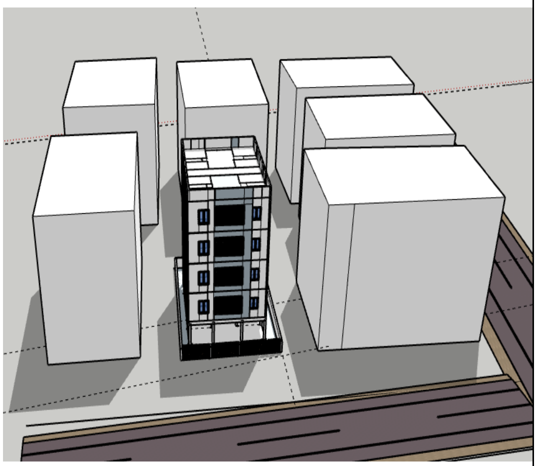
Sketchup which is a 3D modelling computer-aided design (CAD) programme for a variety of drawing and design applications, such as architectural, interior design, industrial and product design, landscape architecture, civil and mechanical engineering, theatre, film, and video game development, is included in the SketchUp Pro Desktop subscription product suite.

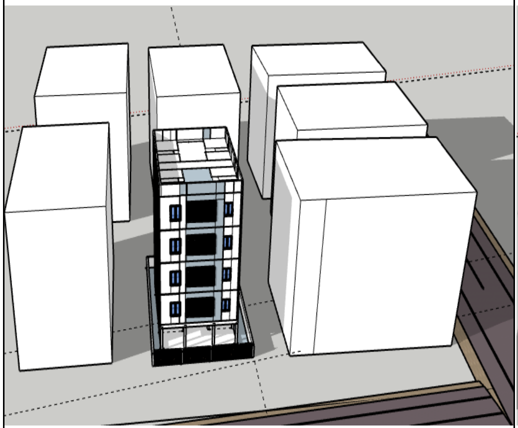
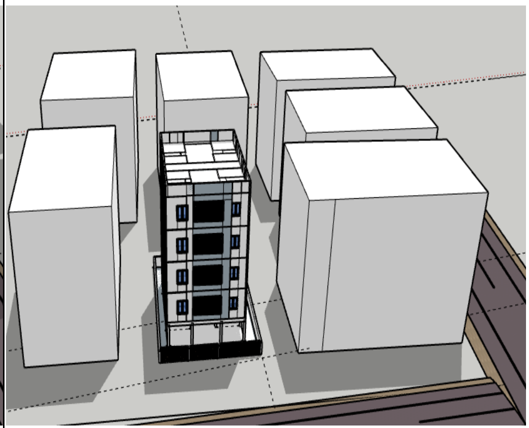
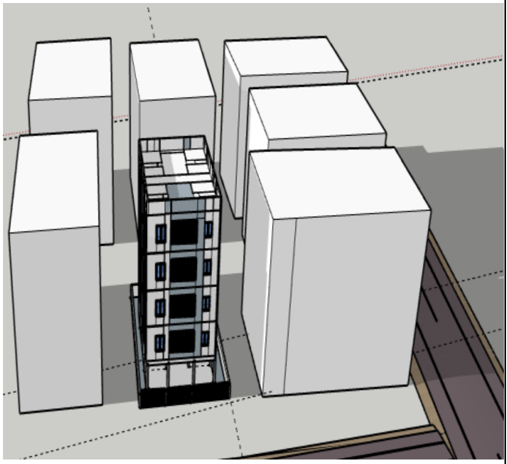
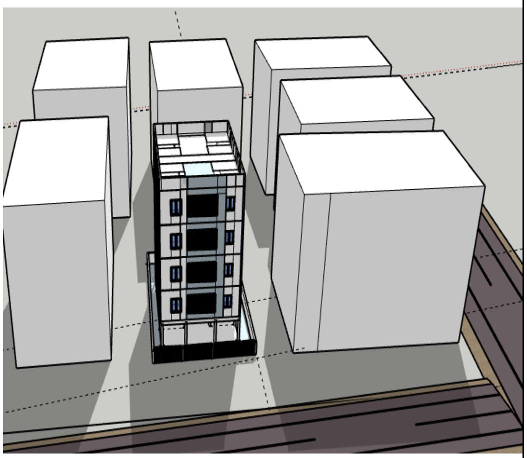
5.3.3 Analysis of standalone building shadow with surround buildings:

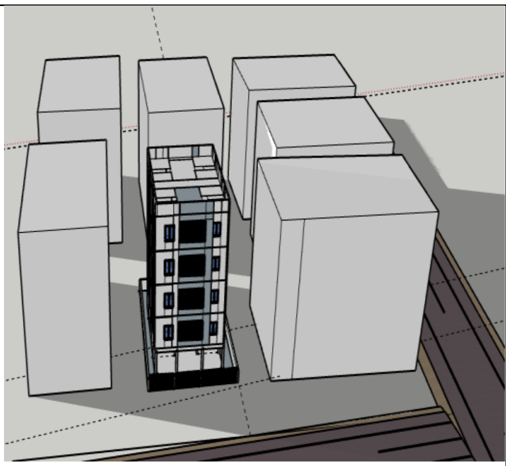
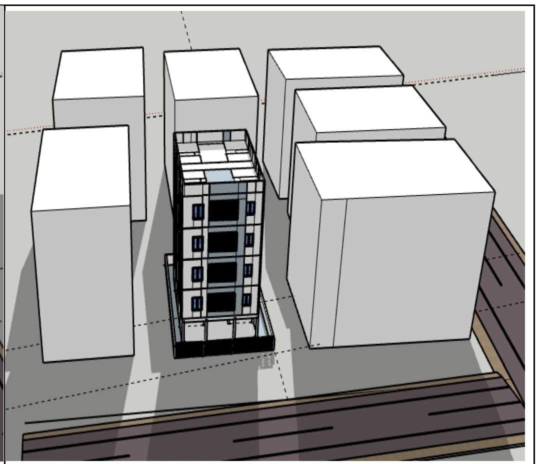
The shadow analysis of the building is done with sketchup. Considered four different times of every month respectively 9am and,3 pm This has allowed me to examine the variations in the shadow cast by the nearby structures.

Table-5: Shadow analysis with sketch up at 9 am and 3 pm

Month	Time	
	9 am	3 pm
January	 Fig 18: Shadow at direction at 9 am It is evident from the fig 18 that all of the buildings' shadows falls to the west at 9 am in the morning in January.	 Fig 19: Shadow at direction at 3 pm It is evident from the fig 19 that in the month of January, at 3 pm, the shadow moves to the north.

Month	Time	
	9 am	3 pm
March	 Fig 20: Shadow at direction at 9 am It is evident from the fig 20 that all of the buildings' shadows falls to the west at 9 am in the morning in March.	 Fig 21: Shadow at direction at 3 pm It is evident from the fig 21 that in the month of March, at 3 pm, the shadow moves to the north.
May	 Fig 22: Shadow at direction at 9 am It is evident from the fig 22 that all of the buildings' shadows falls to the west at 9 am in the morning in May.	 Fig 23: Shadow at direction at 3pm It is evident from the fig 23 that in the month of May, at 3 pm, the shadow moves to the north but smaller than March.

Month	Time	
	9 am	3 pm
July	 Fig 24: Shadow at direction at 9 am It is evident from the fig 24 that all of the buildings' shadows falls to the west at 9 am in the morning in July.	 Fig 25: Shadow at direction at 3 pm It is evident from the fig 25 that in the month of July, at 3 pm, the shadow moves to the north but smaller than the shadow of in the month of March and May.
September	 Fig 26: Shadow at direction at 9 am It is evident from the fig 26 that all of the buildings' shadows falls to the west at 9 am in the morning in January.	 Fig 27: Shadow at direction at 3 pm It is evident from the fig 27 that in the month of January, at 3 pm, the shadow moves to the north.

November	 Fig 28: Shadow at direction at 9 am It is evident from the fig 28 above that all of the buildings' shadows falls to the west at 9 am in the morning in January	 Fig 29: Shadow at direction at 3 pm It is evident from the fig 29 above that in the month of January, at 3 pm, the shadow moves to the north.

The effect of the surrounding shadow is seen to be greater in the months of January and March compared to the months of July and September because, according to study, the shadow in these two months is narrower than that in January and March.

5.4 Daylight Analysis by using DIALux :

5.4.1 What is DIALux Evo?

Plan, calculate and visualize lighting for indoor and outdoor areas. From entire buildings and individual rooms to parking spaces or road lighting. Create a unique atmosphere with real luminaires of our DIALux members and convince your client with an individual lighting project. **DIALux evo offers you a multitude of features and functions-**

Indoor areas
Plan light for complex architecture. From entire buildings with several floors to single rooms
Outdoor areas
Plan individual outdoor scenes like green areas, paths, parking spaces or road lighting
In- & Exterior
See how interior lighting affects the exterior and how exterior planning affects the interior
Artificial & Daylight
Combine artificial and daylight for different light scenes and create a unique atmosphere
Light distribution
Get information about the light distribution by means of value graphics and false colors
Standards
Plan your project considering important requirements such as current standards.

5.4.2 Simulation of a proposed building:

At first imported the CAD file for daylight analysis with DIALux and considered two flats of two different floor- flat no 8 on 4th floor (South facing), flat no 2 on 1st floor (South facing) as well as flat no 5 on 3rd floor (North facing).

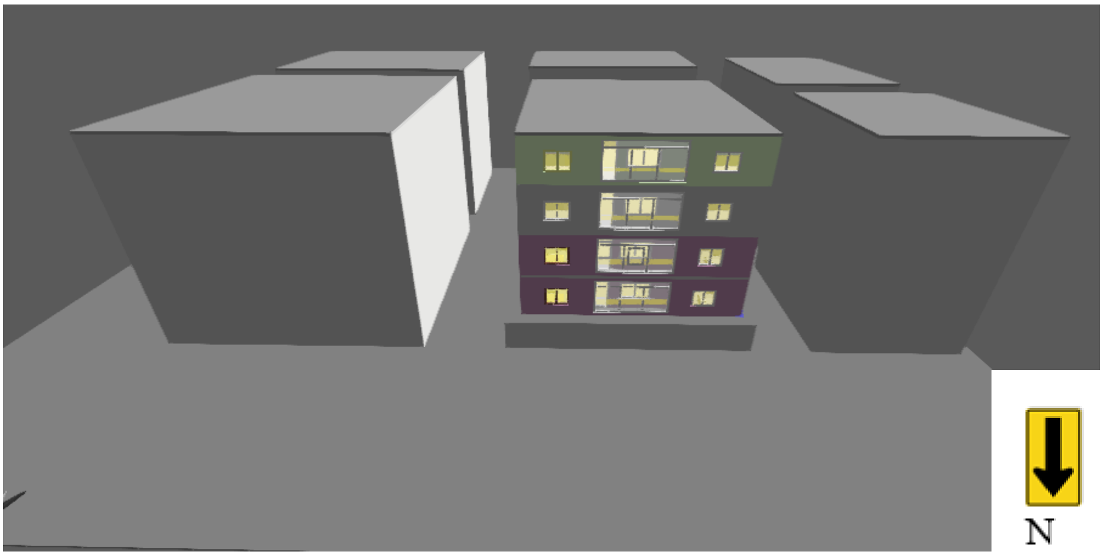


Figure 30: Building front view along with surrounding building.

5.4.3 Room Dimension:

Table-6: Dimension of each room of considered building

Room	Dimension (meter^2)	Location of each room
Balcony	4.8x0.7	Each flat has one balcony. The balcony in a north-facing apartment faces north, whereas the balcony in a south-facing apartment faces south.
Master Bed room	4.1x3.5	Each flat has one master bed room. The master bed room in a north-facing apartment faces east, whereas the master bed room in a south-facing apartment faces east also.
Bed room 2	3.6x4.1	The bed room 2 in both north-facing and south-facing apartment faces west.
Bed room 3	4.1x2.5	The bed room 3 in both north-facing and south-facing apartment faces west.
Kitchen	3.9x2.7	The kitchen in a north-facing as well as south-facing apartment faces east.
Dining room	6.7x4.7	The dining room in a north-facing apartment faces north, whereas the master bed room in a south-facing apartment faces south.
Bath room 1	3.2x1	Bath room 1 in both north-facing and south-facing apartment faces east.
Bath room 2	3.2x1	Bath room 2 in both north-facing and south-facing apartment faces west.

Each flat has one balcony. The balcony in a north-facing apartment faces north, whereas the balcony in a south-facing apartment faces south. Each flat has one master bed room. The master bed room in a north-facing apartment faces east, whereas the master bed room in a south-facing apartment faces east also.

The bed room 2 in both north-facing and south-facing apartment faces west and the bed room 3 in both north-facing and south-facing apartment faces west as well as kitchen in a north-facing as well as south-facing apartment faces east.

Bath room 1 in both north-facing and south-facing apartment faces east as well as Bath room 2 in both north-facing and south-facing apartment faces west.

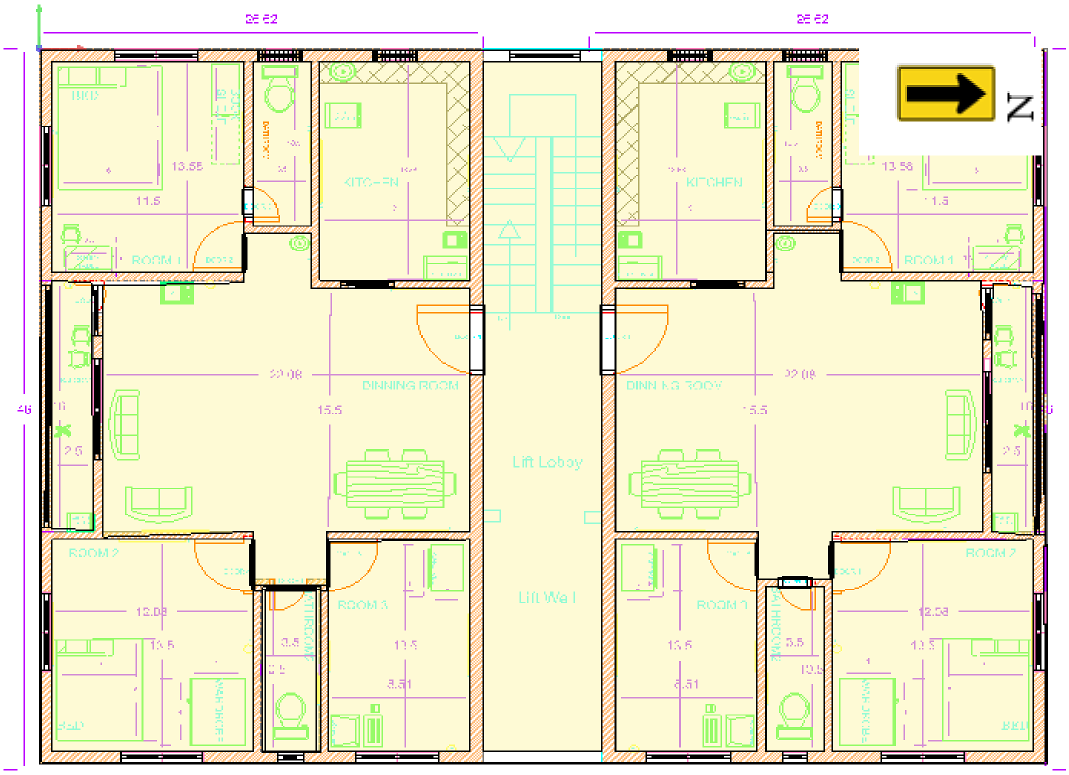


Figure 31: Dimension and location of each room on a floor of the considered building

From the figure 31 it clearly visible that there is one balcony having dimension 4.8 by 0.7 meter and one dining room having dimension 6.7 by4.7 meter. There is a Bed room 2 and Bed room 3 with dimensions of 3.6 by 4.1by 0.7 meter and 4.1 by 2.5 meter respectively. A Kitchen room with measurements of 3.9 by 2.7 meter. There are two bath rooms having same dimension of 3.2 by 1 meter.

5.4.3 Dimension of windows:

- Windows:

Table 7: Dimension of windows in each and every room

Room	No of windows	Dimension (HxW meter^2)
Master Bed room	2	1.3x1.5
Bed room 2	2	1.3x1.5
Bed room 3	1	1.3x1.5
Kitchen	1	1.5x0.8
Dining room	1	1.3x1.9
Bath room 1	1	1.5x0.8
Bath room 2	1	1.5x0.8

Table 7 describes dimension of each window in each room. In bed room 2 and master bed room there are two windows present with same dimension i.e., 1.3 by 1.5 meter.

Bed room 3 has only one window and dimension is 1.3x1.5. Two bathrooms measuring 1.5 by 0.8 meter and each with just one window. Kitchen measuring 1.5 by 0.8 meter and with only one window.

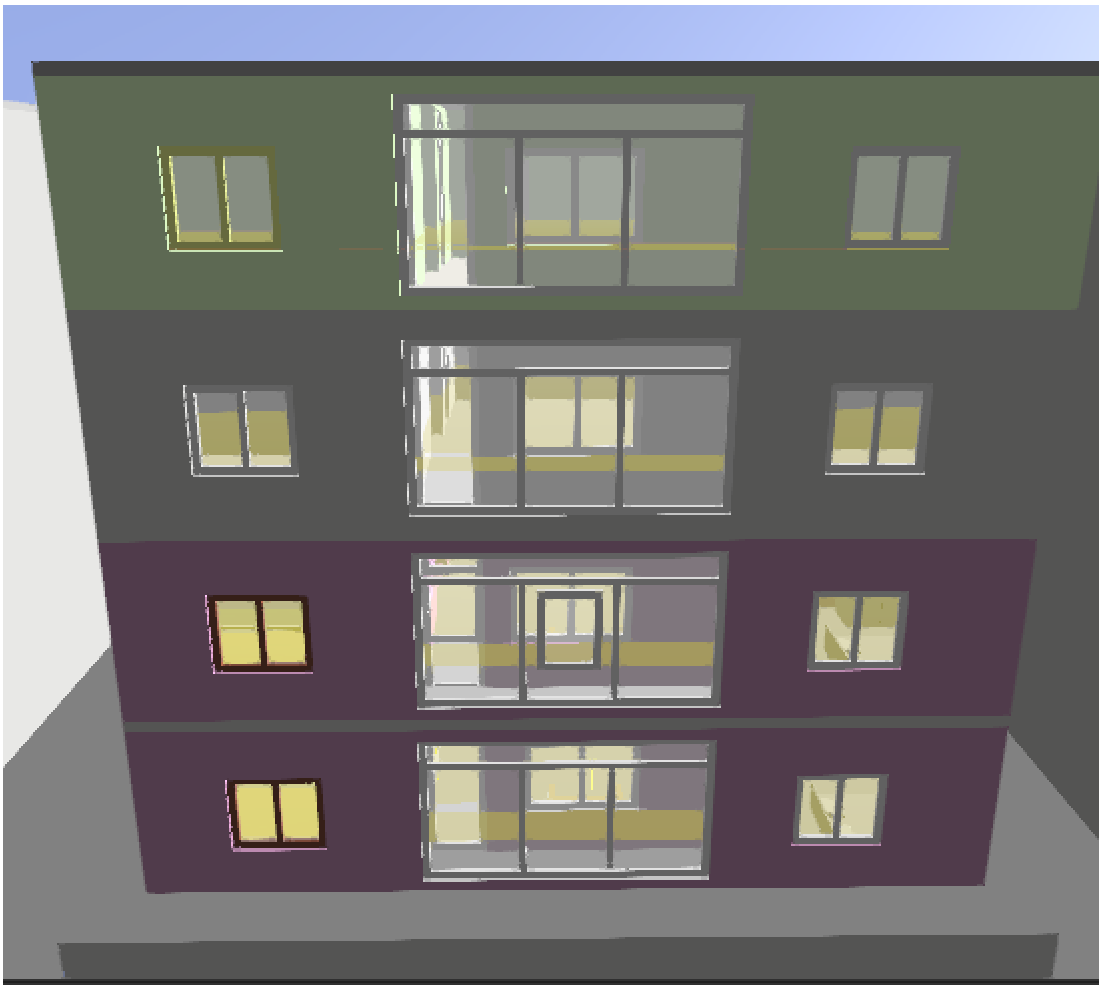


Figure 32: Windows from the front view of the considered building taken for analysis

A simulated view of the front of the structure under examination that was captured for analysis is shown in Figure 32. The graphic shows the location windows. Each flat has two windows and a balcony on the front, which is the northern side.

The dining area is lighted by a second window in the inner wall of the balcony. One of the front-side windows is for the third bedroom, and the other is for the master bedroom.

5.4.4 Result and analysis:

- **Result for 4th floor flat no 8 (on 4th floor and South facing):**

Table-9: Illumination level for 4th floor flat 8

Month	Time	Daylight(lux)						
		Balcony	Bathroom 2	Bedroom 2	Bed room 3	Kitchen	Master Bed room	Bathroom 1
January	9:00 AM	24030	1573	2500	152	1152	4600	54
	12:00 noon	37233	210	3433	369	97.8	3636	95.7
	3:00 PM	9068	114	1704	1547	53.8	1059	115
	8:00 PM	0	0	0	0	0	0	0
February	9:00 AM	28000	270	2100	160	1500	4657	57
	12:00 noon	43988	227	3000	360	103	3200	104
	3:00 PM	12828	759	3297	3303	62	1190	131
	8:00 PM	0	0	0	0	0	0	0
March	9:00 AM	27554	4682	1430	164	1671	4144	59
	12:00 noon	40678	231	2200	500	100	2277	118
	3:00 PM	10878	141	3382	4327	66	663	1794
	8:00 PM	0	0	0	0	0	0	0
April	9:00 AM	9678	548	458	169	1661	3052	62
	12:00 noon	15405	228	1124	787	100	876	344
	3:00 PM	2100	146	3453	4733	68	311	2600
	8:00 PM	0	0	0	0	0	0	0
May	9:00 AM	25510	5300	331	171	1618	2773	63
	12:00 noon	2713	229	816	846	100	407	442
	3:00 PM	1850	150	3400	4650	69	293	2500
	8:00 PM	0	0	0	0	0	0	0
June	9:00 AM	23100	5200	313	171	1590	2710	63
	12:00 noon	2465	234	650	613	102	390	390
	3:00 PM	1789	153	3337	4542	71	291	2433
	8:00 PM	0	0	0	0	0	0	0
July	9:00 AM	23800	5470	317	169	1660	2875	62
	12:00 noon	2565	239	532	468	104	400	310
	3:00 PM	1867	154	3380	4612	71	298	2450
	8:00 PM	0	0	0	0	0	0	0
August	9:00 AM	30000	5670	345	168	1712	2900	61
	12:00 noon	7383	235	670	590	100	438	300
	3:00 PM	2040	150	3480	4700	70	309	2600
	8:00 PM	0	0	0	0	0	0	0
September	9:00 AM	19870	5674	345	168	1712	2980	61
	12:00 noon	7480	235	673	590	102	438	320

	3:00 PM	2040	150	3480	4760	70	309	2615
	8:00 PM	0	0	0	0	0	0	0
October	9:00 AM	34764	3030	2086	170	1310	4277	61
	12:00 noon	43180	207	3128	1241	94	2662	183
	3:00 PM	8013	121	1759	3222	56	598	269
	8:00 PM	0	0	0	0	0	0	0
November	9:00 AM	18650	1676	2652	165	1100	4590	58
	12:00 noon	36975	196	3620	1050	91	3307	111
	3:00 PM	5881	101	669	1190	60	603	107
	8:00 PM	0	0	0	0	0	0	0
December	9:00 AM	25414	1298	2700	157	977	4523	55
	12:00 noon	34085	196	3589	630	92	3615	97
	3:00 PM	5972	98.2	686	296	46.7	700	92.3
	8:00 PM	0	0	0	0	0	0	0

- **Result for 1st floor flat no 2(on 2nd floor and South facing):**

Table-10: Illumination level for 1st floor flat 2

Month	Time	Daylight(lux)						
		Balcony	Bathroom 2	Bedroom 2	Bed room 3	Kitchen	Master Bed room	Bathroom 1
January	9:00 AM	10456	55	50	70	50	110	25
	12:00 noon	965	38.8	238	283	15	89.2	38.5
	3:00 PM	363	14.7	60	111	6.36	33.6	46
	8:00 PM	0	0	0	0	0	0	0
February	9:00 AM	13468	244	76	51	25	124	25
	12:00 noon	1348	24	76	51	25	124	25
	3:00 PM	470	17.5	78.4	161	7.43	42	66.6
	8:00 PM	0	0	0	0	0	0	0
March	9:00 AM	25340	89	1133	54.6	30	277	27.5
	12:00 noon	1664	49	1950	446	18	170	83
	3:00 PM	511	19.2	99	851	8	45.2	98
	8:00 PM	0	0	0	0	0	0	0
April	9:00 AM	7478	107	202	57	37	257	28
	12:00 noon	1900	50	950	800	18	485	270
	3:00 PM	480	20	127	3750	9	44	2470
	8:00 PM	0	0	0		0	0	0
May	9:00 AM	25510	1622	73	58	473	650	29
	12:00 noon	9670	50	642	892	18.5	84	371

	3:00 PM	448	21	1548	208	9	42	2400
	8:00 PM	0	0	0	0	0	0	0
June	9:00 AM	800	1521	70	58	436	605	29
	12:00 noon	877	52	500	700	19	80	322
	3:00 PM	445	21	2497	188	9	42	118
	8:00 PM	0	0	0	0	0	0	0
July	9:00 AM	6290	112	70	57	38	114	29
	12:00 noon	922	53	396	490	20	83	250
	3:00 PM	467	21	2000	199	9	43	123
	8:00 PM	0	0	0	0	0	0	0
August	9:00 AM	11380	109	75	56	36	125	28
	12:00 noon	4630	52	470	648	19	92	233
	3:00 PM	490	21	500	1900	8.8	45	2470
	8:00 PM	0	0	0	0	0	0	0
September	9:00 AM	11380	110	75	56	37	125	28
	12:00 noon	4630	52	471	648	19	92	233
	3:00 PM	492	21	500	1955	8.8	44	2478
	8:00 PM	0	0	0	0	0	0	0
October	9:00 AM	11888	260	89	56	33	289	28
	12:00 noon	8618	40	2764	1215	15	222	265
	3:00 PM	369	15	74	179	6.4	34	73
	8:00 PM	0	0	0	0	0	0	0
November	9:00 AM	9770	67	77	52	180	209	26
	12:00 noon	1000	35	1836	918	14	85	54
	3:00 PM	291	12	52	112	5	27	45
	8:00 PM	0	0	0	0	0	0	0
December	9:00 AM	813	55	68	49	21	143	24
	12:00 noon	888	34	444	13	12	81	38
	3:00 PM	288	12.5	49.4	93	5.42	27	39.4
	8:00 PM	0	0	0	0	0	0	0

- **Result for 3rd floor flat no 5 (on 3rd floor and North facing):**

Table-11: Illumination level for 3rd floor flat 5

Month	Time	Daylight(lux)						
		Balcony	Bathroom 2	Bedroom 2	Bed room 3	Kitchen	Master Bed room	Bathroom 1
January	9:00 AM	1586	111	195	42.8	950	1612	120.5
	12:00 noon	1789	127	258	97	167	789	134
	3:00 PM	1267	78	168	65	43	564	45
	8:00 PM	0	0	0	0	0	0	0
February	9:00 AM	1666	123	189	42.8	950	1612	12.5
	12:00 noon	1789	127	258	97	167	789	34
	3:00 PM	1267	78	168	65	43	564	45
	8:00 PM	0	0	0	0	0	0	0
March	9:00 AM	1732	223	289	53	960	1715	19.1
	12:00 noon	1829	127	338	121	174	769	44
	3:00 PM	1557	72	161	75	52	564	55
	8:00 PM	0	0	0	0	0	0	0
April	9:00 AM	2296	123	189	156.8	948	1612	12.5
	12:00 noon	2769	127	258	321	67	789	34
	3:00 PM	1577	78	168	95	43	564	75
	8:00 PM	0	0	0	0	0	0	0
May	9:00 AM	1866	123	189	122.3	970	1612	129.5
	12:00 noon	2649	89	633	325	134.6	1683	342
	3:00 PM	1957	78	168	65	33	564	95
	8:00 PM	0	0	0	0	0	0	0
June	9:00 AM	2356	134	427	267	836.7	2340	87
	12:00 noon	2783	159	567	343	138.8	432	264
	3:00	1897	89	408	293	31	371	127

	PM							
	8:00 PM	0	0	0	0	0	0	0
July	9:00 AM	2403	136	344	232	940	2432	108
	12:00 noon	2829	159	427	267	136.7	340	94
	3:00 PM	2743	68	564	421	31.8	234	73
	8:00 PM	0	0	0	0	0	0	0
August	9:00 AM	2403	136	344	232	840	2432	108
	12:00 noon	2829	159	427	267	136.7	340	94
	3:00 PM	2743	58	564	421	31.8	234	73
	8:00 PM	0	0	0	0	0	0	0
September	9:00 AM	2129	980	236	50	1387	2424	16
	12:00 noon	2064	266	716	743	33	276	82
	3:00 PM	1906	39	246	90	16	232	31
	8:00 PM	0	0	0	0	0	0	0
October	9:00 AM	2245	945	243	53	1243	2321	18
	12:00 noon	2180	321	721	741	54	265	83
	3:00 PM	1867	48	276	94	25	243	30
	8:00 PM	0	0	0	0	0	0	0
November	9:00 AM	1666	1110	205	48	965	1766	48
	12:00 noon	1679	33	244	816	28	740	66
	3:00 PM	1110	27	147	47	11	148	15
	8:00 PM	0	0	0	0	0	0	0
December	9:00 AM	1570	349	196	44	697	1425	12
	12:00 noon	1617	65	460	412	28	240	27
	3:00 PM	1049	27	142	46	11	144	13
	8:00 PM	0	0	0	0	0	0	0

5.4.5 Variations in daylight between three flats with various rooms on various floors:

For this analysis, one flat on the north side of the first floor, one flat on the north side of the fourth floor and one flat on the south side of the third floor are all taken into account. Apartment No. 4 is on the fourth level, Apartment No. 2 is on the first floor, and Apartment No. 5 is on the third floor. While flats 2 and 8 have south-facing orientations, flat 5 has a north-facing orientation. Using data from DIALux collected over a year, the daylight on different floors of a building was analyzed.

5.5 Daylight variation on different rooms of three flats on various floor at 9 am:

- **Balcony:**

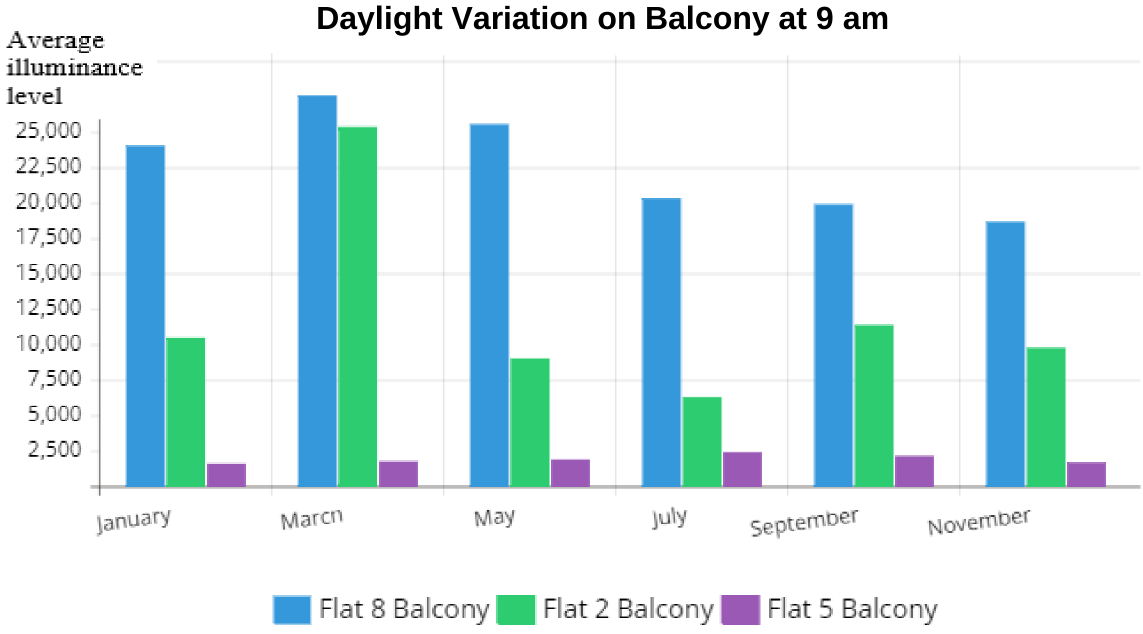


Figure 33: Daylight variation on Balcony

(i)This graphical representation demonstrates that the fourth-floor apartment, or flat number 8 on the south side, illuminates at its peak level in March, progressively declines, and illuminates at its lowest level in November.

(ii)Again, in the case of apartment number 2, which is located on the south side of the first floor, the label is maximum in March and the illumination level is lowest on the balcony in July. Additionally, some periods of the year have illumination levels that are essentially identical to flat number 2.

(iii) The third-floor apartment, or apartment number 5, on the north side, has nearly constant balcony lighting throughout the year.

- **Master bed room:**

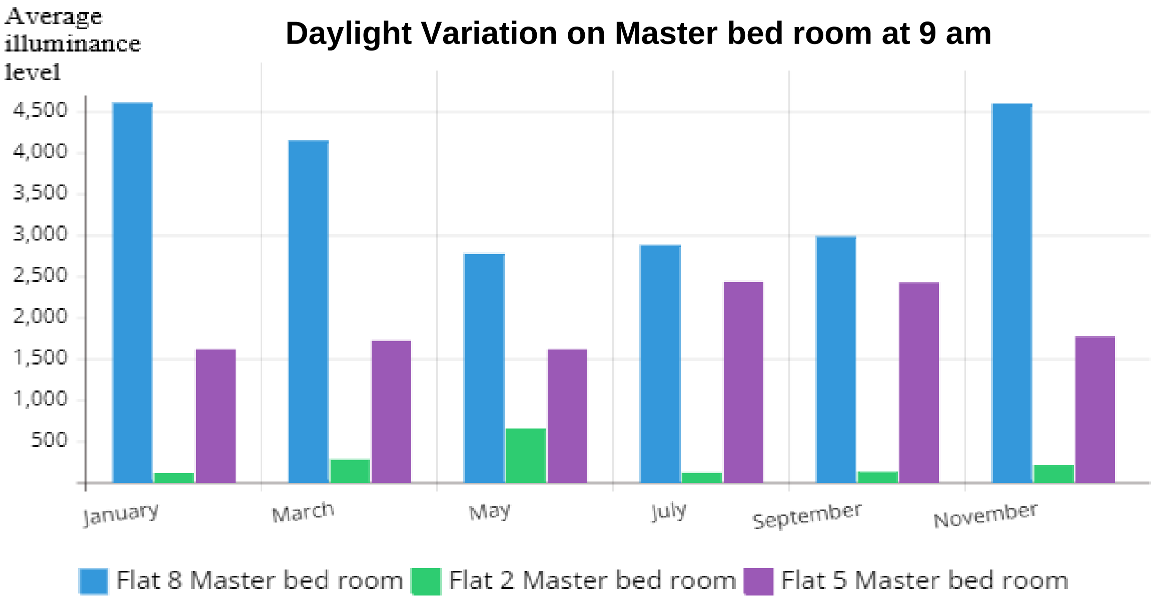


Figure 34: Daylight variation on Master Bed room

(i) The fourth-floor apartment, or flat number 8, on the south side, has illumination levels that peak in January and November, gradually fall, and reach their lowest levels in May, as shown by the graphical representation.

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(ii) Once more, in the case of flat number 2, which is situated on the southern portion of the first floor, the label is highest in May and the level of illumination in the master bedroom is lowest in July, September and January. During other months of a year changes are very minimal.

(iii) In the months of January, March, May and November, the master bedroom illumination level is nearly constant in the third-floor flat, also known as apartment number 5, on the north side. The graphical representation shows illumination levels that peak in September and to their lowest levels in May.

▪ **Kitchen:**

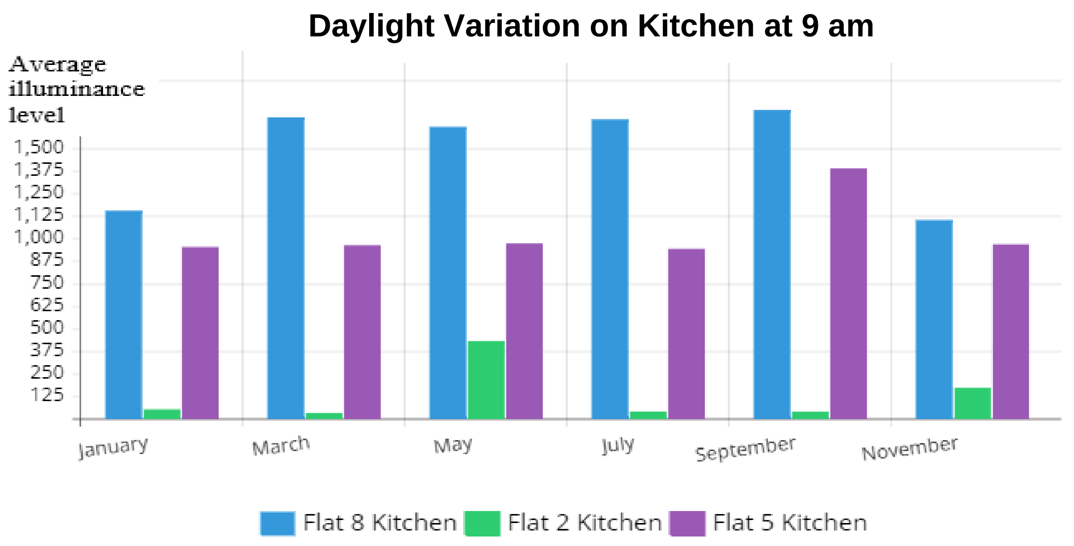

Figure 35: Daylight variation on Kitchen

(i) This figure shows that the south-facing flat number 8 on the fourth-floor illuminates at its highest level in September, but illumination level is close to the maximum illumination level in the months of March, May, and July, and at its lowest level in November and January.

(ii) For apartment number 2 on the south side of the first floor, the label is maximum in May and the kitchen light level is lowest in September.

(iii) Apartment number 5, on the north side, has nearly constant Kitchen lighting throughout the year. The label is maximum in September and the kitchen light level is lowest in July.

▪ **Bathroom 2**:

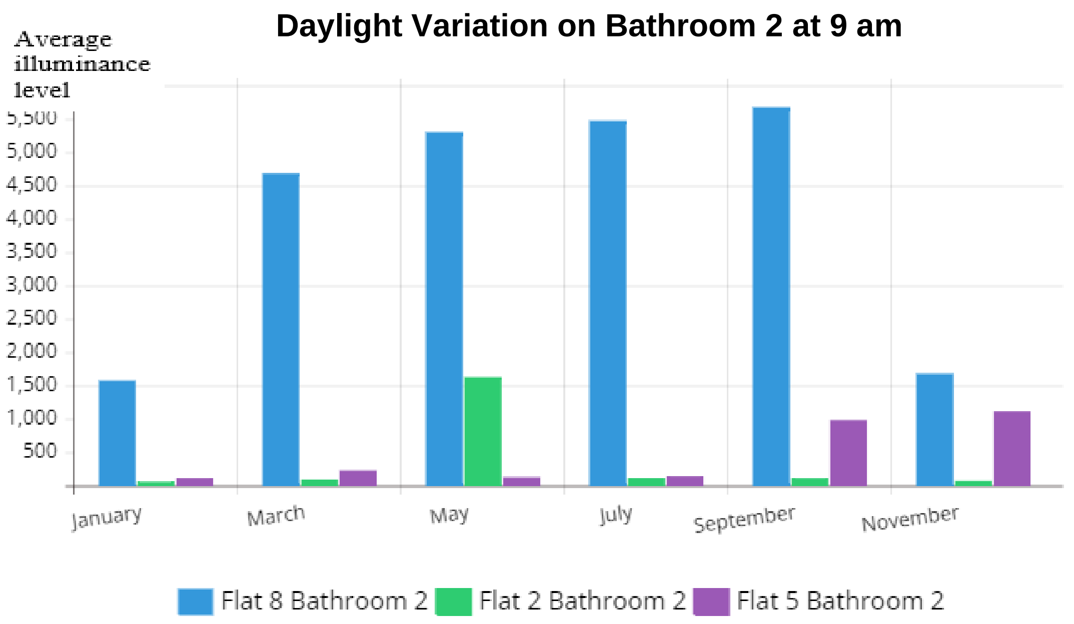

Figure 36: Daylight variation on Bathroom 2

(i) This graphical representation shows that the illumination level in bathroom 2 of flat number 8 on the south side is highest in September and lowest in January.

(ii) Once more, in the case of flat number 2, which is situated on the southern portion of the first floor, the label is highest in May and the level of illumination in the bathroom 2 is lowest except May. During other months of a year changes are very minimal.

(iii) The north side apartment on the third floor, or apartment number 5, has the maximum illumination level in November and the lowest in January. Additionally, with the exception of November and September, illumination intensity is nearly at the minimal illumination level.

- **Bedroom 2**:

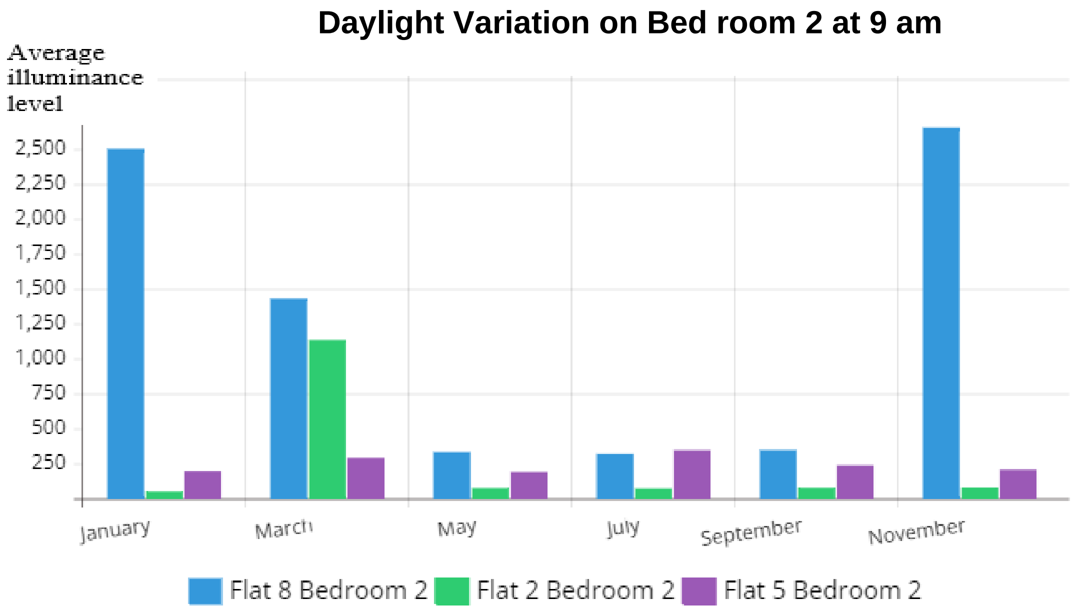

Figure 37: Daylight variation on Bedroom 2

(i) In flat no. 8, both January and November have the maximum illumination levels in bedroom 2. Except for these two months, illumination intensity is almost at the lowest possible level.

(ii)Again, in the case of apartment number 2, which is located on the south side of the first floor, the label is maximum in March and the illumination level is lowest on the bedroom 2 in July. Additionally, some periods of the year have illumination levels that are essentially identical to flat number 2.

(iii) The third-floor apartment, or apartment number 5, on the north side, has nearly constant bedroom 2 lighting level throughout the year.

5.6 Daylight variation on different rooms of three flats on various floor at 3 pm:

- **Balcony:**

Daylight Variation on Balcony at 3 pm

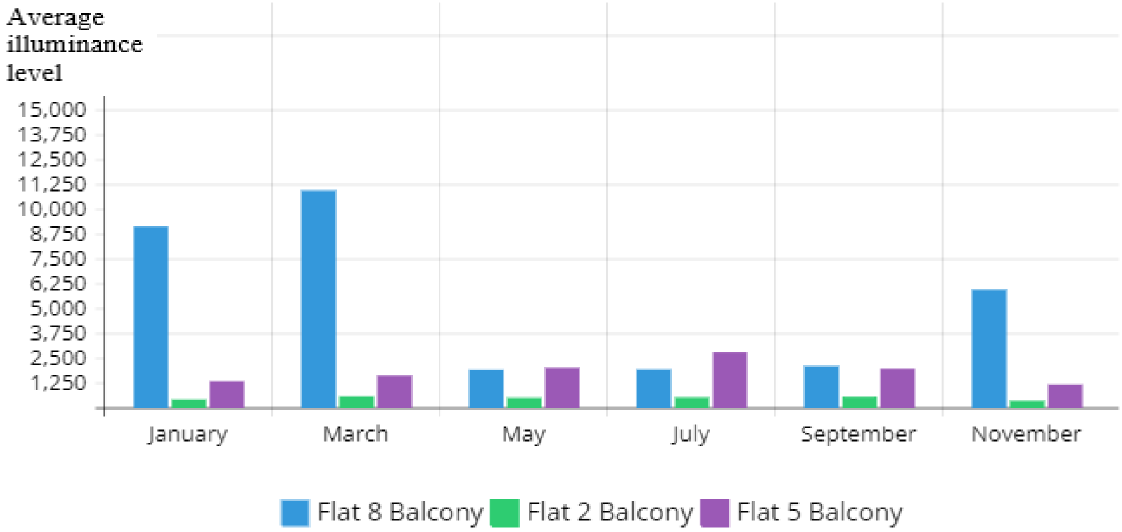

Figure 38: Daylight variation on Balcony

(i)This graphical representation demonstrates that the fourth-floor apartment, or flat number 8 on the south side, illuminates at its peak level in March, progressively declines, and illuminates at its lowest level in May.

(ii)Again, in the case of apartment number 2, which is located on the south side of the first floor, has nearly constant balcony lighting throughout the year.

(iii) The third-floor apartment, or apartment number 5, on the north side, has nearly constant balcony lighting throughout the year.

- **Master bed room:**

Daylight Variation on Master bed room at 3 pm

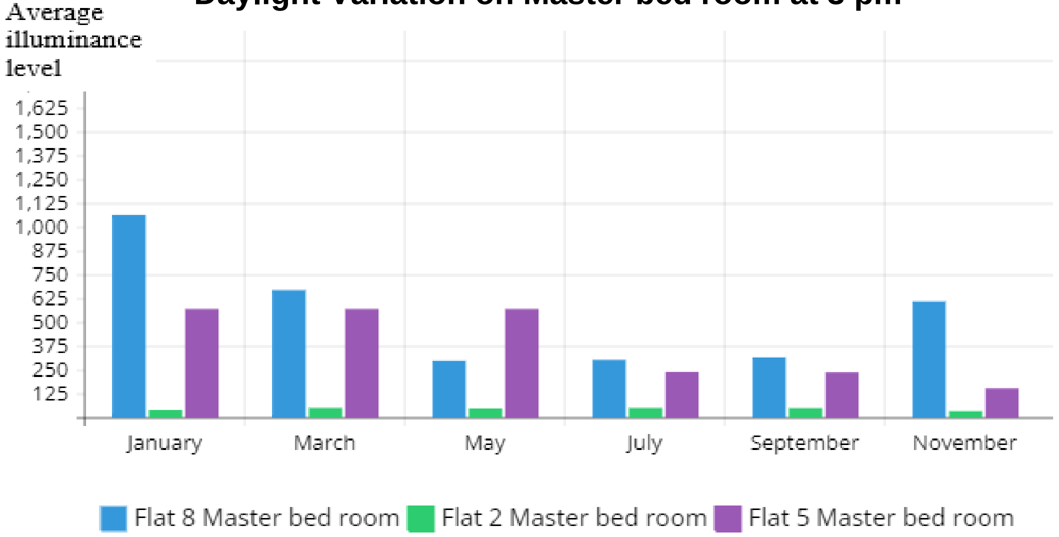

Figure 39: Daylight variation on Master Bed room

(i) The fourth-floor apartment, or flat number 8, on the south side, has illumination levels that peak in January and January, gradually fall, and reach their lowest levels in May, as shown by the graphical representation.

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(ii) Once more, in the case of flat number 2, which is situated on the southern portion of the first floor has nearly constant balcony lighting throughout the year.

(iii) In the months of January, March and May, the master bedroom illumination level is nearly constant in the third-floor flat, also known as apartment number 5, on the north side. The graphical representation shows illumination levels that lowest levels in November.

- **Kitchen**

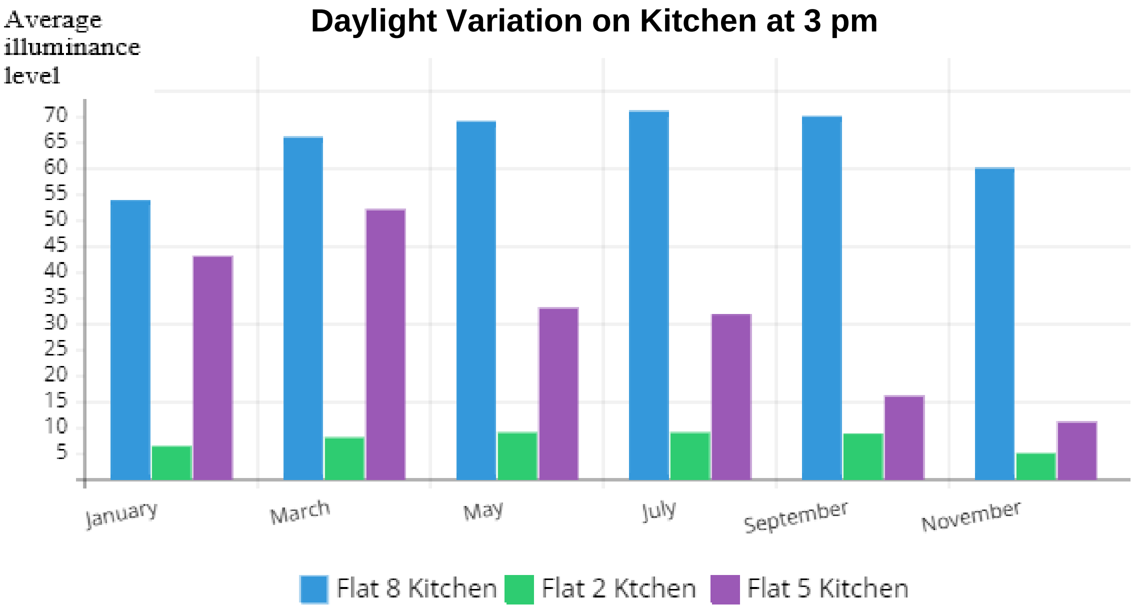

Figure 40: Daylight variation on Kitchen

(i) This figure shows that the south-facing flat number 8 on the fourth-floor illuminates at its highest level in July, but illumination level is close to the maximum illumination level in the months of March, May, and September, and at its lowest level in November and January.

(ii) For apartment number 2 on the south side of the first floor, has nearly constant Kitchen lighting throughout the year.

(iii) Apartment number 5, on the north side, the label is maximum in March and the kitchen light level is lowest in November.

- **Bathroom 2:**

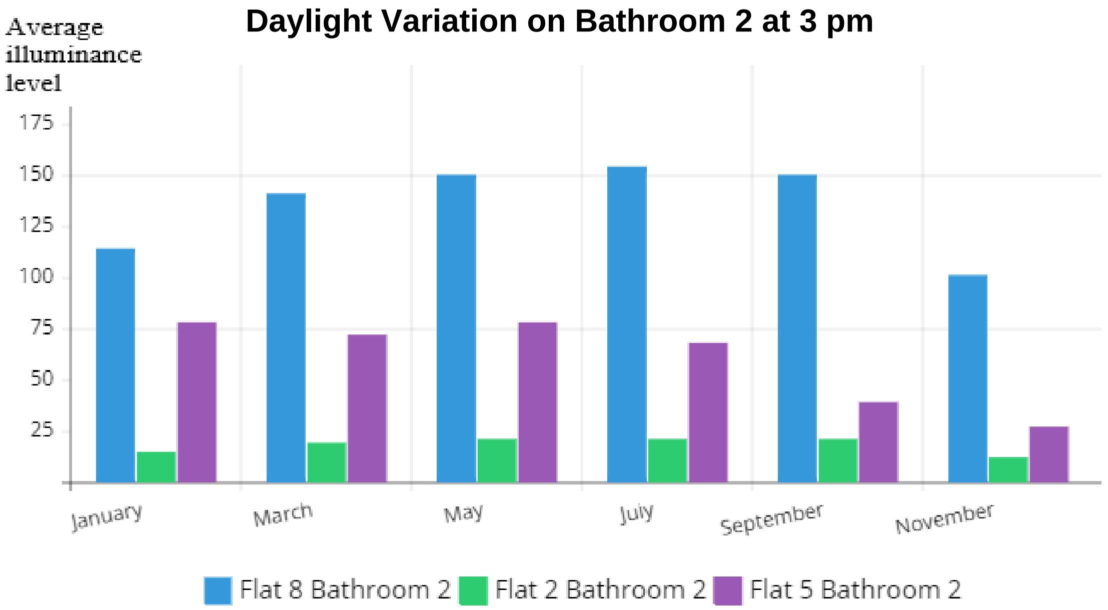

Figure 41: Daylight variation on Bathroom 2

(i) This graphical representation shows that the illumination level in bathroom 2 of flat number 8 on the south side is highest in July and lowest in November.

(ii) In addition, with, in the case of flat number 2, which is situated on the southern portion of the first floor, the label is highest in May as well as July and the level of illumination in the bathroom 2 is lowest in November. During other months of a year changes are very minimal.

(iii) The north side apartment on the third floor, or apartment number 5, has the maximum illumination level in May and the lowest in November.

- **Bedroom 2:**

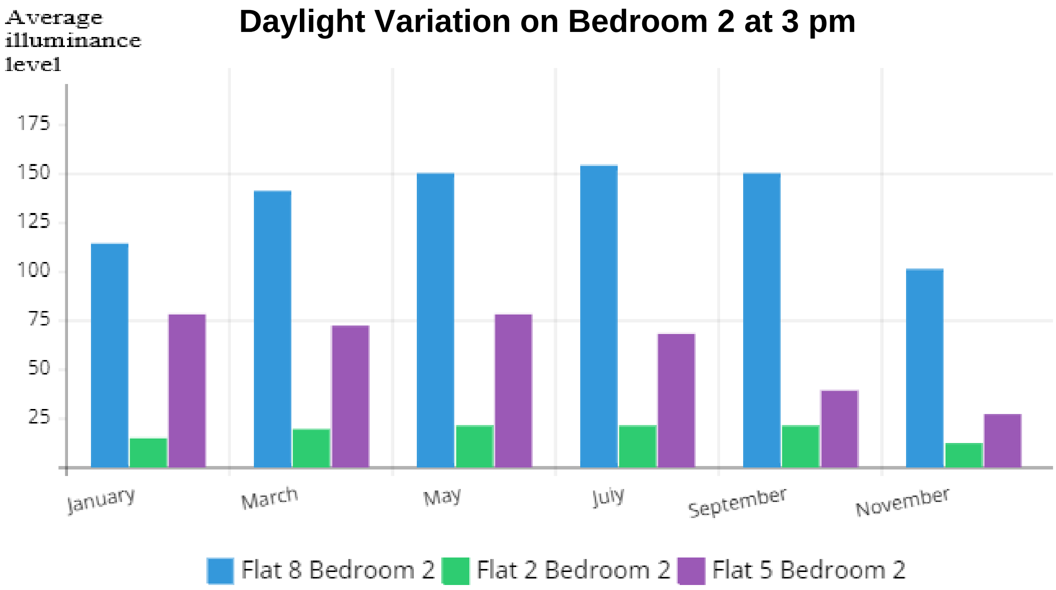

Figure 42: Daylight variation on Bedroom 2

(i) In flat no. 8, May, July and November have the maximum illumination levels in bedroom 2. Except for these three months, illumination intensity is almost at the lowest level.

(ii)Again, in the case of apartment number 2, which is located on the south side of the first floor, the label is maximum in May as well as July and the illumination level is lowest on the bedroom 2 in November. Additionally, some periods of the year have illumination levels that are essentially identical to flat number 2.

(iii) The north side apartment on the third floor, or apartment number 5, has the maximum illumination level in May as well as March and the lowest in November.

6. Conclusion and Future Work:

6.1 Conclusion:

The results of the analysis show that the illuminance level on the 4th floor is higher than on the 1st and 3rd floors. On the 4th floor, the building envelope opening is wider than openings on floors 1 and 2 so it can be seen that the opening area in the building envelope affects the illuminance level in space.

In the morning, afternoon and evening, the average level on the 3rd floor is higher than the 1st floor, so it can be seen that in the same condition outside the building, there is an increase in illuminance level in the room on the 3rd floor. So, it can be concluded that the level of illuminance affects the height building floor. The distribution of light enters the space higher in the area near the building envelope, the farther away from the opening of the building envelope, the lower the level of illuminance into the space. Based on this analysis, it can be seen that the depth of space affects the distribution of natural light.

The goal of this research was to concentrate on how floor levels affect how light is distributed, without necessarily taking thermal discomfort and glare into account. This research has shown that building heights have their own effects on the amount and distribution of daylight in the interiors of buildings, in addition to the effects of towering neighbouring buildings shading the lower levels.

6.2 Future scope:

- This study is that because the focus of this work was on the effects of floor levels on daylight distribution rather than necessary taking into account thermal discomfort and glare, using SDA without studying the Annual Sun Exposure (ASE) can lead to unacceptable performance. It can be considered in future work.

- By varying the window dimension, daylight distribution can lead a vital role and contribution of daylight utilization can be analyzed.

- Studying the findings in additional areas and nations will be necessary to confirm the study's findings' generalizability. Hyogo Prefecture, however, is one of the best places for this study; we intend to find out if there are regional variations in the relationship between NL and building height.

7. References:

[1] Sugianto 1998 *Building in Indonesia with a Tropical Climate Humidity from Aspect Building Physics* Jakarta (Original in language)

[2] Rahim R 2009 *Theory and Application of sky Luminance Distribution in Indonesia* Nasional Library (Original in Indonesia language)

[3] Satwiko P 2009 Building Physics. Andy Publisher (Original in language)

[4] Jamala N *The Effect of building Façade on Natural lighting (Case Study: Building Of Phinisi*

[5] Indonesia National Standard 03-2396-2001 *The Design of The System of Natural Light in The Building* (Original in Indonesia language)

[6] Indonesia National Standard 03-6575-2001 *The Design of The System of Artificial Light in The Building* (Original in Indonesia language)

[7] Australian standard, 1990, *Interior lighting: General Principles and Recommendations*, Published by Standards Australian, North Sidney NSW, p.46

[8] Manurung 2012 *Natural Light in Architecture* Andy Publisher

[9] Rahim, R. et. al. 2004. Classification of daylight and Radiation Data into Three Sky Condition by *Cloud Ratio and Sunshine Duration*, Journal Energy and Building, Elsevier, Vol 36, 2004 pp.660-666

[10] Nakamura H et. al. 1985 *Luminance Distribution of Intermediate Sky* Journal of light and Vis.

[11] Daylight in Buildings: A Sourcebook on Daylighting Systems and Componentshttp://www.iea-shc.org/task21/source_book.html

[12] Survey of Architectural Daylight Solutions

http://www.iea-shc.org/task21/publications/A_survey_architectural_solutions/1-intro.pdf

[13] Application Guide for Daylight Responsive Control Systems http://www.iea-shc.org/outputs/task21/8-1%20Application%20Guide.pdf

[14] Daylight simulation: Methods, algorithms, and resources http://gundog.lbl.gov/dirpubs/daysim_algo.pdf

[15] Daylight design tools http://btech.lbl.gov/pub/iea21/documents/cdrom/Appendix8.09/8.9.1.pdf

[16] The majority of the Task 21/Annex 29 project reports are available from the IEA at:www.iea-shc.org/task21/deliverables.htmand from the ECBCS at: www.ecbcs.org/annexes/annex29.htm

[17] Many reports and the Case Studies are also available at:btech.lbl.gov/pub/iea21/ieacd.htm

[18] Crawley D B, Hand J W, Kummert M and Griffith B T 2005 Contrasting the capabilities of

building energy performance simulation programs *Proc., of 9th International IBPSA Conference Montréal* (Canada:Building Simulation) pp 231-238
[19] Guglielmetti R, Pless S and Torcellini P 2010 On the use of Integrated Daylighting Energy Simulations To Drive the Design of a Large Net-Zero Energy Office Building *Presented at SimBuild,* (New York)
[20] An J and Mason S 2010 Integrating Advanced Daylight Analysis into Building Energy Analysis *Proc., of 4th National Conference of IBPSA-USA* (New York: IBPSA)
[21] Guglielmetti R and Ball B L 2016 A Frmework for Daylighting Optimisation in Whole Buildings with Openstudio, *Presented at ASRAE and IBPSA-USA SimBuild,* (Salt Lake City: UT)
[22] Kamel E and Memari A M 2018 Automated Building Energy Modelling and Assessment tool *Energy,* **147** pp 15-24
[23] Salisu A S 2015 Optimising Fenestration for Daylight for daylight provision in the Architecture of Secondary Schools in Nigeria using Climate-Based Daylight Modeling, Unpublished PhD thesis, Department of Architecture, Ahmadu Bello University Zaria, Nigeria, 2015.
[24] Musa M A 2019 *Validation Study of OpenStudio Simulation tool for Optimising Indoor Environmental Comfort in Mid-rise Office Buildings in Composite Climate of Nigeria* Unpublished Second Seminar of PhD thesis, Department of Architecture, Ahmadu Bello University Zaria, Nigeria
[25] Lighting Measurement 83 LM-83 2013 *Approved Method: IES Spatial Daylight Autonomy and Annual Sunlight Exposure* (USA: IES Daylight Metrics Committee)
[26] Rafferty J P 2016 Classification of major climatic types according to the modified Köppen-Geiger scheme table revised and updated
[27] Koenigsberger O H, Ingersoll T G, Mayhew A and Szokolay S V 2013 *Manual of Tropical Housing and Building Climatic Design* (India: Universities Press)
[28] Nwalusi D M, AnierobiC M, Efobi K O and Nwokolo C N 2015 Climatic Considerations in Architectural Design of Buildings in Tropics: A case study of hot dry and warm humid climate in Nigeria *Journal of Environmental Management and Safety* **6** pp 54-63
[29] Eludoyin O M and Adelekan I O 2012 The physiologic climate of Nigeria *International Journal of Biometeorology* **3** pp 549-553
[30] Alcox H 2017 *Multi-storey buildings; Classification and benefits* http://www.alcox.in/blog/multi-storey-buildings-classification-benefits
[31] Musa M A and Garba A I 2019 Assessing the Effects of Building Floor Levels on Passive Ventilation rate in Courtyard Mid-rise Office Building in Temperate Dry Climate Of Nigeria, *Proc., of the National Conference of Nigerian Association of Architects Educators* (Nigeria : AARCHES) pp 320-334
[32] Meir I A, Pearlmutter D and Etzion Y 1995 On the microclimatic behavior of two semienclosed attached courtyards in a hot dry region *Building and Environment* **30** pp 563–572.
[33] Muhaisen A S and Gadi M B 200b, Shading performance of polygonal courtyard form *Building and Environment* **41** pp 1050-1059
[34] Newtown Kolkata Development Authority https://www.nkdamar.org/Pages/index.aspx