Inclusion of Daylighting Guidelines: Sustainable approach towards more Comprehensive Building - Byelaws of India

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Abstract

Daylight has been used for centuries as the primary source of illumination in interior environment of a building and has been an implicit part of architectural built form. It can be defined as the composition of all indirect and direct light originating from the sun during the daytime. It is dynamic in nature and its availability varies with geographical locations due to different sun paths, solar elevation and sky conditions through the entire course of the day, the season, and the year. Due to the unique and dynamic spectral power distribution of the daylight, none of the artificial lighting technology source can replace the daylight in practical. The variation of daylight intensity and spectral composition throughout the day is critical to human health, as it adjusts our biological clock and related functions that follow the circadian rhythms. The criteria of good daylighting vary with the geography, the society, the function of the building and the specific needs of occupants. The daylight apertures, such as windows, curtain wall, skylights etc. and other fenestrations, plays important role being a sensory organ of the building and the occupants. Building byelaws are intended to safeguard the health, safety, and welfare of the society and building occupants. In addition to the above standards and regulations, many of the countries have laws and regulations on energy efficiency of buildings. In India, cumulative spent on indoor lighting needs is as large as 42% of total residential electrical energy and the energy consumption in building segment is rising at 8% per annum due to the rapid urbanization. Here, different Building codes, Byelaws, regulations and related research of developed and developing countries including of India has been studied in order to Daylighting aspects and investigated the possibility of inclusion of the specific design guidelines within Indian Building Byelaws for incorporating daylight in architecture as an energy saving metric.

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1.0 Introduction:

1.01 Daylight, the Primary Source of Illumination:

Sun and fire were the major sources of illumination since primitive ages before the invention of electric or artificial lighting. Living organisms of the mother earth have evolved over thousands of years under these mentioned sources of light. Human biology is closely linked to solar energy for vision, as well as for biological functions, especially those that follow circadian rhythms [1].

Daylight has been used for centuries as the primary source of illumination in interior environment of a building and has been an implicit part of architectural built form. Its presence has reduced the cumulative energy use for lighting by replacing the use of artificial light during daytime and influences both heating and cooling loads, which makes the Daylight an important parameter of an energy efficient design. There are several studies in recent days, which have proved that the daylight provides an array of health and comfort benefits that make it essential for buildings' occupants [2].

Daylight can be described as the combination of all indirect and direct light originating from the sun during the daytime. Among the total solar energy received on the earth surface, 40% is visible radiation and the rest are ultraviolet (UV) and infrared (IR) wavelengths. [Fig.1.01] Daylight is dynamic and its availability outside, varies for different geo-locations due to different sun paths and sky conditions through the entire course of the day, the season, and the year. The amount of incident light on the ground depends on the solar elevation, the higher the elevation of the sun, the greater the illuminance on the ground. Daylight levels vary significantly on horizontal and vertical surfaces by time of the day and the season, directly related to the local sun paths and sky conditions. While certain artificial or electric light sources can be constructed to match a certain spectrum of daylight closely but not precisely, none could be made that mimic the variation in the light spectrum that occurs with daylight at different times, in different seasons, and under different weather conditions [3].

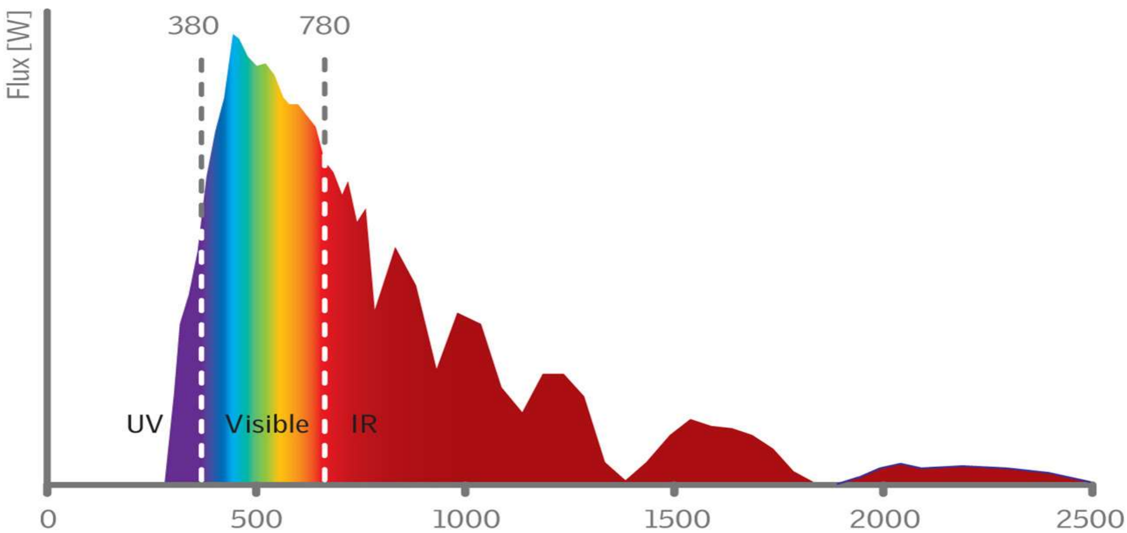


Figure 1.01 *[Electromagnetic spectrum showing the location of the visible spectrum]*

1.02 Daylighting through Fenestration:

Daylighting can be described as the controlled use of natural light in and around the built form[4]. The term "fenestration" refers to all glazed apertures in the building envelope that bring daylight in interior spaces. The term comes from the Latin word "fenestra", which means "window, opening for light" [1]. It is the practice of placing fenestrations; like windows, or other transparent media and reflective surfaces so that natural light provides effective internal illumination during the day.

Daylighting strategies and architectural design strategies are inseparable. Successful daylighting application requires few design considerations at all stages of the building design process, from site planning to architectural, interior and lighting design. Planning for daylight therefore involves integrating the perspectives and requirements of various specialities and professionals. Daylighting design starts with the selection of a building site and continues till the building is occupied.

1.03 Daylighting Components:

Daylight in buildings is composed of direct sunlight, diffuse skylight, and light reflected from the ground and surrounding elements. [Fig.1.02] Daylighting design needs to consider the orientation of the building, geographical and topographical characteristics of site, physical characteristics of facade and roof, size and positioning of window openings, glazing and shading device, geometry and reflectance of interior surfaces etc. Good daylighting design must ensures adequate light during daytime [2].

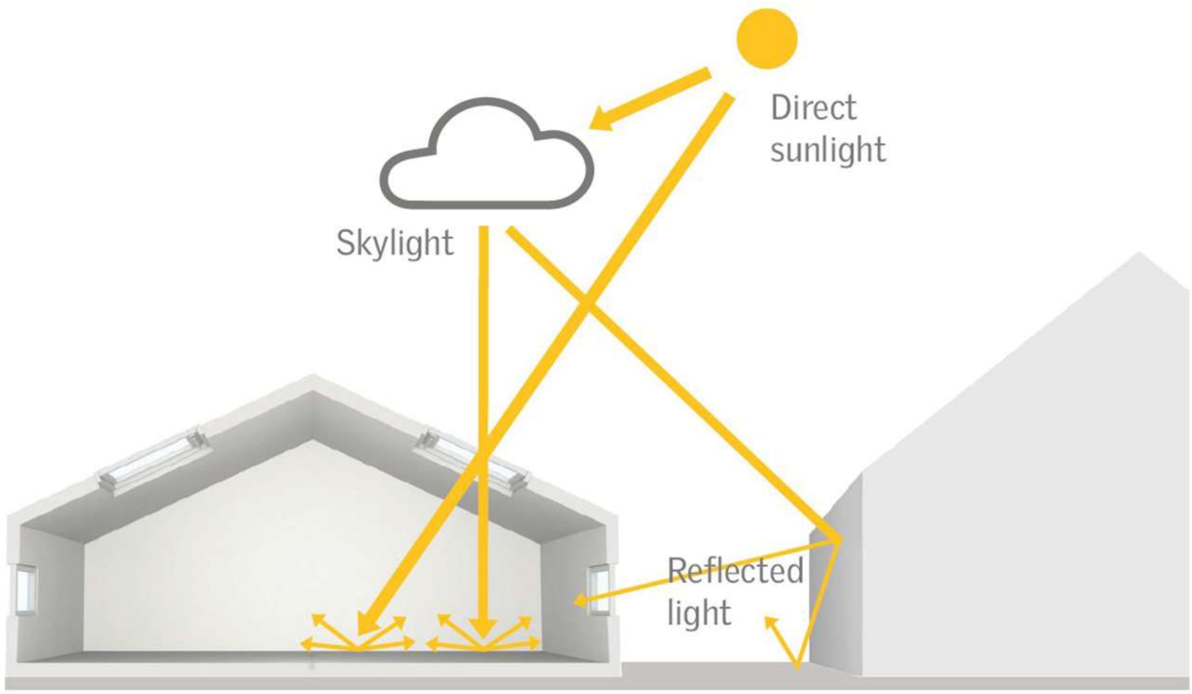


Figure 1.02 *[Components of Daylight]*

- Direct sunlight is characterised by very high intensity and constant movement. The illuminance produced on the surface of the earth may exceed 100 000 lux. The brightness of direct sunlight varies by season, time of day, location and sky conditions. In a sunny climate, thoughtful architectural design is required, with careful management of allowance, diffusing, shading and reflecting.

- Skylight is characterised by sunlight scattered by the atmosphere and clouds, resulting in soft, diffuse light. The illuminance level produced by an overcast sky may reach 10 000 lux in the winter and as high as around 30 000 lux on a bright overcast day in the summer. In a cloudy climate, the diffuse sky is often the main source of useful daylight.

- Reflected light is characterised by light (sunlight and skylight) that is reflected from the ground: terrain, trees, vegetation, neighbouring buildings etc. The surface reflectance of the surroundings will influence the total amount of reflected light reaching the building facade. In some dense building situations, the light reflected from the ground and surroundings can be a major contributory part of daylight provisions indoors.

1.04 Goals of Daylighting:

During the energy crises period of the 1970s, considering heating and cooling loads, fenestrations or windows were identified as the most energy inefficient building envelope component. Hence, the access to daylight and outdoor views from the interior of the building was compromised to a larger extent. Initial energy efficiency metrics were majorly focused on reduced sized of window. In some extreme cases, those were even completely eliminated from the building envelope. Commercial spaces and educational institutes spaces, for example, were designed to operate without any daylight apertures, resulting in major negative impacts on the well-being of occupants. In todays context, we have a much better understanding of daylight harvesting benefits including psychological, physiological, biological and energy benefits [1].

A good quality lighting design should consider the aspects of lighting for wellbeing, in parallel with meeting several needs of the occupier of the space. The goals of daylighting of interior spaces are to "*adequately illuminate visual tasks, to create an attractive visual environment, to minimize consumption of electrical energy and to provide the light needed for our biological needs*". [2]. "*A good luminous environment is simultaneously comfortable, pleasant, relevant, and appropriate for its intended uses and users*" (Lam, 1977) [5].

Daylighting systems can be as simple as combining fenestration design with required internal and external shading with use of different blinds – to systems designed to redirect sunlight or skylight to the required areas through "sun tunnels". More complex systems can be designed by implementing passively controlled fenestration device with the dynamics of direction of sunlight and skylight.

1.05 Benefits of Daylighting:

The daylight apertures, such as windows, curtain wall, skylights etc. and other fenestrations, plays an important role as a sensory organ of the building and the occupants. These are the connection to the outdoors that which provide information about the changes of time of the day, dynamic weather conditions and outdoor activities. These are critical for occupants psychological well-being and key aspects of overall health [1].

To align the human body clock, morning light is the most important signal for entrainment and also increases the levels of alertness and performance from the beginning of the daytime. High levels of daylight during the mid-morning to the early evening allow us to regulate our sleep-wake timing and levels of alertness. Whereas the minimum light levels in the evening in a darker ambience, promote sleep at night time. The daily variation of daylight intensity and spectral composition is critical to our health, as it adjusts our biological clock and related functions, such as alertness, hormone levels and body temperature [Fig.1.03]. The limitation of good overall lighting environment to the building occupants can have a subsequent impact on the health of individual, society and the broader economy [2].

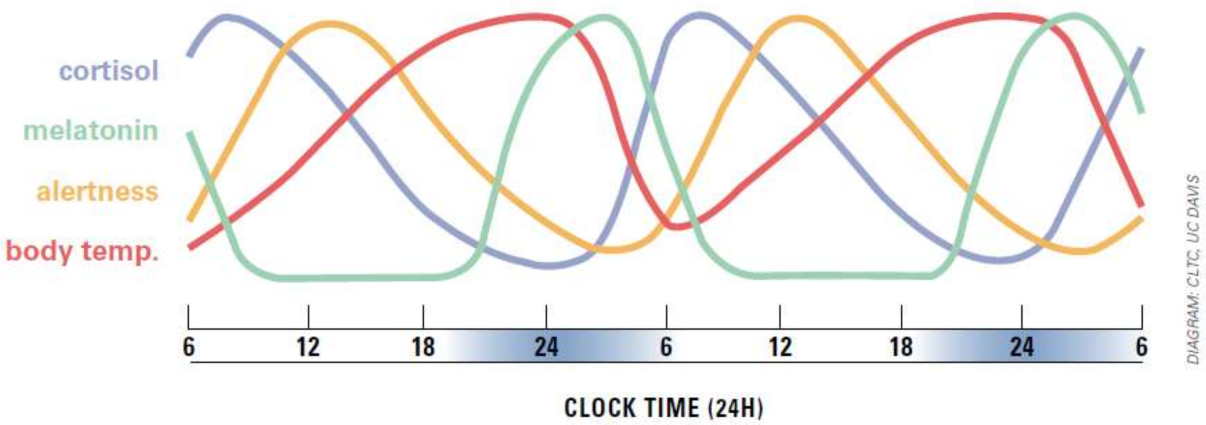


Figure 1.03 *[Circadian Rhythms showing the variation of cortisol, melatonin, alertness and body temperature over two 24-hour periods]*

2.0 Aims and Objectives of the Study:

2.01 Aim of the Thesis

The aim of the thesis is **"To understand the aspects of Daylighting considerations in formulation of Building Byelaws and Regulations, to identify the limitation and to recommend daylight specific proposals for more comprehensive Byelaws".** Various performance metrics are observed to identify the future opportunities to support the policy formulation process and an avenue towards the more sustainable and comprehensive Building Byelaws from daylighting aspect.

2.02 Objective of the Thesis

Main objective of this Thesis work is-

- To Study the Daylighting aspects of Design of a building and its effect on Occupants.
- To study the various Daylighting influencing parameters.
- To study the different Daylighting performance metrices.
- To Study the various global Regulations, 'Rule of Thumb' Practice and the regulations based on Daylighting tools.
- To Study the daylighting aspects of the Indian Building Codes, Regulations, Byelaws, Energy Conservation Building codes etc.
- To perform the daylighting simulation of a model building encloser with respect to variation of daylighting influencing parameters and to analyse the output simulation data of various Daylighting performance metrices with the help of software.
- To Identify the limitations of Design Guidelines and regulations and to Propose recommendation.

3.0 Daylight and Human Health

Daylight is electromagnetic radiation from the sun with both direct and indirect component, which is altered by different reflections, refractions and then conveyed and filtered through the atmospheric layers. The duration and availability of daylight depends on geo location, weather condition and seasons. Daylight has a broad continuous spectral power distribution [Fig.1.01], changing within and across days and with weather and sky conditions in absolute power (irradiance), colour, diffuseness, polarity and direction [9].

In outdoors, illuminance may vary between 20,000 to 100,000 lux in a sunny day, whereas it is around 3000 lux during rains. In indoors, illuminance is much lower and tends to decline exponentially with the distance from the fenestrations. The highly dynamic pattern of daylight contrasts with the constant availability of the artificial light source. Additionally, depending on the artificial light sources, the spectral power distribution (SPD) of the lights are quite different from each other and from daylight, even though they may all be perceived as apparent “white” light [Fig.3.01] [2].

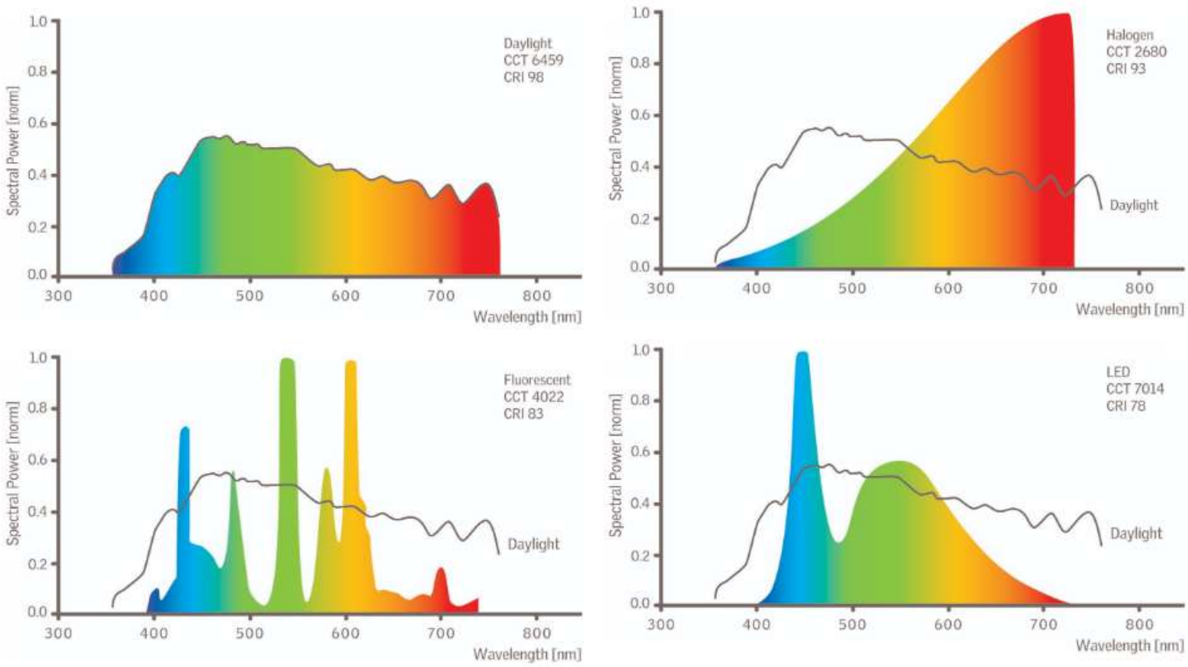


Fig 3.01 *[Spectral composition of four typical light sources - daylight, halogen, fluorescent, and LED]*

3.01 Light input to the eye and brain:

In human biology, light reaching to the retina is very crucial for vision to identify the motion, spatial detail, colour etc., then transduced into electrical signals in the rod cell and cone cell. Light is also important for non-visual input to the brain via a subset of intrinsically photosensitive retinal ganglion cells (ipRGCs) that express the short-wavelength-sensitive photopigment melanopsin. It mediate entrainment of the circadian clock in the suprachiasmatic nuclei (SCN) to the 24-hour light–dark cycle, modify sleep, alertness, pupil size and many more physiological functions. They also interact with other retinal ganglion cells to convey visual and non-visual light input. These two photic systems were long considered independent, however newer evidence indicates interactions in human visual perception, e.g. melanopsin-mediated information via the primary visual cortex.

"The range of central nervous system functions found to be affected by light continues to grow. The most important - now classical - zeitgeber role of light, is to synchronise and shift circadian rhythms. Daylength (and rate of change of daylength) triggers seasonal responses, and the day-night transitions at twilight are crucial. Not only does light directly increase alertness, but daytime exposure appears to modify night-time sleep. The mood-enhancing effects of light (known from clinical applications) are mediated not only by circadian mechanisms but also by a SCN-independent pathway linking ipRGCs to the perihabenular nucleus (PHb), itself close to neurons modulating mood and stress. Photic information to the PHb can also influence learning separately from the circadian role of the SCN. The habenulae are small paired nuclei in the brain contributing to many cognitive and motivational functions and are additionally part of the circadian circuitry. In both animals and humans, habenular neurones respond to retinal illumination with a time of day dependency. It is clear that further studies of such basic mechanisms relating to the eye and its signalling pathways to the brain and the neurotransmitters involved will remain laboratory based, using controlled and well-defined electric light sources. However, understanding these basic mechanisms will help define, direct and analyse daylight data from field research." [9].

3.02 Biological effect due to lack of Daylight:

There are major epidemiological developments related to deficiency of daylight.

In Asia, there is a widespread and growing cases of myopia among the young, which starts between the age of 4 to 6 years or later, and even though wearing glasses can correct vision, it cannot stop the progression of myopia. Exposure to natural daylight, like being in outdoor for 2 to 3 hours daily, has been observed to be protective against the development of cases of myopia including young humans. A few hours of outdoor daylight exposure every day, seems to be a miracle preventive prescription. Natural daylight helps to stimulate the retinal dopamine, which control the growth of the eye. Involvement of circadian regulation on refractive development in myopia has also been suggested.

Apart from myopia, in the digital era, youths' health appears to be at risk with increased screen time with using blue-emitting screens of mobile phones or tablets, is also well known for the reason of the delay of sleep timing found in young people in the evening. *"The developing child's lack of natural daylight exposure, a major consequence of increased time spent indoors online, is correlated with multiple health risks ranging from physiological disorders (sleep, obesity), psychological problems (depression, anxiety), and cognitive impairment. Key neurotransmitters widespread in brain neuronal networks are involved. For example, serotonin is a crucial neurotransmitter linked with mood and circadian regulation; dopamine regulates the brain's reward circuits (motivation, attention) and movement centres"* [9].

Vitamin D, synthesised by ultraviolet-B in daylight reaching the skin, is essential for bone development and health, without which bones can become soft, thin and brittle and causes rickets, osteoporosis etc. Studies suggest that Vitamin D is additionally linked to the circadian system possibly through the immune system or the newly discovered melanopsin-photosensitive system in human skin.

Immune responses are also regulated by central and peripheral circadian clocks and proper coordination between the two is crucial for adaptive immunity, such as for protective antibody production after vaccination (e.g. via T and B-cells).

"Low Vitamin D. levels are associated with a higher risk of COVID-19 infection; a recent study of a Vitamin D metabolite administered to hospitalised COVID-19 patients showed significantly reduced intensive care unit admission. Humans are more susceptible to infections at certain times of the day, because the function of our defence systems follows a daily rhythmic pattern. Circadian clocks control the function of our immune system, virus replication and the severity of infections. Circadian rhythms have a profound impact on human health, because they have a central role in coordinating daily physiological processes, including the functions of innate and adaptive immunity. Circadian clock disruption in hosts leads to increased pathogen replication and dissemination, which indicates that the severity of acute infections could be markedly influenced by circadian rhythms" [9].

These findings open up entirely new interactions of daylight with clocks, sleep, and immunological health, with emphasis on the current pandemic COVID-19 situation worldwide.

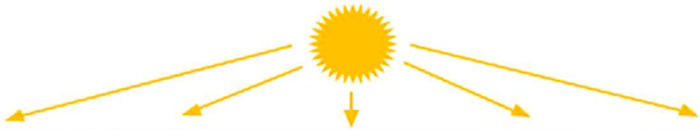
3.03 Light and mood disorders:

In our modern times it has been found that imposed circadian disruptions due to shift work, light at night, and trans meridian flight promote affective symptoms in vulnerable individuals. Animal models suggest that even short-term exposure to night-time light can trigger depressive-related symptoms. On the other hand, bright light is an established antidepressant for seasonal and other depressions. A daily walk outdoors can similarly improve mood. Linking to today's COVID-19 pandemic, daylight might be helpful in limiting both the psychiatric sequelae of hospitalisation and the probability of infection itself: through the antidepressant effect of bright light, and its disinfectant properties.

3.04 The Future with Daylight:

The recent debates on climate and environment change have put serious consideration for sunlight, not just for solar power but also for health. Though the new generation LEDs can approach the spectral distribution of daylight and are programmable in terms of intensity and Correlated Colour Temperature throughout the day to simulate daylight as well as the crucial dawn-dusk transitions, a new focus on natural daylight is required in architectural solutions to attain better energy efficiency.

There are no standardised tools to measure accurately and continuously individual daylight exposure across multiple time scales including spectral composition. Also there is a key gap of knowledge in daylight research related to the variable quantity and quality daylight needed for ’optimal’ physiological and psychological functioning and general health. *“Not only is the daily exposure to a given light intensity, duration, wavelength, and timing important, but the modification by prior light exposure, age, eye problems, medication etc. needs to be documented and integrated into optimisation of (day-)light exposure. We need consensus on methodologies to determine the effects of daylight on visual, psychological, and somatic functions, as well as a better integration and exchange of daylight knowledge bases from different disciplines*” [9]. [Fig.3.02].



Functions of daylight	Reflection of the environment	Reduce risk of myopia	Bone health, Immune system	Major zeitgeber	Anti-depressant
Realised via	Visual system	Eye development	Skin	Circadian system	Multiple systems
Content	Vision	Myopia	Vitamin D synthesis	Circadian entrainment	Mood

Fig 3.02 *[Overview of the important functions of daylight (first row), its realisation (second row) and the main content this article addresses (third row)* [9] *]*

On a broader scale, this means translation into appropriate design for daylight-enhanced buildings and urban settings. From this study, one of the research problems can be identified as: daylight as a dynamic natural source is difficult to control, predict, or replicate. It is to be identified, whether it can be developed a metric to measure the “naturalness” of light. And it can be determined, if and how the effects of daylight are different from the effects of artificial light.

Daylight may also be efficiently used to strengthen circadian entrainment (e.g., in hospitals) to improve efficacy and reduce side effects of any therapeutic intervention. The timing of an individual’s clock is relevant for the timing of drug administration, and the timing of treatment in turn modifies its effects.

In summary, we need more evidence-based data to support and design the premise that access to natural daylight is necessary and advantageous for sustainable and healthy living. The circadian and sleep community is intellectually rich enough to meet this research challenge to define the necessary parameters but will need to interact better across disciplines and develop an updated theoretical framework, in which it will be crucial to integrate the findings of daylight research, thus creating the groundwork for beneficial community applications.

3.05 Health, Wellbeing and Performance:

Industrial Revolution made a significant difference to the living style at international level, where the society gradually changed from an outdoor agrarian to a more indoor, urban environment and traded off in order to live indoors, with artificial lighting, heating and cooling - a new world order structured than biological concerns. “*The availability of daylight and its impact on the health and wellbeing of occupants is generally nowadays acknowledged as fact* *and writing some five years later Gallagher (1999) cites winter statistics for the north of the United States, pointing out the serious nature of an illness known as Seasonal Affective Disorder (SAD). Six percent of New York residents suffer severe depression during winter, but As many as 50% of the residents suffer mild symptoms, including low energy, and disturbed eating and sleeping patterns. Gallagher believes that this behavioural problem has a specifically environmental cause: lack of light"* [10].

Ruck has commented specifically on the issue of health and wellbeing of the occupants of buildings that *"… light can also be considered on physiological and biological grounds as being essential for the wellbeing of a building's occupants owing to its non-visual effects such as brain stimulation and body orientation and balance. A good luminous environment therefore depends not only on environmental and task lighting design, but also on the spectral composition effects of the light on individuals. Great architects, including the designers of the Parthenon, the craftsmen of the Gothic cathedrals, and indeed certain twentieth-century architects, have understood the impact of natural light and its importance for putting human beings in touch with their environment"* (Ruck, 1989:40-42).

Study suggests that architects are starting to respond to the growing awareness of the importance of light to wellbeing, and the New York Board of Education and their experimentation with classroom shape, [Fig.3.03] *"… rather than the traditional box, this version's plan resembles a bisected square whose halves have been pushed in opposite directions; because it has eight corners and walls instead of four, the room allows for bay windows and a lot more light" (Gallagher, 1994:49).*

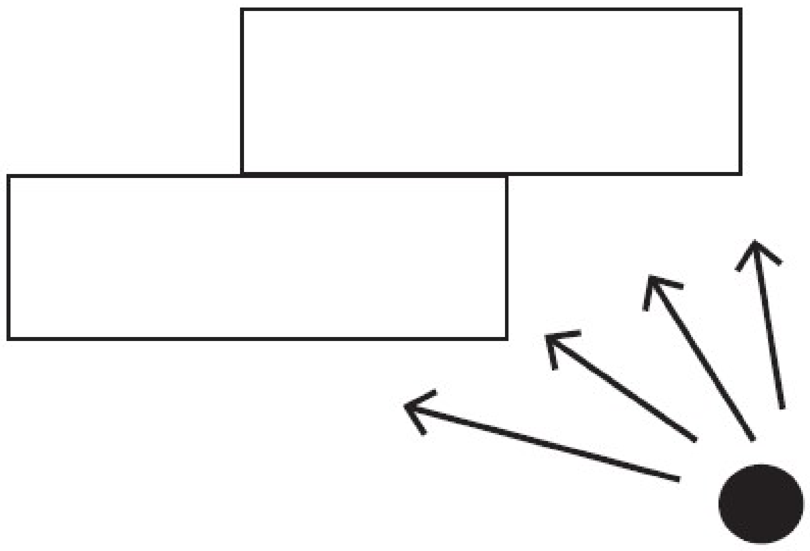


Fig 3.03 *[The geometry of plan form can be altered to take best advantage of Daylight* [10] *]*

Another study demonstrated that greater satisfaction with lighting conditions (both daylight and electric lighting) contributed to environmental satisfaction, which, in turn, led to greater job satisfaction (Veitch et al., 2008). Studies also show that daylit environments lead to more effective learning. It was found that students in classrooms with the most window area or daylighting produced 7% to 18% higher scores on the standardised tests than those with the least window area or daylight (Heschong, 2002) [2].

According to the study, increased daylight is estimated to reduce the need for artificial lighting by 16-20%, depending on the location and orientation of the house. In LichtAktiv Haus in Germany, the electric lighting used in the kitchen and living room shows a significant tendency of being affected by the interior daylight level; the lights are typically switched on before sunrise and after sunset. Temporal map of lighting use in the kitchen (2012) [Fig.3.04], showing time of sunrise (blue) and sunset (red). Lighting use and sunrise/sunset depends on local time, which accounts for Daylight Saving Time (DST). There is a reasonable correlation between high daylight level and switching probability, while outside weather, the day of the week has less impact (e.g. family with children).

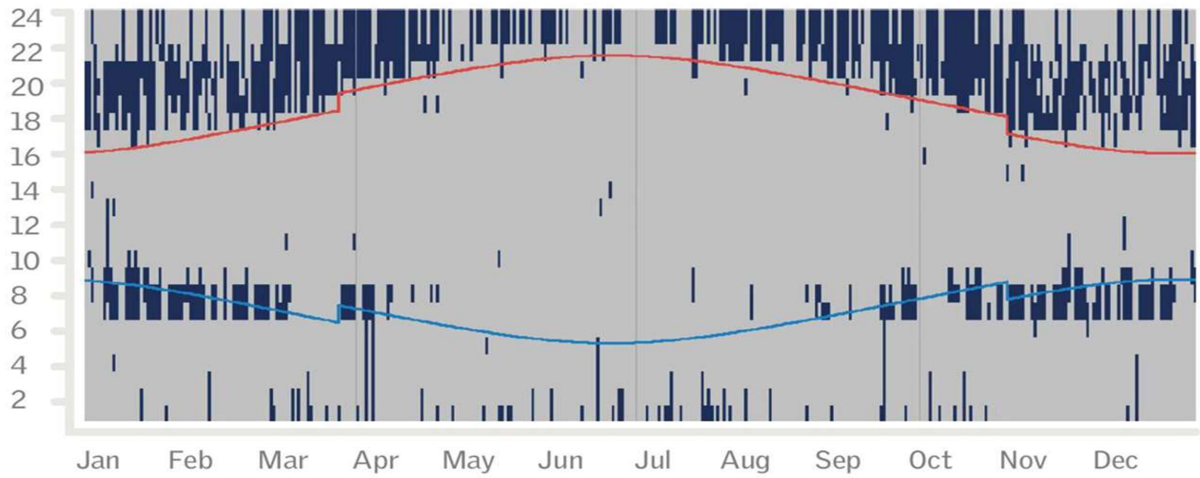


***Fig 3.04** [Temporal map of lighting use in the kitchen (2012) [2]]*

In non-residential buildings, recommended illumination levels are defined for the spaces they illuminate. Guidelines and recommendations for light levels exist for communal residential buildings but not for single-family houses. Global electricity consumption for lighting with current socio-economic trends and policies is projected to rise [Fig.3.05]. The actual growth will depend on demand for artificial light and the efficiency of lighting technologies, just two of the factors influencing increased consumption (IEA, 2006). [2]

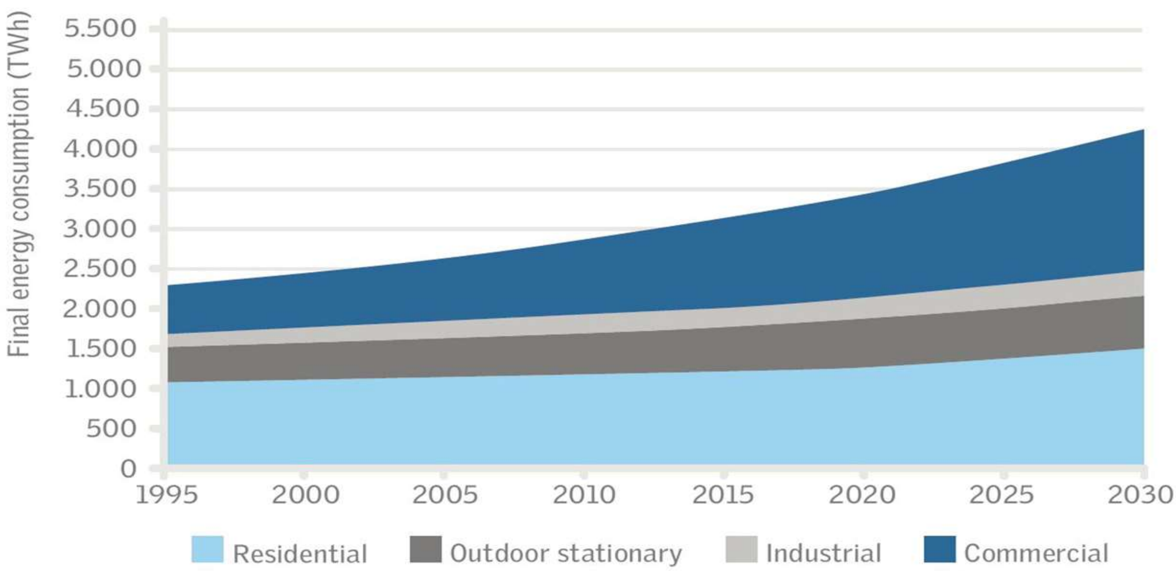


***Fig 3.05** [Projected rise in Global electricity consumption[2]]*

4.0 LITERATURE STUDY:

4.01 Regulations and Practice across the World

Building codes and regulations are intended to safeguard the health, safety, and welfare of building occupants. In practice, it is evident that daylighting can reduce not only electric energy used for lighting but also lower and displace peak-demand, and at the same time the heat-cooling loads. Despite the energy benefits, daylighting is not yet a mainstream energy saving strategy within the building industry, at least not an enforceable tool of practice in Indian sub-continent, whereas the similar implementations already started globally as discussed in the literature study.

"*During construction of new or renovation of existing buildings, an optimum use must be made of direct insolation to make the above mentioned economic savings during the use of the building. In addition, it is advisable, and in many countries specified by law, to take into account the influence of the project on neighbouring buildings. Thus in some countries, including the United Kingdom, the "right of light" has been specified in national regulations. According to this right, new buildings can not be built if they block direct access to sun rays to the existing buildings*." [11]

4.01.01 Regulations in United Kingdom [11]

In the UK, the significance of natural lighting was recognised for the first time in 1832 when appropriate provisions were introduced in the scope of *the Prescription Act* [12]. According to this Act, each owner is guaranteed the right to light after twenty years of existence of a residential building, i.e. after thirty years of existence of an office building. This Act protects the rights of each resident with respect to inadequate construction on neighbouring plots that would prevent direct insolation.

The law on the right to light was revised on 16 July 1959 when the "Right of light Act, 1959 was passed [13]. This modification has clearly defined the "Rule 45" which has become and integral part of all local bylaws and laws on construction in the United Kingdom. According to this rule, the construction is permitted until an imaginary line placed at an angle of 45° with respect to the existing wall from the centre of the neighbour's closest window [Fig.4.01]. This rule could also be applied only in case the existing building has been at the same position for an appropriate number of years. In this respect, the limit for residential buildings was changed from 20 to 27 years, while it remained the same, i.e. 30 years, for office buildings.

Although today the "Rule 45" is no longer officially in force, it is still often used for settling out-of-court disputes in the United Kingdom, simply because it can easily be implemented. According to latest legal modifications introduced in 1990 by means of the Town and Country Planning Act 1990, Section 237 [14], the principle of "50:50" has been adopted as an official rule for protection of the right to light. This rule for measuring the level of light implies calculation of the percentage of the room's area that can benefit from adequate lighting. The calculation is conducted for a working area that is 85 cm away from the floor level. It is considered that a point receives a sufficient quantity of light if it receives 0.2 percent of the external intensity of light. Therefore, this process is considered disrupted, and the basic right to light is violated, if less than 50 percent of the working area receives less than 0.2 percent of the external intensity of light. However, as of 2010, some bigger cities have succeeded in easing provisions of the existing law in cases when a newly constructed building is considered to be of significant social or economic benefit to the local community.

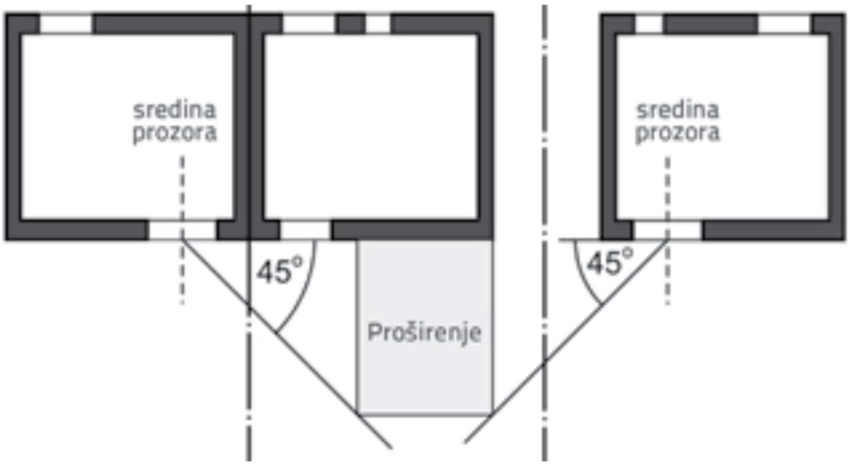


Fig 4.01 *[Construction rule "45" [11]]*

4.01.02 Regulations in Poland [11]

In compliance with the construction law of the Republic of Poland adopted on 7 July 1994, [15] the Ministry of Infrastructure has passed the "Byelaw on construction with technical requirements for buildings" [16] . Rules for construction of new buildings, specifically pertaining to the use of direct sunlight by buildings, are defined more closely in Section 2 "Lighting and sunlight", Paragraph 60, of this Byelaw. According to the Byelaw, public buildings such as kindergartens, hospitals, and schools must have a minimum of three hours of direct insolation during the equinox, on 21 March or 21 September, in the period from 8 a.m. to 4 p.m. In case of residential buildings, direct insolation of the living room must be ensured for at least 3 hours on the equinoctial days, in the period from 7 a.m. to 5 p.m. Exceptions can be made for buildings located in the centre of the cities. During construction of new buildings, care must be taken that neighbouring building get fifty percent less insolation, i.e. 1.5 hours on equinoctial days. In case of residential buildings, these requirements would have to be met only for apartments with more than one bedroom. Polish regulations do not specify computer programs to be used for this kind of solar analysis. An appropriate example of the solar analysis made in Poland is the town of Szczecin where the analysis was made by the design office "W+architekci" using the computer program "SketchUp" [Fig.4.02], prepared for 21 September, for the period from 7 a.m. to 5 p.m. [11].

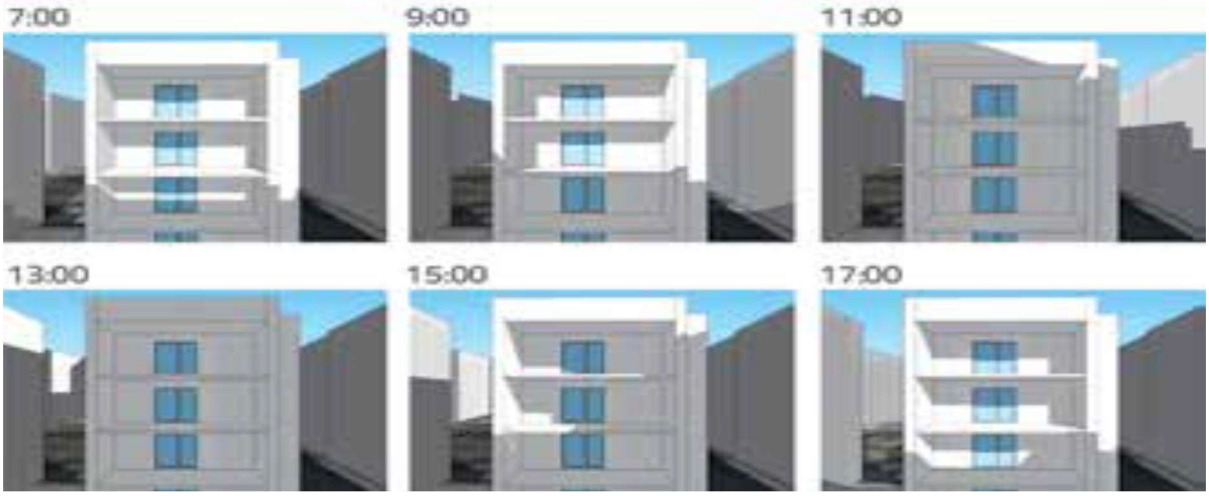


***Fig 4.02** [Solar analysis of a building in Szczecin, Poland [11]]*

4.01.03 Regulations in U.S.A. [11]

In the USA, there are no laws, either on the federal level, or on the level of individual states, that would regulate construction of new buildings, and influence of their shadows on the existing buildings. This area is in fact regulated by byelaws and laws passed on the local or municipal level. However, here the attention is paid only to the protection of open spaces, historic and cultural resources, and natural areas, against shadows of newly constructed buildings.

The Department of Energy acting in the scope of the US Government is inter area concerned with problems related to shadows created by newly designed buildings. This Department of Energy provides recommendations for the construction, and offers computer programs for analysing the influence of sun and shadows.

New York

The rules on acceptable shadows occurring during construction of new buildings are defined in Chapter 8 (Shadows) of the Code of the Mayor's Office for Environmental Coordination of the City of New York . This document contains provisions aimed at preserving the existing insolation of public spaces, parks and significant buildings. According to this Code, the influence of shadows has to be analysed during the construction work only if new buildings are more than 15 m higher than the existing ones, or if parts added to existing buildings are higher than 15 metres. In case of intervention on a building situated on the side opposite to the spaces that are considered significant for protection, then the analysis of the influence of shadows must be made regardless of the change in height.

In cases when shadows have to be analysed, the work starts with preliminary assessment [Fig.4.03] in order to determine whether the shadow of the building can reach sensitive spaces in its surroundings during the entire year. The preliminary assessment implies consultation of the layout plan so as to identify the spaces surrounding the newly planned building that can be actually attained by shadows. The limit of this area is situated at the end of the longest shadow that can be created by the building during the entire year, for the period of winter solstice on 21 December. It is considered that this shadow will be 4.2 times greater than the height of the future building. As New York is situated in the Northern Hemisphere, a triangular part of the area will constantly be insolated. A part to be shadowed is situated from -108° to 108°, viewed from the north direction.

The next stage of verification, if needed, implies a detailed solar analysis using an appropriate computer program such as: Sketchup, Autodesk's AutoCAD, 3ds Max, AutoDesSys' FormZ, and Bonzai3d. According to the Code, a whole day analyses must be made for: 21 June, 6 May, 21 March, and 21 December. The analysis has to be made for the period that starts 1.5 hours after the sunrise and lasts until 1.5 hours prior to sunset. This analysis is formed of two parts, the first being the solar analysis on the layout plan [Fig.4.04] , while the second analysis may imply an extremely detailed analysis using the 3D model of the entire area [Fig.4.05] . The approval for construction work can be obtained if the detailed analysis shows that the shadow does not cover critical areas for more than 10 minutes. If this is not the case, a project correction must be made.

Fig 4.03 *[Preliminary assessment of shadows [11]]*

Fig 4.04 *[Shadow of the future building analysed on the layout plan [11]]*

Fig 4.05 *[Shadow of the future building analysed on the 3D model of the site [11]]*

San Francisco

The Code of the San Francisco Planning Department is yet another interesting example from the USA about regulations concerning influence of shadows of newly built buildings on the existing ones . Detailed rules which are related, just like in New York, solely to the protection of public surfaces, parks and cultural & historic buildings and spaces, are presented in Chapter III, Article III, Shadows . These rules are exactly the same as those relating to New York except for the part about the time in which an area can be under shadow, which is 45 minutes in this particular case.

4.01.04 Regulations in Austria

In Austrian regulations, there are no laws that would regulate construction of new buildings and influence of their shadows on existing buildings. However, in big cities, this area is regulated by byelaws or codes. One of such codes is the Construction Code of the City of Vienna. In this Code, proper care is taken not to compromise direct insolation of existing buildings or significant public spaces by construction of new buildings. According to the Code, the allowable height is regulated on the basis of simple principles developed by studying position of sun during the year in the city of Vienna. Thus it is indispensable to ensure that newly constructed buildings do not block the sunlight, by their average shadow, to ground-floor windows of existing buildings. This rule does not apply to buildings situated on the north side an average 45-degree orientation of the shadow with respect to the horizontal plane is obtained according to expression (1), and a more detailed account is shown in [Fig.4.06]. Besides limiting the building height, these shadow orientations also define the maximum pitch of roofs of new buildings.

$$H = a+p \tag{1}$$

$$H=\frac{a}{\cos 30}+p \tag{2}$$

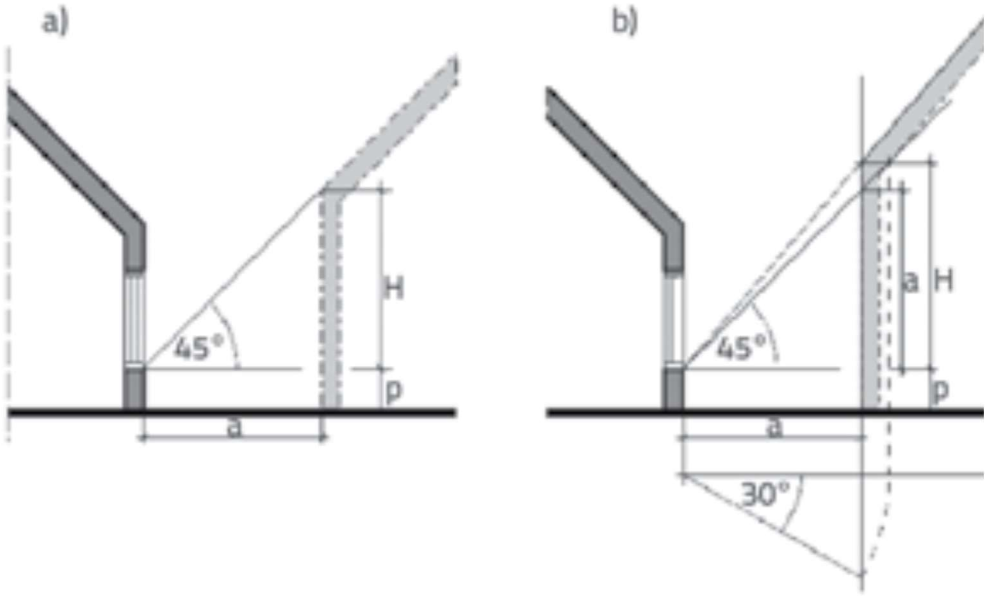


Fig 4.06 *[Diagram of allowable building height in Vienna]*

4.01.05 Regulations in Austria Southern and Eastern Europe

In the legislation of the Republic of Serbia, there are no strict national-level rules that would regulate the control of shadows cast on existing buildings, due to construction of new ones. Only one sentence can be found in the Byelaw on General Conditions on Plot Definition and Construction, and on the Content, Conditions and Procedure for the Delivery of the Act on Town Planning Conditions for Buildings for which Construction Permits are Delivered by District of Municipal Authorities: "a detached multistorey building must not prevent direct insolation of an another building for more than one half of total duration of direct insolation". The following sentence is included in some planning documents, such as the plan for the detailed regulation of a part of the central zone of the Vračar Municipality, Article 2.6, Conditions for Protection of Living Environment: "construction of planned buildings must not greatly reduce insolation and lighting of residential rooms of existing buildings". In this way, an emphasis is placed on the significance of daylight, but no detailed definitions and rules are given as to potential "more significant" reduction of insolation and lighting.

In Croatia, Bosnia & Herzegovina and Montenegro, there are no national-level regulations or laws that regulate construction of new buildings from the standpoint of protection of existing building against shadows of the new built ones. However, at local, municipal, and district levels, some very scarce provisions - emphasizing the need to take into account shadows - can be found in town planning documents. For instance, in the detailed development plan for Polje-Zaljevo in the Bar District, in Montenegro, the following is indicated in Section 3.6, Conditions for Development and Protection of Living Environment: "new buildings should be positioned so as not to reduce the amount of insolation and daylight to apartments situated in existing neighbouring buildings".

Byelaws and other regulatory documents passed in Serbia and other countries in the region contain regulations on the distance between newly constructed buildings and existing ones, but mostly from the safety aspect, as a protection in case of building collapse. The following is specified in Article 40 of the development plan for Kukljica District in Croatia: "the building should be located within the plot in such a way that the minimum distance from the neighbouring building plot and from the access road amounts to one half of the building height". The following is indicated in Article 12 of the urban development plan for the Ravna Gora District in Croatia: "the smallest distance of the building from the neighbouring buildings amounts to ½ of the building height (h/2), but shall amount to no less than 4 meters from the edge of the buildable plot". The following provisions are contained in the detailed block regulation plan for the Čukarica District in Belgrade, Serbia: "The distance between a building and a neighbouring building in open urban blocs, with respect to the facade with residential rooms, amounts to one height of the taller building. With respect to the façade with accessory rooms, this distance amounts to one half of the height of the taller building. The minimum distance for a detached building is defined with respect to the neighbouring building, and it amounts to no less than 2/3 of the height of the taller building. The distance can be reduced to 1/3 of the height of the taller building if buildings do not have windows of residential rooms, offices, and ateliers, on side facades". The following is indicated in the Byelaw on General Conditions on Plot Definition and Construction, and on the Content, Conditions and Procedure for the Delivery of the Act on Town Planning Conditions for Buildings for which Construction Permits are Delivered by District of Municipal Authorities: "The distance between detached multistorey houses and buildings that are built in an interrupted row amounts to no less than one half of height of the taller building. This distance can be reduced to one quarter if buildings do not contain windows of residential units, ateliers and offices on side facades. This distance can be no less than 4.0 m, if one of the building walls contains openings that provide daylight".

4.02 Regulations based on Daylighting Tools

There is increasing evidence suggesting that meeting the illuminance requirements alone does not necessarily guarantee the success of a design solution, and that illuminance should not be the only predominant requirement while designing with Daylight. The nature of daylight source further complicates standardization. It is dynamic, constantly changing in terms of intensity and colour properties, unpredictable and unreliable.

As the daylight itself is dynamic in nature, for illuminance-based legislation shall deal not only with illumination levels but also with their duration within a space. Legislation pertaining to daylighting has been expressed in several forms varying from one country to another, as we found in earlier chapter. In this chapter, we will study the review of Mohamed Boubekri on the various forms in which such legislations are expressed and will identify the limitations of these forms of expression.[17]

4.02.01 Standards based on Illuminance

In the United States for example, the Building Officials and Code Administrators International, Inc, (BOCA) National Building Code stipulates the following:

“the standard for natural light for all habitable and occupiable rooms shall be based on 250 footcandles (2691 lux) of illumination on the vertical plane adjacent to the exterior of the light-

transmitting device in the enclosure wall and shall be adequate to provide an average illumination of 6 footcandles (64.58 Lux) over the area of the room at a height of 30 inches (762 mm) above the floor level." [17]

According to BOCA officials, such illuminance levels must be supplied to all habitable spaces except for crawl spaces underneath buildings or in the attics. These levels need not necessarily be supplied by natural light, but can be provided by electric light sources as well.

In contrast, the Department of Public Works of Canada recommends an average daylight level of 200 lux along the perimeter of the office space at a depth of 3 meters for 80% of business hours during a regular 8 AM to 5 PM schedule (Archer, 1998 and Wotton, 1998). However, these are only recommended levels not enforceable by law.

In France, requirements for lighting of workplaces can be found in the Decret no. 83-722 of August 2, 1983 concerning general lighting and Lettre-circulaire DRT no. 90/11 of June 28 1990 relative to daylighting and the provision of view towards the outdoors.

The Decret no. 83-721 fixes minimal general illuminance levels to be observed in 4 four different types of interior spaces and two types of exterior spaces [Table 1]. It is made explicitly clear in this Decret that these daylight levels are intended to be minimal values in space and in time. On other words, they must be met at any given point in the room and at any given time all the time.

Table 1: *Recommended illuminance levels as prescribed by Circulaire DRT no. 90/11*[17]

Type of activity	Decreed Level [lux]	I.A.M.* [lux]
Interior circulation space	40	70
Stairs and storage	60	110
Workplaces, dressing rooms, and bathrooms	120	210
Windowless spaces used for work	200	350
Exterior circulation space	10	20
Exterior spaces where permanent work is performed	40	70

* Initial Average Illuminance: these are initial levels during start up phase of the lighting system. These tend to be higher then the decreed levels due to lamp lumen Depreciation, that takes place over time.

Daylight levels are not described as being mandatory but preferred or recommended. Lettre-circulaire DRT no. 90/11 of June 28 1990 relative to daylighting stipulates the following:

"in general and for new construction, daylight coming from side and overhead apertures must be usable in workspaces, but there aren't any minimal levels that are required".

It is however much more explicit when it comes to the provision of views:

"Spaces destined for work must have transparent apertures at eye level with view towards the exterior, unless windows are incompatible with the type of activity in that taking place in that space. Interior workstations must be protected from unwanted direct solar radiation…"

In Germany, the DIN 5034-4 standard provides recommendations for daylight. Tasks are not sorted based on their nature, but on their degree of difficulty or duration [Table 2]. The standard considers daylight provision as good practice but not a requirement.

Table 2: *Recommended Daylight levels per degree of difficulty of visual task in the German DIN 5034-4 Standard.* [17]

Stage	Daylight Illuminance (Lux)	Visual task
1	15	Temporary task
2	30	
3	60	Easy task
4	12	
5	250	Normal Task
6	500	
7	750	Difficult Task
8	1000	
9	1500	Very Difficult Task
10	2000	
11	3000	Very Special Task
12	5000 and more	

4.02.02 Daylight-Factor-Based Standards

The Daylight Factor (DF) is defined as the percentage of horizontal indoor illuminance in relation to the outdoor illuminance on the ground under a CIE (Commission Internationale de l'Eclairage) overcast sky condition. DF-based legislation does not target a specific daylight illuminance level in the room because of constantly changing outdoors conditions, but rather a percentage of whatever is available outside. An example of such legislation can be found in France. The 1997 Cahier des Recommendations Techniques de Construction of the French Ministère de l'Education (Minitère de l'Education, 1977) recommends a Daylight Factor at a minimum of 1.5% under overcast sky conditions in classrooms.

In the UK during the post-war era, government regulation prescribed a minimum Daylight Factor of 2% in classrooms. This regulation was subsequently dropped, as it became apparent that it is not always possible to meet the 2% target from windows on only one side of the room. Otherwise, windows would have to be so large that they may have caused other problems, such as overheating in the summer, excessive glare or other kinds of visual discomfort. There is currently no real daylighting legislation in the UK of any kind but only a set of recommendations established by the Building Research Establishment (British Standard 8206, 1982) and there is some flexibility in the way planners and architects use these recommendations in zoning and site planning. If planners think a site is over developed they might request a daylighting and sunlighting study on surrounding properties. In the UK, a 27% Vertical Sky Component opening is recommended as an acceptable level of light that a window should receive. This level is based on a window looking across a 12 meter-wide-street at an average terraced house with ground and first floor levels. Within an inner city center, the 27% Vertical Sky Component cannot always be applied. Therefore, these standards are applied mainly to residential buildings, assessing only habitable rooms, such as living rooms, dining rooms, studies, kitchens, and bedrooms. Although the guidelines suggest all buildings are susceptible to the daylighting test, in reality this is rarely done.

4.02.03 Window-Size-Based Legislation

The most frequently used type of legislation that relates, albeit indirectly, to daylighting is the requirement of windows for various types of spaces. Such practices, however, do not specifically seek to supply spaces with daylight but rather provide means of egress and ventilation.

An example of such legislation can be found in the UK. The British Code BR 8206 (Part 2) recommends that windows should be, at a minimum, 20% of the external window wall for room measuring less than 8 meters in depth and 35% of the external wall for rooms deeper than 14 meters (Department of the Environment, 1971). In offices windows should be 35% of exposed wall area and in institutional buildings, 25% of the total area of the exterior walls (Littlefair, 1999).

In Germany, the standard DIN 5034-4 Daylight in interiors- Simplified regulation for minimum window sizes is more comprehensive as it is more fitting and specific to daylight supply and the role of window as a daylight source. The standard prescribes recommended window sizes for good practice of daylighting given various room dimensions [Table 3].

The Building Code of Australia has a10% floor area requirement for habitable rooms in residential buildings (Australia DCP, 2002). In Japan, regulations for windows provision concern only buildings of continuous occupancy such as houses, schools, or hospitals. Industrial and office buildings are not considered to fit this category of continuous occupancy; as a result, there are no minimum window size requirements for them. Article 28 of the Japanese building code stipulates that habitable rooms of continuous occupancy buildings shall have window sizes no less than 14% or 1/7 of the total floor area in a house and between 20% and 40% of the floor area in other types of buildings. Article 19 of the Japanese Building Standard Law Enforcement Order also prescribes the criteria of the opening ratio. Article 20 of the same code prescribes the method of calculating the effective aperture area.

In the US, the BOCA national Building Code specifies that:

"every room or space intended for human occupancy shall have an exterior glazing area of not less than 8% of the total floor area. Natural light shall be provided by glazing areas that open onto courts or yards (as required by the code) or by other approved means (section 704.2). Similarly, where natural light for rooms and spaces is provided through an adjacent room, the opening within the wall separating these two spaces must also be no less than 8% of the total floor area of the room (Section 704.2)"

(BOCA, 1990).

Table 3: *Recommended window sizes for daylighting in the German DIN 5034-4 standard*

Distance between window and opposite building (m)	Ceiling height (m)	b (m)	Minimum window width given a room depth (m)					
			3.00- 6.25 (m)	6.50 (m)	6.75 (m)	7.00 (m)	7.50 (m)	8.00 (m)
15	2.80 (h_F = 1.65)	2.00	1.31	1.31	1.34	1.42	1.57	1.73
		2.50	1.64			1.64	1.78	1.97
		3.00	1.97			1.97	1.99	2.21
		3.50	2.30				2.30	2.45
		4.00	2.63				2.63	2.70
		4.50	2.96					2.96
		5.00	3.29					3.29
		5.50	3.62					3.62
		6.00	3.94					3.94
		6.50	4.27					4.27
		7.00	4.80					4.60
		7.50	4.93					4.93
		8.00	5.26					5.26
15	2.90 (h_F = 1.75)	2.00	1.31	1.31	1.31	1.32	1.46	1.61
		2.50	1.64			1.64	1.65	1.82
		3.00	1.97				1.97	2.04
		3.50	2.30					2.30
		4.00	2.63					2.63
		4.50	2.96					2.96
		5.00	3.29					3.29
		5.50	3.62					3.62
		6.00	3.94					3.94
		6.50	4.27					4.27
		7.00	4.80					4.60
		7.50	4.93					4.93
		8.00	5.26					5.26

h_F = Window height
b = Room width
Source: http://www.bauphysik.de/lehre/fh-rosenheim-kr/Tageslicht_Ro.pdf

4.02.04 Solar Zoning Legislation

Solar access ordinances are one of the most important legislative aspects of building regulation that affect daylight in building. While this type of legislation does not guarantee or prescribe a certain level of natural light inside a building, but it is a necessary first step to ensure that there is enough daylight around a building and enough exposure of building facades to the sky.

Zoning and access to sunlight legislation typically is the domain of local and municipal ordinances and can vary widely because of various factors. With the realization that access to sunlight is not just an amenity, but rather a health issue, several countries and municipalities around the world have adopted clear guidelines and requirements for solar access.

In the US, the concept of daylight legislation is rooted in the 1916 Zoning Ordinance of New York City, one of the first cities in the US to ever have provisions for solar access. Applied to districts or zones, this ordinance restricted the use of height and bulk of buildings by using the concept of a zoning envelope for the building. This legislation was designed to protect access to daylight and air in Manhattan street canyons by restricting the maximum mass that could be constructed on a given site. The concept of zoning envelope resulted in wedding-cake-shaped buildings the then signature of Manhattan's architecture. Since its creation, the 1916 zoning ordinance has seen several alterations due to political and economical forces.

Another US example of strict zoning ordinance for access to sunlight is the city of San Francisco's Proposition K. This ordinance, known as the "sunlight ordinance," was voted in 1985 (Phillips, 1985; Kwartler and Masters 1984). Proposition K mandates year round, all day sun access to open spaces and parks within the city and on selected streets.
It would appear that early zoning ordinances in the U.S. had laid adequate groundwork for the protection of the right to access to sunlight. In 1959, however, a plaintiff sought injunction against a neighbour who was obstructing sun on his property. The court decided against the plaintiff, and in doing so set legal precedent that solar access is not a constitutional right (Knowles, 1979).

In Japan, zoning ordinances pertaining to solar access were established later than the early U.S. municipal initiatives like the 1916 New York City ordinance. For example, the 1977 Japanese Building Standard Act allowed municipalities to deny permits to buildings over a certain height that cast shadow more than a certain number of prescribed hours (Koga and Nakamura, 1998; Julian, 1998).

4.02.05 Preference of Sunlight

Numerous surveys conducted around the world have evidenced people's preference for sunlight in their homes and workplaces. It is argued that the desire for sunlight is subject to the type of climate. That is, people in cold climates may have stronger desire for sunlight penetration than those in milder or warmer climates. One of the main reasons for the desire for sunlight is that it produces sensations of warmth and pleasantness (Hopkinson et al., 1965). However, complaints about sunlight's negative effects are numerous and are mainly centered on the visual and heating discomforts caused by sunlight. (Ne'eman, et al., 1976). The positive emotional, psychological and health benefits, that sunlight create, are often in direct conflict with the visual discomfort that it can also cause. However, peoples' overall preferences for degrees of sunlight presence in their indoor environments have yet to be transformed into codes that would require certain amounts of sunlight penetration for certain durations in building interiors. One of the elements that compound the complexity of this issue is the question of how to measure the intrusion of sunlight inside a building both quantitatively and qualitatively.

Surveys assessing people's preference for sunlight have lead to recommendations for the duration of penetration usually expressed usually in hours per day per season without reference to how much sunlight should be admitted inside the room. These recommendations forget the visual and qualitative effects caused by sunlight such as veiling reflections and the glare. The excessive intrusion of sunlight can impede the visual quality of the space. Current lighting standards do not deal adequately with excessive light levels as they are designed to meet minimum requirements for visual task performance. One study, however, introduced a unique way for assessing sunlight penetration in space by using the size of sunlit area in relation to the floor area of the room (Boubekri et al., 1991). Since illuminance levels are almost always met under sunlighting conditions, this study used occupants' response as the measurement instrument. The study established a causal relationship between varying degrees of sunlight penetrations and building occupants' emotional response measured on a well validated affective scale. The central questions being asked were whether small patches of sunlight (i.e. sparkles) are preferred to large floods and what the acceptable threshold of acceptance was. The proposed argument for using the emotional response as a gauge was that it significantly mediates building occupant's mood and, consequently, dictates their behavior (Mehrabian and Russell, 1974; Marans and Spreckelmeyer, 1981; Russell, 1980; Russell and Pratt, 1980).

4.02.06 Daylighting Recommended Practices

Several countries have recommended practices for daylighting. In the United States, the IESNA RP-5-99 latest Recommended Practice of Daylighting provides some basic design aides and strategies for controlling light levels and glare without prescribing any kind of indoor daylight illuminance levels for building interiors (IESNA, 1999). In other countries, these practices are more descriptive in terms of levels of daylight illumination suitable for building interiors. Table 4 illustrates a sample of recommended daylighting levels according to the 1982 British Draft Development DD 73 Standard (British Standard Institute, 1982). Data are provided in terms of electric lighting levels, electric glare index, whether daylighting should be the primary source of illumination (full) or only supplementary, the average daylight factor (DF) and the maximum glare index level (DGI) [Table 4].

Table 4: *Sample of lighting recommendations in workplaces in the UK.*

Activity/Space	Building Type	Artificial Lighting		Daylighting		
		Illuminance (Lux)	Glare Index	Type of Daylighting	Average DF (%)	G.D.I.
Formal teaching and seminars	Schools & Colleges	300 to 500	16 formal	A	5	21 formal
Deep (open) Plan teaching spaces	Schools & Colleges	300 to 500	19 seminar	B	2	23 seminar
Lecture theaters and examination halls	Schools Colleges Hospitals	500 (300 on desks)	16	A B	5 2	21
Music Rooms and music practice rooms	Educational recreational	300	19	A B	5 2	23
Offices (enclosed)	Offices Educational Factories Hospitals Banks Insurance Libraries	500 (300 on desks)	19	A B	5 2	23
Deep open plan offices	Offices Colleges Banks Others	500 to 750	19	A B	5 2	23
Drawing offices	Educational Offices Factories	500 to 750	19	A B	5 1 (in supplemented area)	21

4.03 Inference from the Study

In addition to the above standards and regulations, all countries have laws and regulations on energy efficiency of buildings. The problem with these energy efficiency standards and principles is that they do not take into account subsequent construction on neighbouring plots, which may prevent direct insolation and hence compromise the already conducted certification or functioning of the equipment installed in the building. The solution lies in the introduction of such laws and byelaws on the construction of new buildings that define the right of owners of existing buildings to continue benefiting from the level of direct insolation they had prior to construction of new buildings. Such laws are present to various extents and at different levels in legal documents of economically strong countries. Their common feature is that they all recognise significance of daylight and the right to the use of the amount of solar light that was guaranteed at the time the building was initially built. In big US cities a considerable attention is paid to the "right to light" of public buildings and public spaces, to the detriment of individuals and apartments. In some European countries, much attention is paid to private buildings. Evidently, there are always exceptions, justified by socioeconomic significance of new building projects in densely populated areas. The fact is that laws, regulations and byelaws of this type are indispensable in all regions of the world, and especially in developing countries. Clear and accurate definition of relevant legislation is needed so as to curb down and prevent abuse. The definition of national laws is indispensable because a similar influence is exerted on all citizens, and as the of right every individual to its part of solar light has to be protected.

This Study of standards and regulations related to Daylight indicates the deficiency of building codes regarding daylighting. There are not any existing daylighting standards that are enforceable by law at any country level. Legislation which mandates the minimum window sizes for different types of spaces cannot be considered as the daylighting legislation. For most cases, window size legislation is meant as means of egress and ventilation in case of fires and emergencies.

Several countries have some recommended practices for daylighting but none of them or make it mandatory. Daylighting legislation should prescribe it in the form of real light levels inside a room for certain duration throughout the day according to the season, the climate and the function of the space, to make it more credible.

This type of legislation that would mandate actual daylight levels to force the Architect or Designer to design their buildings and fenestration system such that it would meet the required daylight levels and daylighting calculations become necessary. Such legislation would inevitably push the limit of creativity and incite designers and architects to formulate the spaces, position and size building openings and select the proper optical properties of windows.

5.0 Daylighting System: Indian Guidelines

5.01 Geography of India:

India experiences a variety of climates ranging from tropical in the south to temperate and alpine in the Himalayan north. The Himalayas and the Thar Desert strongly influence the climate of the country. The Tropic of Cancer passes through the middle of the country, and this makes its climate more tropical. India is a big tropical country and is famous for its diverse climatic features. India has an extraordinary variety of climatic regions with a majority in cooling dominated climate zones. *"Traditionally and historically, buildings in India were designed with courtyards to bring daylight into the core of the buildings and overhangs that were appropriately sized to shade the interior from the summer sun. After the advent of the air-conditioning systems and electric light, buildings were accordingly designed to have artificial ventilation and lighting systems*" [18].

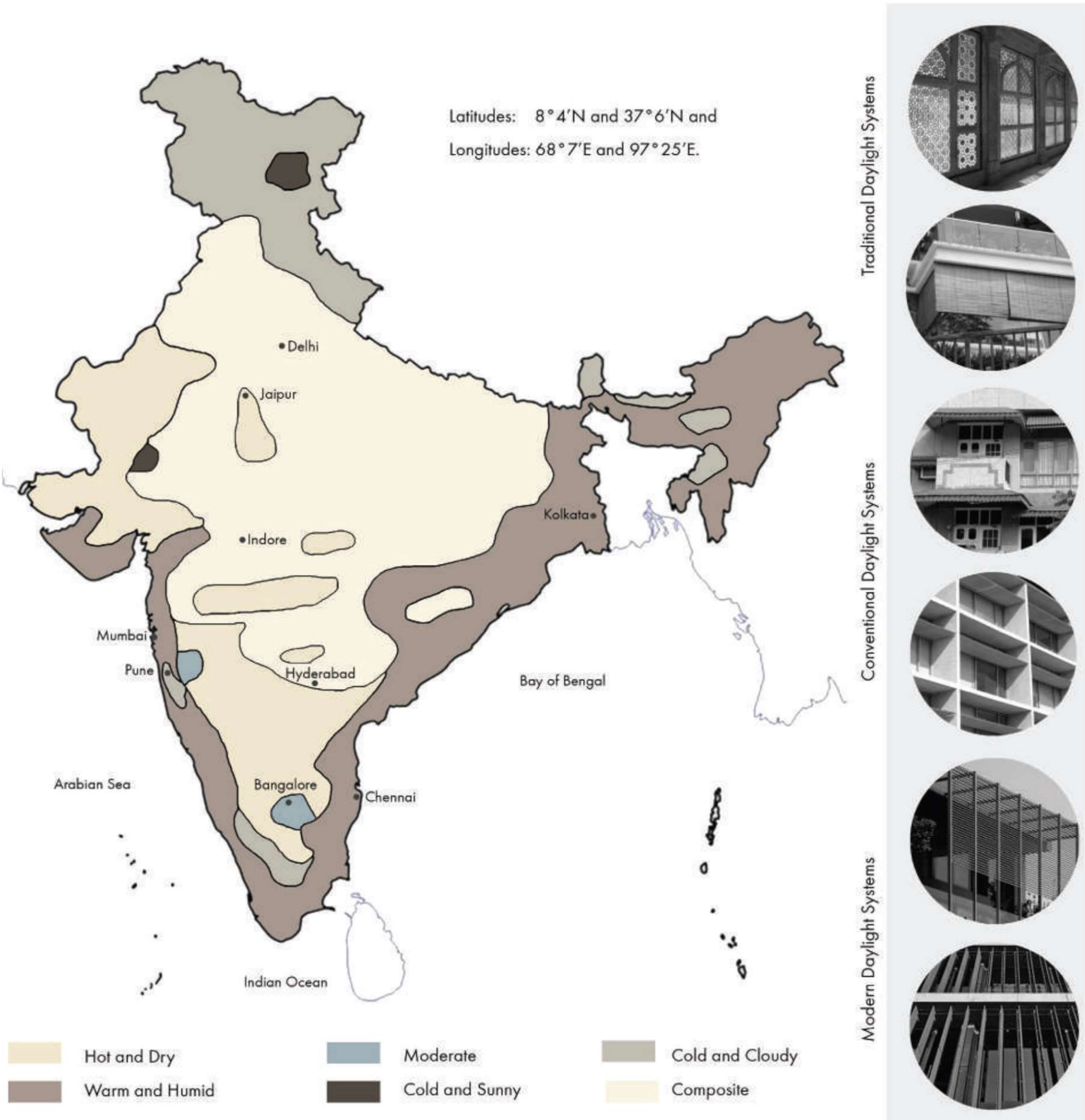


Figure 5.01: *Climatic zones of India and hierarchy of shading systems*

The daylight systems, in India, can be classified into three broad categories, i.e., traditional, conventional, and modern daylight systems as shown in [Fig 5.01]. We can get guidelines for designing and incorporating daylighting strategies in an Indian building form IS codes, and standards such as ECBC-R, NBC, and SP41. They cover the aspects of building orientation, fenestration size, position, height, and glazing treatments along with the form and dimensions of shading devices and the technical parameters confined with it, but in these manuals there is no specific list of daylight systems.

It is also important to understand that India being a culturally rich country has different styles of construction techniques and practices with aesthetical variations in buildings when it comes to local, traditional, and vernacular architecture. For example, massive screen with patterned form shading systems is mostly applied to vernacular building facades in hot climates to provide protection from direct sun and regulate social interaction. Thus, one may approach different practices of daylighting systems in different climatic locations in the country. [19]

There is no significant literature available in India that is completely devoted to daylighting for affordable housing with an understanding of the techno-economic performance evaluation of daylighting systems. The report by TERI [19] would help in understanding these strategies which are another step forward in providing daylit, user-friendly, energy-efficient building environment. It is important to understand that these systems need to be integrated into a building's overall architectural strategy and should be incorporated into the design process from its earliest stage. Size and position of fenestrations, type of shading device, nature of the material, and the surroundings together impact daylighting in a building.

5.02 National Building Code of India:

National Building Code (Part 8/Section 1) covers requirements and methods for lighting and natural ventilation of buildings. As pe the code, Illumination levels for different tasks are recommended to be achieved either by daylighting or artificial lighting or a combination of both. This Section, read together with Part 8 .Building Services, Section 2 Electrical and Allied Installations. of the Code, adequately covers the illumination levels required and methods of achieving the same. The portion of 4.2 of the Section 1, guidelines regarding the Daylight has been discussed.

As per the code, The light received by the earth from the sun consists of two parts, namely, direct solar illuminance and sky illuminance. For the purposes of daylighting design, direct solar illuminance shall not be considered and only sky illuminance shall be taken as contributing to illumination of the building interiors during the day. The relative amount of sky illuminance depends on the position of the sun defined by its altitude, which in turn, varies with the latitude of the locality, the day of the year and the time of the day, as indicated in [Table 5]. The external available horizontal sky illuminance (diffuse illuminance) values which are exceeded for about 90 percent of the daytime working hours may be taken as outdoor design illuminance values for ensuring adequacy of daylighting design. The outdoor design sky illuminance varies for different climatic regions of the country. The recommended design sky illuminance values are 6 800 lux for cold climate, 8 000 lux for composite climate, 9 000 lux for warm humid climate, 9 000 lux for temperate climate and 10 500 lux for hot-dry climate. For integration with the artificial lighting during daytime working hours an increase of 500 lux in the recommended sky design illuminance for daylighting is suggested.

Table 5 *Solar Altitudes (to the Nearest Degree) for Indian Latitudes*

Period of Year	22 June						21 March and 23 September						22 December					
Hours of Day (Sun or Solar) Latitude	07 00 17 00	08 00 16 00	09 00 15 00	10 00 14 00	11 00 13 00	12 00 —	07 00 17 00	08 00 16 00	09 00 15 00	10 00 14 00	11 00 13 00	12 00 —	07 00 17 00	08 00 16 00	09 00 15 00	10 00 14 00	11 00 13 00	12 00 —
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
10°N	18	31	45	58	70	77	15	30	44	59	72	80	9	23	35	46	53	57
13°N	19	32	46	60	72	80	15	29	44	58	70	77	8	21	33	43	51	54
16°N	20	33	47	61	74	83	14	29	43	56	68	74	7	19	31	41	48	51
19°N	21	34	48	62	75	86	14	28	42	55	66	71	5	18	29	48	45	48
22°N	22	35	49	62	75	89	14	28	41	53	64	68	4	16	27	36	42	45
25°N	23	36	49	63	76	88	13	27	40	52	61	65	3	14	25	34	39	42
28°N	23	36	49	63	76	86	13	26	39	50	59	62	1	13	23	31	37	39
31°N	24	37	50	62	75	82	13	25	37	48	56	56	—	11	21	28	34	36
34°N	25	37	49	62	73	79	12	25	36	46	53	56	—	9	18	26	31	33

Daylight Factor:

The daylight factor is dependent on the sky luminance distribution, which varies with atmospheric conditions. A clear design sky with its non-uniform distribution of luminance is adopted for the purposes of design. Daylight factor is the sum of all the daylight reaching on an indoor reference point from the following sources: a) Direct sky visible from the point, b) External surfaces reflecting light directly to the point, c) Internal surfaces reflecting and inter-reflecting light to the point. The daylight factors on the horizontal plane only are usually taken, as the working plane in a room is generally horizontal; however, the factors in vertical planes should also be considered when specifying daylighting values for special cases, such as daylighting on classrooms, blackboards, pictures and paintings hung on walls.

Sky Component:

Sky component for a window of any size is computed by the use of the Table [Table 6,7 and 8].

a) The recommended sky component level should be ensured generally on the working plane at the following positions:1) At a distance of 3 m to 3.75 m from the window along the central line perpendicular to the window, 2) At the centre of the room if more appropriate and 3) At fixed locations, such as school desks, blackboards and office tables.

b) The daylight area of the prescribed sky component should not normally be less than half the total area of the room.

The values obtainable from the tables are for rectangular, open unglazed windows, with no external obstructions. The values shall be corrected for the presence of window bars, glazing and external obstructions, if any. This assumes the maintenance of a regular cleaning schedule. The three sky component tables are as given below. All the tables are for an unglazed opening illuminated by the clear design sky.

a) Table 6 . Percentage sky components on the horizontal plane due to a vertical rectangular opening for the clear design sky.
b) Table 7 . Percentage sky components on the vertical plane perpendicular to a vertical rectangular opening for the clear design sky.
c) Table 8 . Percentage sky components on the vertical plane parallel to a vertical rectangular opening for the clear design sky.

The values tabulated are the components at a point P distant from the opening on a line perpendicular to the plane of the opening through one of its lower corners, and *'l'* and 'h' are the width and height respectively of the rectangular opening [Fig 5.02]. Sky component for different h/d and l/d values are tabulated, that is, for windows of different size and for different distances of the point P from the window. By suitable combination of the values obtained from the three tables, for a given point for a given window, the sky component in any plane passing through the point may be obtained.

Method of using the Tables to get the sky component at given point is explained with help of the following example. It is desired to calculate the sky component due to a vertical window ABCD with width 1.8 m and height 1.5 m at a point P on a horizontal plane 3.0 m from the window wall located as shown in the [Fig 5.02]. Foot of the perpendicular N is 0.6 m below the sill and 0.9 m to the left of AD.

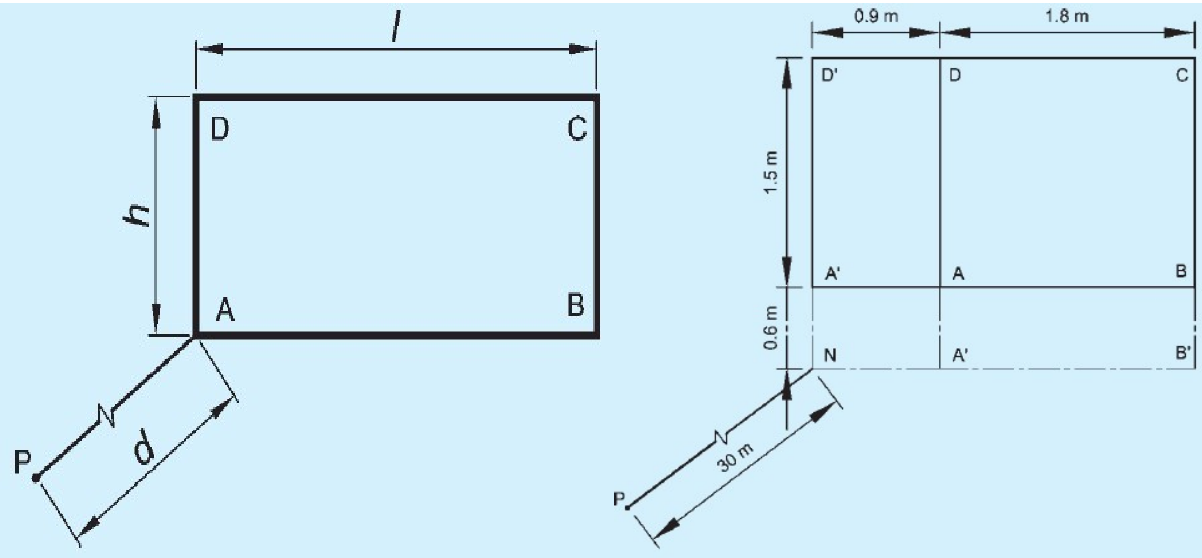


Figure 5.02 *[Sky Component Calculation Diagram]*

Consider ABCD extended to NB'CD'

1) For NB'CD'
l/d = (1.8 + 0.9)/3 = 0.9 h/d = (1.5 + 0.6)/3 = 0.7 F1 = 5.708 percent (from Table 6)

2) For NA'DD'
l/d = 0.9/3 = 0.3 h/d = (1.5 + 0.6)/3 = 0.7 F2 =2.441 percent (from Table 6)

3) For NB'BA'

l/d = (1.8 + 0.9)/3 = 0.9 h/d = 0.6/3 = 0.2 F3 = 0.878 percent (from Table 6)

4) For NA'AA'

l/d = 0.9/3 = 0.3 h/d = 0.6/3 = 0.2 F4= 0.403 percent (from Table 6)

Since ABCD = NB'CD' - NA'DD' - NB'BA' + NA'AA'

Sky Component, F = F1 - F2 - F3 + F4

= 5.708 - 2.441 - 0.878 + 0.403

= 2.792

***Table 6**: Percentage Sky Components on the Horizontal Plane Due to a Vertical rectangular opening for the clear design sky*

l/d	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	3.0	4.0	5.0	10.0	INF
h/d																									
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
0.1	0.036	0.071	0.104	0.133	0.158	0.179	0.198	0.213	0.225	0.235	0.243	0.250	0.256	0.261	0.264	0.268	0.270	0.272	0.274	0.276	0.284	0.286	0.287	0.288	0.288
0.2	0.141	0.277	0.403	0.516	0.614	0.699	0.770	0.829	0.878	0.918	0.950	0.977	0.999	1.018	1.033	1.046	1.056	1.065	1.072	1.079	1.110	1.118	1.122	1.125	1.125
0.3	0.300	0.589	0.859	1.102	1.315	1.499	1.653	1.782	1.888	1.976	2.048	2.108	2.157	2.197	2.231	2.259	2.282	2.302	2.318	2.333	2.401	2.421	2.429	2.436	2.437
0.4	0.460	0.905	1.322	1.702	2.041	2.337	2.590	2.804	2.984	3.134	3.258	3.361	3.446	3.516	3.574	3.623	3.664	3.699	3.728	3.753	3.873	3.909	3.922	3.935	3.937
0.5	0.604	1.189	1.741	2.247	2.700	3.099	3.444	3.740	3.992	4.204	3.383	4.553	4.659	4.765	4.853	4.928	4.990	5.043	5.088	5.126	5.312	5.366	5.387	5.408	5.410
0.6	0.732	1.443	2.114	2.732	3.289	3.781	4.211	4.582	4.900	5.171	5.401	5.596	5.761	5.901	6.020	6.121	6.208	6.281	6.344	6.397	6.661	6.739	6.769	6.798	6.802
0.7	0.844	1.665	2.441	3.159	3.808	4.385	4.891	5.330	5.708	6.034	6.311	6.548	6.751	6.924	7.071	7.198	7.307	7.400	7.481	7.551	7.902	8.006	8.047	8.087	8.092
0.8	0.942	1.858	2.727	3.532	4.262	4.914	5.488	5.989	6.423	6.798	7.119	7.395	7.632	7.836	8.011	8.162	8.292	8.405	8.502	8.587	9.029	9.164	9.217	9.268	9.276
0.9	1.026	2.025	2.974	3.855	4.657	5.375	6.011	6.567	7.051	7.470	7.832	8.144	8.413	8.645	8.846	9.019	9.170	9.301	9.415	9.515	10.045	10.214	10.280	10.345	10.355
1.0	1.099	2.169	3.188	4.135	5.000	5.776	6.465	7.071	7.600	8.060	8.458	8.803	9.102	9.361	9.585	9.780	9.950	10.098	10.228	10.343	10.957	11.162	11.243	11.323	11.335
1.1	1.161	2.294	3.372	4.377	5.296	6.124	6.861	7.510	8.079	8.576	9.008	9.383	9.709	9.992	10.239	10.454	10.642	10.806	10.951	11.078	11.776	12.017	12.114	12.209	12.224
1.2	1.215	2.401	3.531	4.586	5.553	6.425	7.204	7.893	8.498	9.027	9.489	9.892	10.243	10.549	10.816	11.050	11.254	11.434	11.593	11.732	12.509	12.786	12.900	13.013	13.030
1.3	1.262	2.493	3.668	4.767	5.775	6.687	7.503	8.226	8.863	9.422	9.912	10.339	10.713	11.040	11.326	11.577	11.797	11.992	12.163	12.314	13.167	13.478	13.609	13.742	13.762
1.4	1.302	2.573	3.787	4.924	5.968	6.915	7.764	8.517	9.183	9.769	10.283	10.733	11.127	11.473	11.777	12.044	12.279	12.487	12.670	12.833	13.758	14.102	14.251	14.404	14.427
1.5	1.337	2.643	3.891	5.060	6.136	7.114	7.991	8.772	9.664	10.073	10.609	11.080	11.493	11.857	12.176	12.458	12.707	12.927	13.122	13.295	14.289	14.666	14.832	15.006	15.033
1.6	1.367	2.703	3.981	5.179	6.283	7.287	8.190	8.996	9.710	10.341	10.897	11.386	11.817	12.196	12.531	12.826	13.088	13.319	13.525	13.708	14.768	15.176	15.359	15.555	15.585
1.7	1.394	2.756	4.060	5.283	6.412	7.440	8.366	9.192	9.927	10.577	11.151	11.657	12.104	12.498	12.846	13.154	13.427	13.669	13.885	14.078	15.199	15.638	15.838	16.056	16.091
1.8	1.417	2.803	4.129	5.375	6.526	7.574	8.520	9.366	10.119	10.786	11.376	11.898	12.359	12.766	13.127	13.446	13.730	13.983	14.208	14.409	15.590	16.058	16.274	16.516	16.554
1.9	1.438	2.844	4.190	5.456	6.626	7.693	8.656	9.520	10.289	10.972	11.577	12.112	12.587	13.006	13.378	13.708	14.002	14.264	14.498	14.707	15.944	16.441	16.673	16.937	16.980
2.0	1.456	2.880	4.244	5.527	6.714	7.798	8.778	9.656	10.440	11.137	11.755	12.303	12.789	13.220	13.603	13.943	14.246	14.516	14.758	14.975	16.265	16.790	17.037	17.325	17.372
3.0	1.559	3.087	4.553	5.937	7.223	8.403	9.478	10.448	11.321	12.103	12.804	13.431	13.993	14.496	14.947	15.353	15.718	16.048	16.346	16.676	18.301	19.051	19.432	19.943	20.046
4.0	1.600	3.168	4.676	6.100	7.426	8.646	9.759	10.768	11.678	12.498	13.235	13.897	14.493	15.030	15.514	15.951	16.347	16.706	17.033	17.330	19.241	20.142	20.623	21.322	21.495
5.0	1.620	3.208	4.735	6.179	7.525	8.765	9.897	10.925	11.854	12.693	13.448	14.128	14.742	15.296	15.798	16.252	16.664	17.040	17.382	17.695	19.740	20.740	21.293	22.148	22.393
10.0	1.648	3.263	4.818	6.289	7.662	8.930	10.089	11.144	12.100	12.965	13.747	14.454	15.094	15.674	16.201	16.681	17.118	17.518	17.885	18.222	20.491	21.681	22.390	23.676	24.238
INF	1.657	3.282	4.846	6.327	7.710	8.986	10.155	11.220	12.186	13.060	13.851	14.567	15.217	15.806	16.342	16.831	17.278	17.688	18.064	18.410	20.770	22.046	22.838	24.463	26.111

***Table 7** Percentage Sky Components on the Vertical Plane, Perpendicular to a Vertical Rectangular Opening for the Clear Design Sky*

l/d	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	3.0	4.0	5.0	10.0	INF
h/d																									
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
0.1	0.036	0.141	0.303	0.506	0.734	0.971	1.207	1.432	1.643	2.836	1.011	2.168	2.308	2.433	2.544	2.642	2.730	2.808	2.878	2.940	3.309	3.461	3.536	3.641	3.678
0.2	0.071	0.277	0.594	0.993	1.442	1.910	2.374	2.820	3.236	3.618	3.964	4.276	4.554	4.802	5.022	5.219	5.393	5.549	5.688	5.812	6.547	6.850	7.000	7.211	7.284
0.3	0.103	0.401	0.863	1.445	2.100	2.793	3.475	4.180	4.743	5.306	5.818	6.278	6.690	7.058	7.385	7.677	7.936	8.168	8.375	8.560	9.657	10.110	10.335	10.651	10.760
0.4	0.126	0.491	1.059	1.779	2.597	3.460	4.326	5.166	5.958	6.691	7.359	7.967	8.507	8.900	9.420	9.804	10.146	10.451	10.724	10.968	12.421	13.024	13.323	13.743	13.889
0.5	0.142	0.554	1.197	2.015	2.947	3.937	4.938	5.914	6.842	7.707	8.503	9.228	9.883	10.472	10.999	11.476	11.897	12.273	12.610	12.912	14.712	15.462	15.835	16.360	16.542
0.6	0.154	0.600	1.298	2.187	3.204	4.288	5.389	6.468	7.498	8.464	9.358	10.177	10.922	11.596	12.204	12.752	13.244	13.686	14.084	14.441	16.583	17.478	17.924	18.552	18.771
0.7	0.162	0.634	1.372	2.316	3.397	4.552	5.729	6.887	7.997	9.042	10.013	10.907	11.723	12.465	13.138	13.746	14.296	14.793	15.241	15.646	18.111	19.148	19.665	20.397	20.653
0.8	0.169	0.660	1.429	2.413	3.543	4.754	5.990	7.209	8.382	9.490	10.523	11.476	12.350	13.147	13.873	14.531	15.129	15.670	16.161	16.606	19.361	20.538	21.127	21.961	22.253
0.9	0.174	0.680	1.472	2.487	3.655	4.909	6.192	7.460	8.683	9.841	10.924	11.926	12.847	13.690	14.459	15.159	15.796	16.375	16.902	17.381	20.387	21.701	22.360	23.397	23.625
1.0	0.178	0.695	1.505	2.545	3.743	5.030	6.350	7.657	8.921	10.120	11.243	12.284	13.245	14.126	14.931	15.666	16.337	16.948	17.504	18.012	21.237	22.680	23.408	24.446	24.810
1.1	0.181	0.707	1.532	2.591	3.812	5.126	6.475	7.814	9.110	10.342	11.498	12.573	13.356	14.478	15.314	16.079	16.778	17.416	17.999	18.531	21.946	23.508	24.303	25.441	25.841
1.2	0.183	0.716	1.552	2.626	3.866	5.202	6.575	7.939	9.261	10.521	11.705	12.807	13.827	14.766	15.628	16.418	17.141	17.802	18.407	18.961	22.543	24.208	25.072	26.309	26.745
1.3	0.185	0.723	1.568	2.655	3.910	5.263	6.655	8.040	9.384	10.666	11.873	12.998	14.041	15.003	15.887	16.698	17.442	18.123	18.747	19.320	23.049	24.809	25.735	27.070	27.542
1.4	0.186	0.729	1.582	2.678	3.945	5.312	6.720	8.122	9.484	10.785	12.011	13.155	14.217	15.198	16.101	16.931	17.692	18.391	19.032	19.621	23.480	25.326	26.308	27.441	28.249
1.5	0.188	0.734	1.592	2.697	3.973	5.352	6.773	8.189	9.566	10.883	12.124	13.285	14.364	15.361	16.280	17.125	17.902	18.616	19.272	19.875	23.850	25.772	26.808	28.336	28.880
1.6	0.189	0.738	1.601	2.712	3.996	5.385	6.816	8.244	9.634	10.963	12.219	13.394	14.486	15.497	16.430	17.289	18.079	18.806	19.475	20.090	24.169	26.161	27.245	28.866	29.445
1.7	0.189	0.741	1.608	2.724	4.016	5.412	6.852	8.290	9.690	11.031	12.298	13.484	14.589	15.511	16.556	17.427	18.229	18.968	19.648	20.274	24.444	26.501	27.629	29.340	29.955
1.8	0.190	0.744	1.614	2.735	4.032	5.434	6.882	8.328	9.737	11.087	12.364	13.561	14.675	15.708	16.663	17.545	18.357	19.105	19.795	20.431	24.684	26.799	27.969	29.765	30.416
1.9	0.191	0.746	1.619	2.743	4.045	5.453	6.908	8.360	9.777	11.135	12.420	13.625	14.749	15.791	16.755	17.645	18.466	19.224	19.922	20.567	24.893	27.062	28.270	30.149	30.835
2.0	0.191	0.748	1.623	2.751	4.056	5.469	6.929	8.387	9.811	11.175	12.468	13.680	14.811	15.861	16.833	17.731	18.560	19.325	20.031	20.684	25.077	27.294	28.537	30.496	31.217
3.0	0.193	0.756	1.642	2.785	4.109	5.544	7.030	8.517	9.972	11.371	12.699	13.950	15.120	16.211	17.224	18.164	19.036	19.844	20.594	21.289	26.082	28.619	30.108	32.676	32.742
4.0	0.194	0.759	1.648	2.794	4.124	5.566	7.058	8.540	10.018	11.427	12.767	14.029	15.212	16.316	17.343	18.298	19.185	20.008	20.772	21.483	26.439	29.128	30.745	33.687	35.064
5.0	0.194	0.760	1.650	2.798	4.129	5.574	7.069	8.568	10.036	11.449	12.793	14.060	15.248	16.357	17.390	18.351	19.243	20.073	20.844	21.562	26.592	29.359	31.049	34.232	35.872
10.0	0.194	0.761	1.652	2.801	4.135	5.581	7.080	8.582	10.053	11.470	12.818	14.095	15.283	16.398	17.436	18.403	19.302	20.138	20.917	21.641	26.758	29.624	31.419	35.049	37.513
INF	0.194	0.761	1.652	2.802	4.136	5.582	7.081	8.584	10.056	11.473	12.822	14.095	15.288	16.404	17.443	18.411	19.311	20.148	20.928	21.654	26.785	29.672	31.490	35.274	39.172

Table 8 *Percentage Sky Components on the Vertical Plane Parallel to a Vertical Rectangular Opening for the Clear Design Sky*

l/d h/d	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	3.0	4.0	5.0	10.0	INF
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
0.1	0.728	1.429	2.078	2.600	3.167	3.660	3.964	4.265	4.513	4.717	4.883	5.020	5.132	5.225	5.301	5.365	5.418	5.463	5.501	5.533	5.687	5.733	5.749	5.765	5.766
0.2	1.429	2.803	4.007	5.221	6.220	7.073	7.790	8.385	8.876	9.278	9.609	9.880	10.103	10.286	10.439	10.565	10.671	10.760	10.835	10.899	11.207	11.296	11.330	11.362	11.365
0.3	2.068	4.061	5.913	7.580	9.040	10.285	11.337	12.212	12.934	13.528	14.016	14.417	14.747	15.020	15.246	15.434	15.591	15.724	15.836	15.931	16.390	16.523	16.574	16.623	16.627
0.4	2.529	4.970	7.249	9.312	11.133	12.707	14.042	15.164	16.097	16.870	17.507	18.025	18.458	18.816	19.113	19.360	19.568	19.742	19.890	20.015	20.624	20.801	20.868	20.933	20.939
0.5	2.852	5.608	8.186	10.529	12.606	14.401	15.952	17.256	18.350	19.262	20.021	20.652	21.177	21.613	21.978	22.275	22.530	22.746	22.923	23.082	23.836	24.056	24.140	24.222	24.229
0.6	3.086	6.070	8.867	11.415	13.681	15.656	17.353	18.793	20.008	21.027	21.879	22.592	23.189	23.689	24.109	24.462	24.761	25.014	25.229	25.412	26.229	26.561	26.662	26.759	26.768
0.7	3.259	6.413	9.373	12.074	14.482	16.588	18.402	19.949	21.257	22.359	23.285	24.063	24.716	25.267	25.731	26.124	26.458	26.742	26.984	27.192	28.214	28.517	28.634	28.748	28.758
0.8	3.389	6.672	9.755	12.573	15.090	17.296	19.201	20.830	22.212	23.380	24.365	25.195	25.895	26.486	26.987	27.412	27.775	28.084	28.350	28.578	29.720	30.065	30.198	30.327	30.339
0.9	3.489	6.869	10.046	12.955	15.556	17.840	19.817	21.511	22.952	24.173	25.206	26.078	26.816	27.441	27.972	28.424	28.810	29.141	29.426	29.672	30.927	31.303	31.451	31.596	31.610
1.0	3.565	7.024	10.272	13.250	15.917	18.263	20.297	22.043	23.531	24.795	25.866	26.773	27.542	28.196	28.572	29.226	29.633	29.982	30.283	30.544	31.889	32.302	32.467	32.627	32.643
1.1	3.625	7.139	10.447	13.481	16.200	18.594	20.674	22.462	23.989	25.288	26.391	27.326	28.121	28.798	29.375	29.869	30.293	30.658	30.973	31.246	32.670	33.117	33.297	33.473	33.491
1.2	3.672	7.233	10.586	13.663	16.423	18.857	20.973	22.795	24.353	25.681	26.810	27.770	28.587	29.283	29.878	30.388	30.826	31.204	31.532	31.816	33.309	33.796	33.981	34.173	34.193
1.3	3.709	7.307	10.696	13.807	16.602	19.067	21.213	23.062	24.646	25.998	27.148	28.128	28.963	29.676	30.286	30.810	31.261	31.651	31.989	32.283	33.836	34.350	34.550	34.756	34.779
1.4	3.739	7.366	10.784	13.924	16.745	19.236	21.406	23.278	24.884	26.255	27.424	28.420	29.271	29.998	30.621	31.157	31.618	32.018	32.365	32.667	34.374	34.813	35.035	35.247	35.271
1.5	3.763	7.414	10.856	14.018	16.861	19.373	21.563	23.454	25.077	26.465	27.649	28.660	29.523	30.262	30.897	31.443	31.914	32.322	32.677	32.986	34.641	35.202	35.436	35.663	35.689
1.6	3.783	7.453	10.914	14.095	16.956	19.485	21.692	23.599	25.236	26.638	27.835	28.857	29.732	30.482	31.226	31.680	32.160	32.575	32.937	33.253	34.950	35.532	35.776	36.017	36.046
1.7	3.799	7.485	10.962	14.158	17.034	19.578	21.798	23.718	25.368	26.781	27.989	29.022	29.906	30.665	31.317	31.879	32.366	32.888	33.156	33.477	35.211	35.812	36.067	36.321	36.352
1.8	3.812	7.512	11.002	14.211	17.099	19.655	21.886	23.817	25.478	26.900	28.118	29.160	30.052	30.818	31.477	32.046	32.539	32.967	33.340	33.666	35.435	36.052	36.316	36.584	36.617
1.9	3.824	7.534	11.035	14.254	17.153	19.719	21.960	23.900	25.570	27.001	28.226	26.276	30.175	30.948	31.613	32.188	32.686	33.119	33.497	33.828	35.626	35.259	36.532	36.812	36.847
2.0	3.833	7.553	11.062	14.291	17.199	19.773	22.022	23.970	25.647	27.086	28.318	29.374	31.279	31.058	31.728	32.308	32.811	33.249	33.631	33.965	35.791	36.438	36.719	37.011	37.048
3.0	3.876	7.639	11.192	14.463	17.412	20.027	22.316	24.302	26.016	27.491	28.757	29.846	30.783	31.592	32.291	32.898	33.427	33.889	34.294	34.551	36.640	37.380	37.715	38.107	38.157
4.0	3.888	7.663	11.228	14.511	17.471	20.098	22.398	24.398	26.121	27.606	28.884	29.983	30.930	31.748	32.457	33.074	33.611	34.082	34.496	34.860	36.915	37.699	38.063	38.510	38.579
5.0	3.893	7.672	11.241	14.529	17.494	20.125	22.430	24.432	26.161	27.650	28.932	30.035	30.986	31.808	32.521	33.142	33.683	34.157	34.574	34.943	37.028	37.834	38.214	38.696	38.781
10.0	3.897	7681	11.254	14.546	17.515	20.150	22.459	24.466	26.199	27.693	28.978	30.085	31.041	31.867	32.584	33.208	33.753	34.231	34.652	35.024	37.144	37.978.	38.382	38.927	39.057
INF	3.898	7.682	11.256	44.548	17.518	20.154	22.464	24.471	26.205	27.699	28.985	30.093	31.049	31.876	32.593	33.218	33.764	34.243	34.664	35.037	37.162	38.003	38.411	38.978	39.172

General Principles of Openings to Afford Good Lighting

- Generally, while taller openings give greater penetrations, broader openings give better distribution of light. It is preferable that some area of the sky at an altitude of 20° to 25° should light up the working plane.
- Broader openings may also be equally or more efficient, provided their sills are raised by 300 mm to 600 mm above the working plane.
- For a given penetration, a number of small openings properly positioned along the same, adjacent or opposite walls will give better distribution of illumination than a single large opening. The sky component at any point, due to a number of openings may be easily determined from the corresponding sky component contour charts appropriately superposed. The sum of the individual sky component for each opening at the point gives the overall component due to all the openings. The same charts may also facilitate easy drawing of sky component contours due to multiple openings.
- Unilateral lighting from side openings will, in general, be unsatisfactory if the effective width of the room is more than 2 to 2.5 times the distance from the floor to the top of the opening. In such cases provision of light shelves is always advantageous.
- Openings on two opposite sides will give greater uniformity of internal daylight illumination, especially when the room is 7 m or more across. They also minimise glare by illuminating the wall surrounding each of the opposing openings. Side openings on one side and clerestory openings on the opposite side may be provided where the situation so requires.
- Cross-lighting with openings on adjacent walls tends to increase the diffused lighting within a room.
- Openings in deep reveals tend to minimise glare effects.
- Openings shall be provided with Chajjahs, louvers, baffles or other shading devices to exclude, as far as possible, direct sunlight entering the room. Chajjahs, louvers, etc, reduce the effective height of the opening for which due allowance shall be made. Broad and low openings are, in general, much easier to shade against sunlight entry.

Direct sunlight, when it enters, increases the inside illuminance very considerably. Glare will result if it falls on walls at low angles, more so than when it falls on floors, especially when the floors are dark coloured or less reflective.

Availability of Daylight in Multi-storeyed Block

Proper planning and layout of building can add appreciably to daylighting illumination inside. Certain dispositions of building masses offer much less mutual obstruction to daylight than others and have a significant relevance, especially when intensive site planning is undertaken. As guidance, the relative availability of daylight in multi-storeyed blocks (up to 4 storeys) of different relative orientations may be taken as given in Table 9.

Table 9 *Relative Availability of Daylight on the Window Plane at Ground Level in a Four-Storeyed Building Blocks (Clear Design-Sky as Basis, Daylight Availability Taken as Unity on an Unobstructed Facade, Values are for the Centre of the Blocks)*

Sl No.	Distance of Separation Between Blocks	Infinitely Long Parallel Blocks	Parallel Blocks Facing Each Other (Length = 2 × Height)	Parallel Blocks facing Gaps Between Opposite Blocks (Length = 2 × Height)
(1)	(2)	(3)	(4)	(5)
i)	0.5 Ht	0.15	0.15	0.25
ii)	1.0 Ht	0.30	0.32	0.38
iii)	1.5 Ht	0.40	0.50	0.55
iv)	2.0 Ht	0.50	0.60	0.68

NOTE — Ht = Height of building.

5.03 Energy Conservation Building Code of India:

ECBC encourages the use of daylighting features in buildings. Visual Light Transmittance (VLT) is defined as the ratio of light that passes through the glazing to the light passing through perfectly transmitting glazing. It also refers to the fraction of visible light transmitted through the glazing. VLT is concerned with the visible portion of the solar spectrum as opposed to SHGC, which takes into account the entire solar radiation. VLT affects energy consumption in building by providing daylight that creates the opportunity to reduce electric lighting and its associated cooling loads. Glazing with low SHGC generally has a low VLT; however, if the VLT is too low, the outside view from inside the building will be impaired. With lower VLT, the daylighting in the interior may also reduce to a level that may require supplemental electrical lighting for some occupants' functions, or to make the environment productive and enjoyable to the occupants. Thus buildings with lower window to wall ratios (WWR), may need higher VLT.

Table 10 *Minimum VLT Requirements*

Window Wall Ratio	Minimum VLT
0 - 0.3	0.27
0.31-0.4	0.20
0.41-0.5	0.16
0.51-0.6	0.13

Passive designs strategies like daylight and shading are mandatory in ECBC 2017. Objective for this change is to encourage design with passive strategies to be the norm for buildings in India.

As per the ECBC 2017, floor areas shall meet or exceed the useful daylight illuminance (UDI) area requirements listed in Table 11 for 90% of the potential daylit time in a year. Mixed-use buildings shall show compliance as per the criteria prescribed. Compliance shall be demonstrated either through daylighting simulation method or the manual method in. Assembly buildings and other buildings where daylighting will interfere with the functions or processes of 50% (or more) of the building floor area, are exempted from meeting the requirements listed in Table 11.

Table 11 *Daylight Requirement, ECBC 2017*

Building Category	Percentage of above grade floor area meeting the UDI requirement		
	ECBC	ECBC +	Super ECBC
Business, Educational	40%	50%	60%
No Star Hotel Star Hotel Healthcare	30%	40%	50%
Resort	45%	55%	65%
Shopping Complex	10%	15%	20%
Assembly*	Exempted		
*and other buildings where daylighting will interfere with the functions or processes of 50% (or more) of the building floor area			

5.04 National Lighting Code: Part 11, Daylighting For Buildings

This part of the National Lighting Code (NLC) covers the general principles and methods of daylighting of dwellings, offices, and hospitals. It recommends the minimum illumination values to be achieved by daylighting principles and gives general guidance for realizing the values in practice.

Daylight Factor vs Window Location

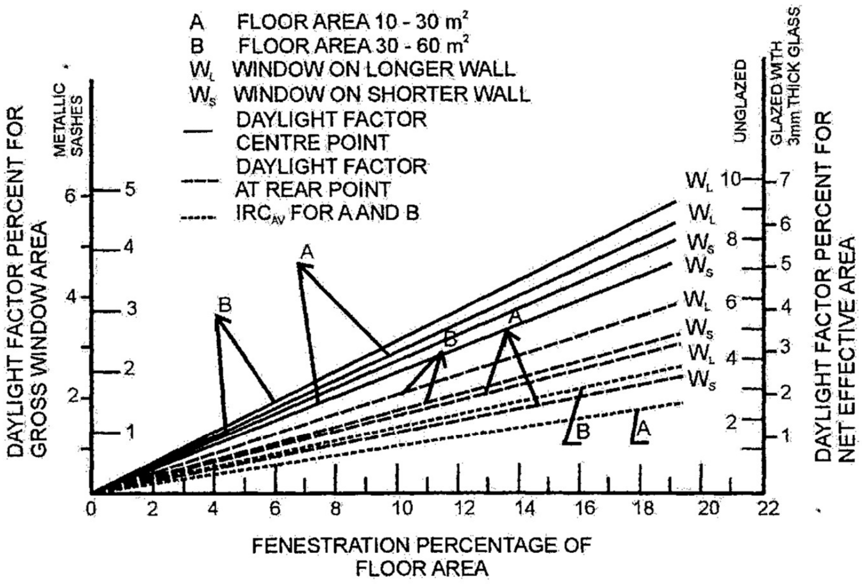


Fig. 2 Daylight Factor on the Working Plane for a Corner located Window

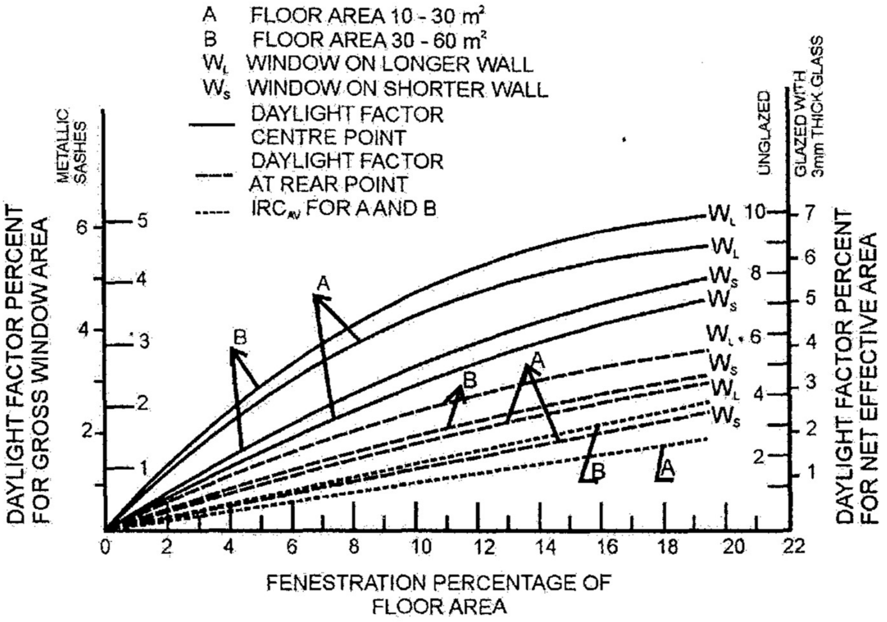


Fig. 3 Daylight Factor on the Working Plane for a Centrally Located Window

Figure 5.03 *Dynamics of Daylight Factor with the change of Window Location*

Recommended Daylighting Metrices as per NLC, 2010

Table 1 Recommended Illuminance Levels on Work Areas for Educational Buildings
(*Clause* 4.1.4)

Sl. No.	Work Area/ Visual Task	Illuminance (lux)	Corresponding Daylight Factor(%)
(1)	(2)	(3)	(4)
i	Class-room desk, writing boards	150-300	1.9-3.8
ii	Laboratories	200-300	2.5-3.8
iii	Library (reading tables)	150-300	1.9-3.8
iv	Drawing, typing, sewing	300	3.8
	Toilets	150	1.9

Table 3 Recommended Daylight Factors for Interiors
(*Clause* 5.3.2)

Location	Daylight Factor (%)
Dwellings	
Kitchen	2.5
Living room	0.625
Study	1.9
Circulation	0.313
Schools	
Class room	1.9
Lecture room	2.0 to 2.5
Study hall	2.0 to 2.5
Laboratory	1.9 to 3.8
Offices	
General	1.9
Enquiry	0.625 to 1.9
Hospitals	
General ward	1.25
Pathological laboratory	2.5 to 3.75
Libraries	
Stock room	0.9 to 1.9
Reading room	1.9 to 3.75
Counter area	2.5 to 3.75
Catalogue room	1.9 to 2.5

NOTE — 100 lux is equal to a sky component of value 1.25 percent based on 8 000 lux.

Table 4 Relative Availability of Daylight on the Window Plane at Ground Level in Four-Storeyed Building Blocks (Clear Design-Sky as Basis, Daylight Availability Taken as Unity on an Unobstructed Facade, Values are for the Centre of the Blocks)
(*Clause* 8.1)

Distance of Separation Between Blocks	Infinitely Long Parallel Blocks	Parallel Blocks Facing Each Other (Length =2 x Height)	Parallel Blocks Facing Gaps Between Opposite Blocks (Length= 2 x Height)
0.5	0.15	0.15	0.25
1.0	0.30	0.32	0.38
1.5	0.40	0.50	0.55
2.0	0.50	0.60	0.68

Figure 5.04 *Recommendation Tables of National Lighting Code*

6.0 Daylighting Performance: Influencing Parameters

6.01 Climate:

The prevailing climatic conditions of a building site define the overall preconditions for the daylighting design in terms of sunlight availability, visual comfort, thermal comfort and energy performance. [Fig 6.01], [Fig 6.02] and [Fig 6.03] show the effect of climatic conditions on the sky luminous distribution and intensity. [2]

- The image below, describes a clear sky luminance distribution. Under clear sky conditions, the sky luminance is about ten times brighter at the horizon than the zenith. In addition to the sky luminance is the sun luminance. The sun acts as a dynamic light source of very high intensity.

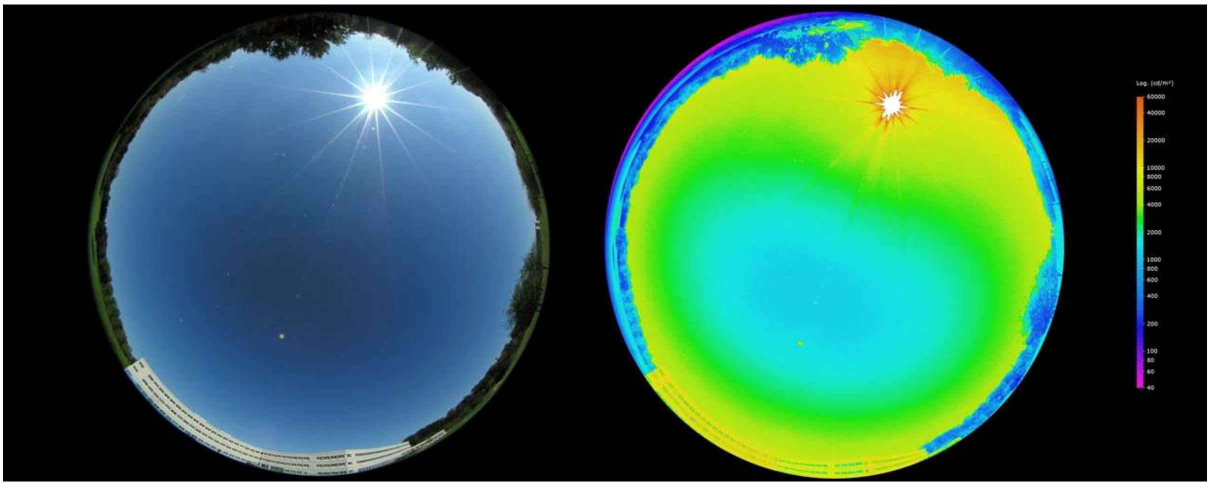


Fig 6.01 *Luminance map of a clear sunny sky*

- The image below describes an intermediate sky luminance distribution. In this particular case, the sun energy has been scattered by the clouds, which results in a softer transition between the very intense luminance of the sun and the luminance of the sky. It is possible to observe that the clouds (illuminated by the sun) have higher luminance values than the sky.

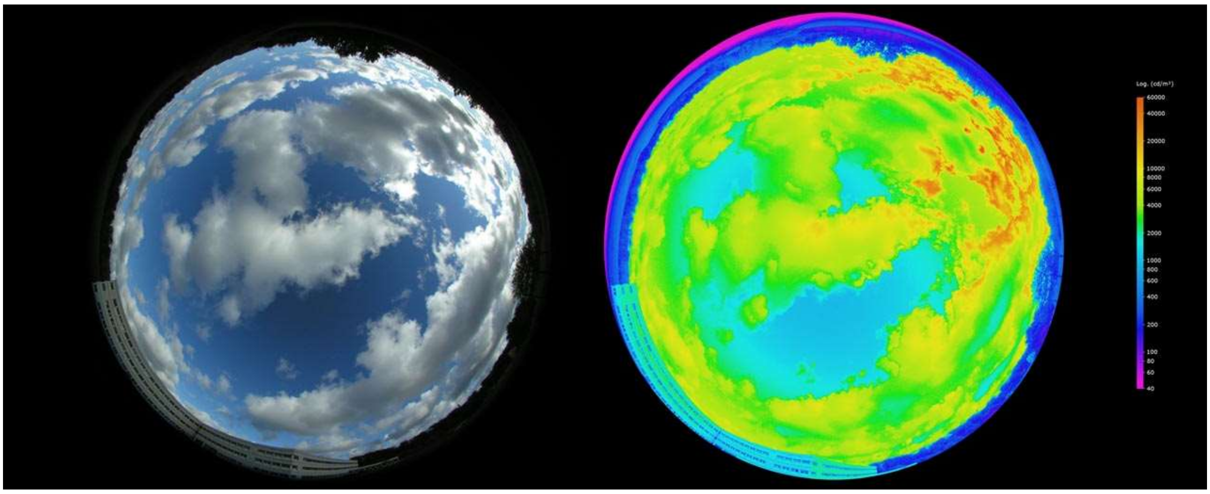


Fig 6.02 *Luminance map of an intermediate sky*

- [Fig 6.03] Luminance map of an overcast sky. The image below describes an overcast sky luminance distribution. Under perfect overcast sky conditions, the sky luminance is the same in all orientations, and the zenith is about three times brighter than the horizon.

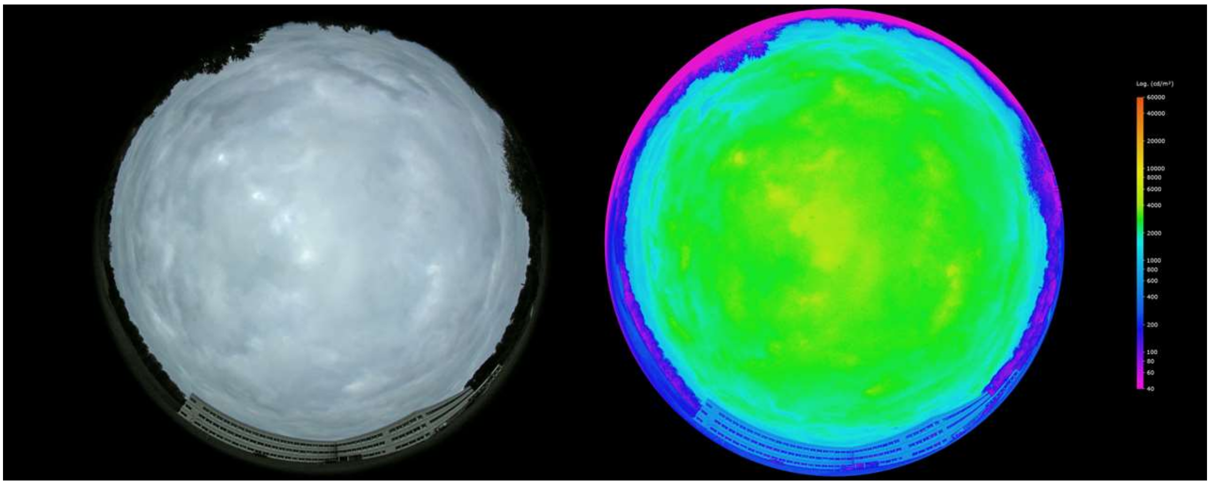


Fig 6.03 *Luminance map of an overcast sky*

[Fig 6.04] shows an overview of the monthly sky conditions for 3 European locations: Rome, Paris and Oslo. Within working hours 8:00am to 5:00pm, cumulative data of daylight availability show that a horizontal illuminance of 10 klx might be available for 60 to 85 % of working hours and 20 klx for around 30% of working hours. By contrast, the global illuminance (total of sunlight and skylight) varies significantly with latitude. A global horizontal illuminance of 30 klx is exceeded for 35% of working hours (8-17) in Oslo, but 65% of the time in Rome. [2]

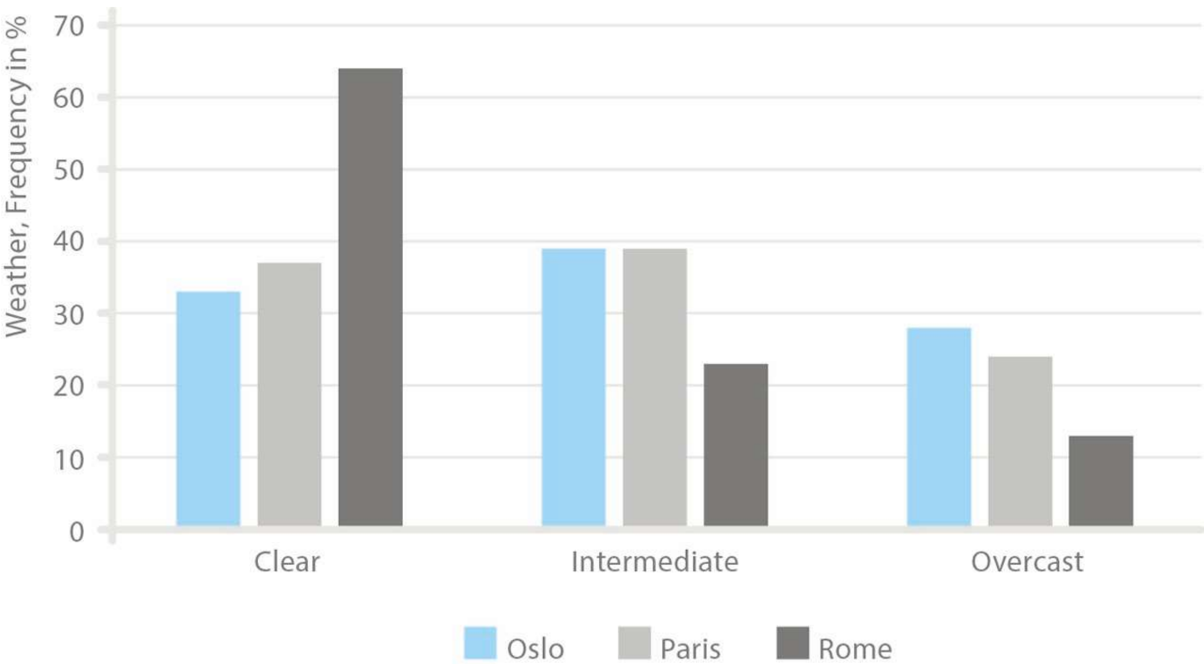


Fig 6.04 *Frequency of weather in % for three different European cities*

6.02 Latitude

The latitude of a building site determines the solar altitude for a given time of day and year. The summer and winter solar altitude properties for a specific location are important design inputs for the control of direct solar radiation. Latitude will also determine the length of daytime and solar availability at different seasons of the year. Maximum and minim solar elevation will depend on the latitude of the site; on moving away from the equator towards north or south, the difference between summer and winter becomes greater as latitudes increase.

[Figure 6.05] show the difference in outdoor illuminance between northern and southern European locations. The highest peak of global illuminance is during the summer (for the northern hemisphere) when the sun is at its highest level, and about two and a half times greater than the lowest peak during the winter, when the sun is at its lowest level.

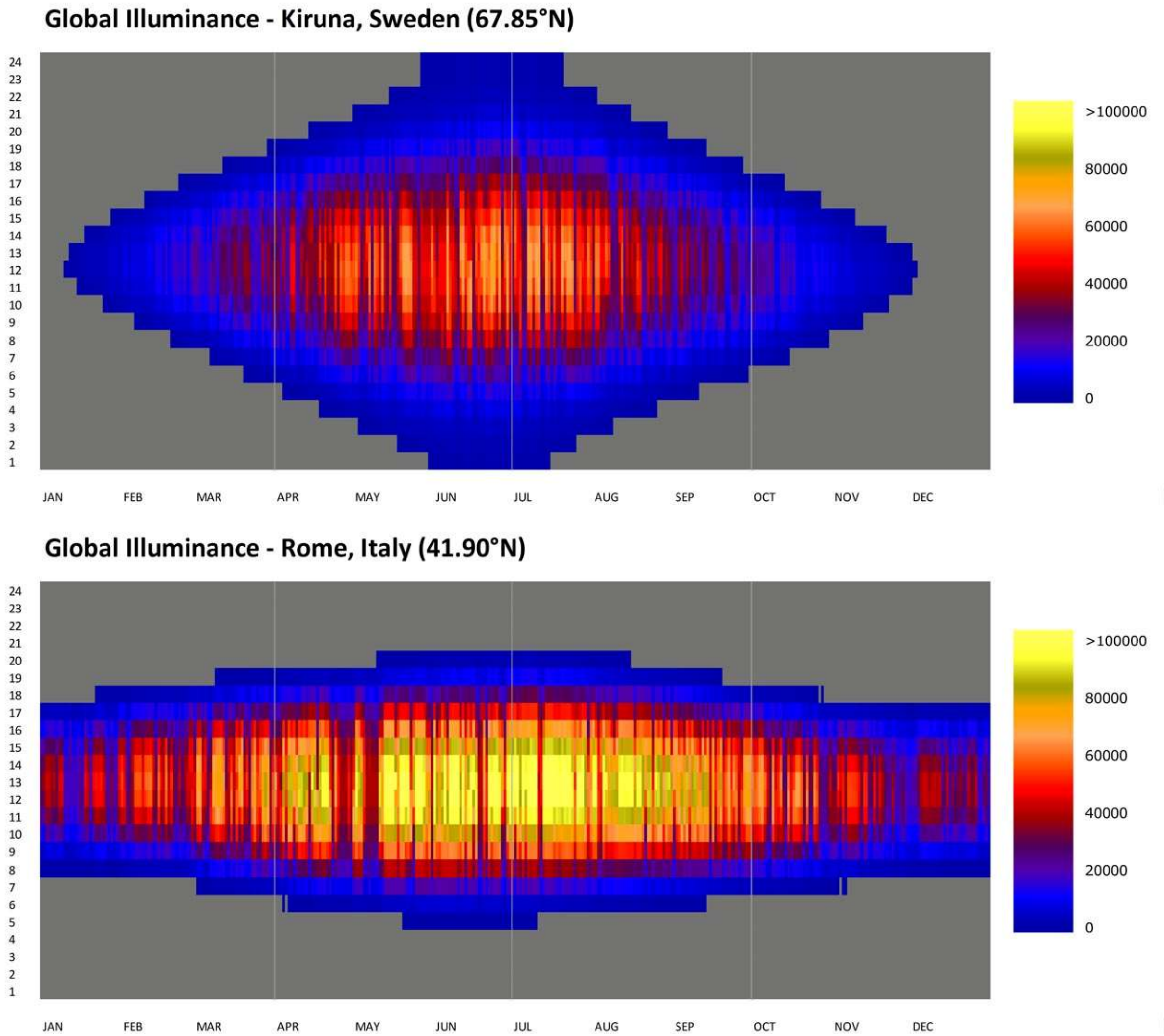


Fig 6.05 *Global illuminance in northern and southern European locations.*

6.03 Sunpath

The sun is the main source of daylight. Its apparent movement through the sky, referred to as “sun paths” is critical for architectural and interior design decisions. Sun paths vary by geographic latitude, which is the angular distance from the equator. Figure 7.06 shows the difference between Sunpath diagram of two cities of India, Kolkata and Kanyakumari, with different latitude.

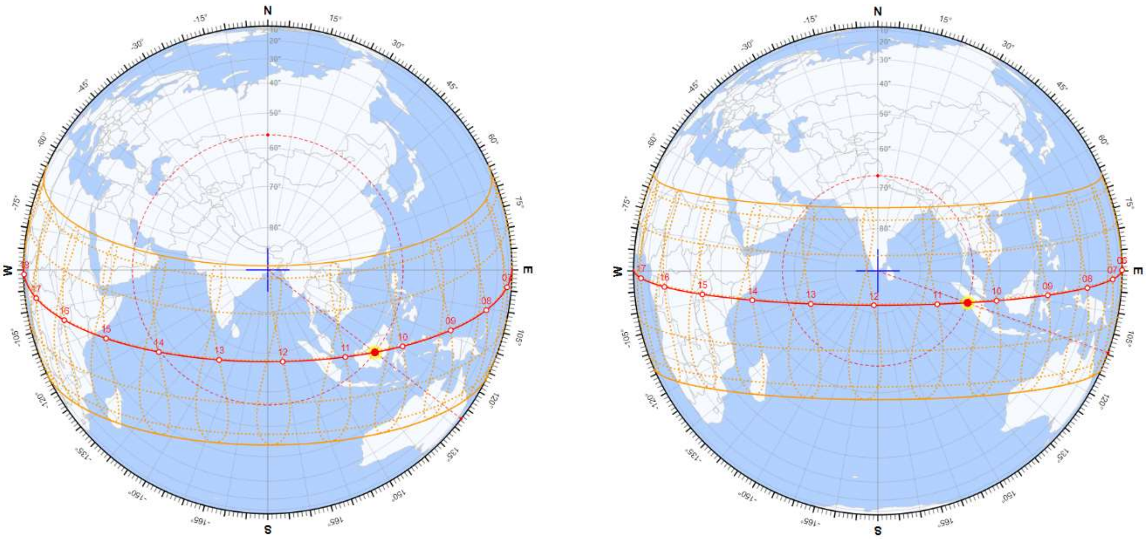


Fig 6.06 *Comparison between Sunpath Diagram of Kolkata and Kanyakumari*

6.04 Obstructions and reflections on site

External reflections and obstructions from surrounding elements on the building site (buildings, vegetation, ground surface etc.) will influence the amount of daylight reaching the interior of a building. External obstructions may block direct sunlight from reaching daylight apertures, or reflect direct sunlight towards them. Roof windows and skylights are generally less affected by obstructions from surrounding elements and have more generous views of the sky than facade windows, as illustrated in [Figure 6.07].

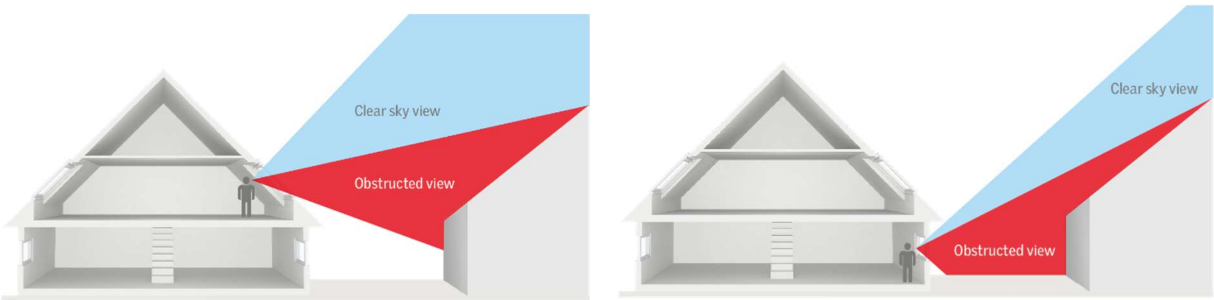
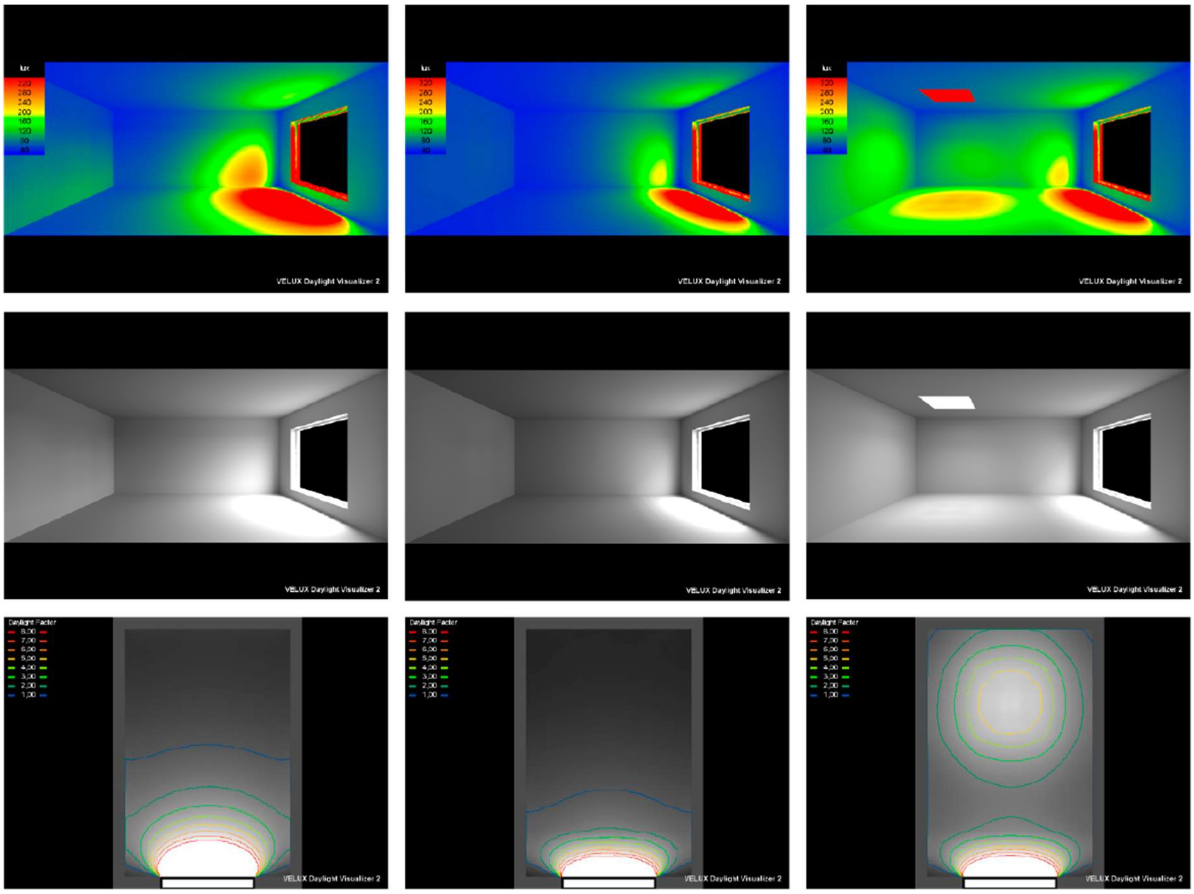


Fig 6.07 *Components of view – Facade-Roof-Window situation.*

The shading effect of external obstructions can be effectively determined and visualized by drawing shadow masks of external obstructions on sun-path diagrams. Shadow masks define the area of the sky that is blocked by an obstruction when viewed from a particular point, usually the middle point of window heads.

The following [Figure 6.08] shows the effect of obstruction on daylight availability in a simple room with a vertical facade window, and the effect of adding a flat-roof window to deliver daylight deeper into the obstructed room. The results show that obstruction can greatly affect the amount of daylight that will reach the building interior, and how adding an unobstructed window on the roof can provide much more daylight.



DF	2.07%	Average DF	1.03%	Average DF	3.24%
Median DF	1.05%	Median DF	0.58%	Median DF	2.96%
Uniformity Dmin/Dav	0.18	Uniformity Dmin/Dav	0.22	Uniformity Dmin/Dav	0.41

***Fig 6.08** Comparison of daylight levels in a room without (left) and with external obstruction. (Center and right)*

External obstructions can reflect sunlight towards daylight apertures. Depending on the magnitude and type of the surface reflectance of external obstructions, the reflected sunlight can be very intense. Reflected sunlight from surfaces with high specular reflectance, such as the façade of glass buildings, has the same, and sometimes worse, effect as direct sunlight.

External obstructions can redirect sunlight through reflection, reaching areas that otherwise would be in the shadow. The photograph shows the heat effects of reflected sunlight being concentrated through reflection off a high reflectance curved façade. The concentrated reflected sunlight deformed a car mirror [Fig 6.09].

Fig 6.09 *concentrated reflected sunlight deformed a car mirror*

6.05 Building Geometry, Orientation and Surface Property

Geometry

The geometry of a building influences its capacity to deliver adequate levels of daylight to the interior. When the building is deep, daylighting solely by facade windows has its limitations. No matter how much glass there is in the facade, it will only be possible to achieve an adequate daylight distribution (DF > 2%) a few metres from the facade, as shown in [Figures 6.10] and [Figure 6.11]. Measures like light shelves and reflective ceilings can improve the light distribution from the facade slightly, but these solutions are often associated with visual discomfort. The most effective way to bring daylight deeper into buildings is to use light from the roof with tools like; roof windows and sun tunnels.

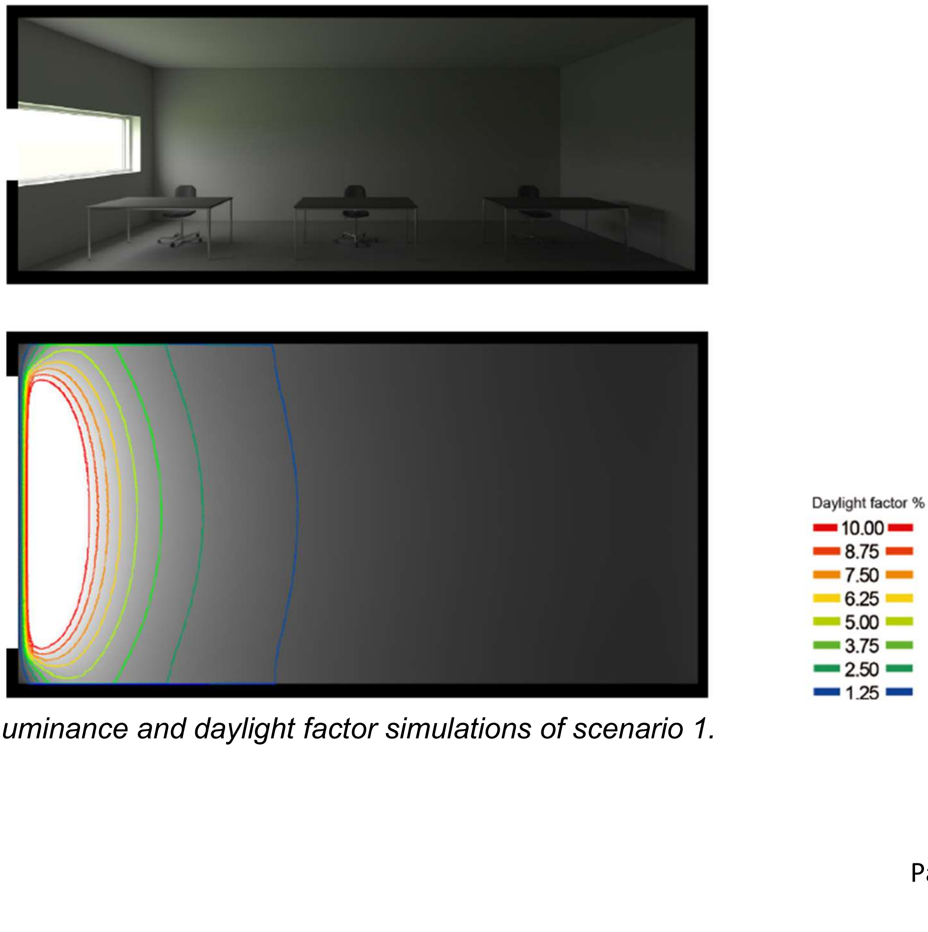


Fig 6.10 *Luminance and daylight factor simulations of scenario 1.*

1. Situation with 10% glazing to floor area ratio (facade window only). The results from scenario 1 show that a 10% glazing to floor area ratio will only achieve a DF of 2% a few metres from the facade and leave the back of the room with very low light levels. Even though the average DF of the room is equal to 1.9%, only a small work plane area achieves values above 2%, and only one of the three workplaces represented can be considered daylit.

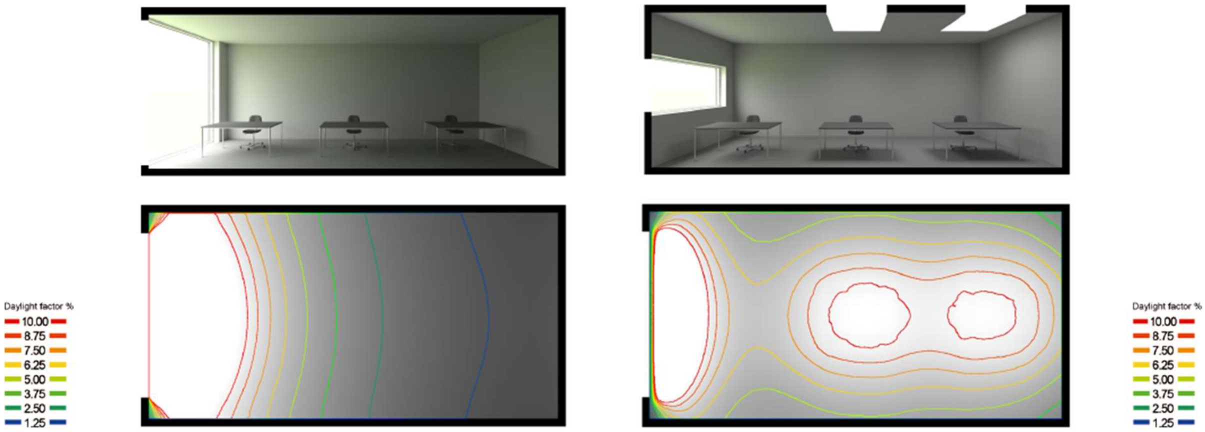


Fig 6.11 *Luminance and daylight factor simulations of scenario 2 and 3.*

2. The situation with 30% glazing to floor area ratio (facade window only). The results from scenario 2 show that a 30% glazing to floor area ratio will achieve a DF facade of 2% approximately 4.5 meters from the facade. The DF average is equal to 5.1%, but it is highly nonuniform and not well distributed over the work plane area, with very high values near the window and low values at the back, a luminous environment likely to cause visual discomfort and glare. In this scenario, two of the three workplaces represented can be considered daylit.

3. The situation with 20% glazing to floor area ratio (11% facade window + 9% roof window).The results from scenario 3 show that a combination of facade and roof windows with a 20% glazing to floor area ratio provides generous and useful DF levels over the entire work plane, within average DF of 6.4%. The results demonstrate that the use of roof windows means better daylighting performance and a luminous environment not as likely to cause glare and visual discomfort. In this scenario, all of the three workplaces represented can be considered well daylit.

Orientation

Building massing and arrangement of spaces are the most important daylighting decisions, as they define the total building area of the building that will be adjacent to daylight apertures, and also the orientation of the different spaces that will be benefiting from daylighting [Fig 6.12]. Building massing also defines shadow effects of the building shape on its own fenestration. Orientation of building spaces initiates the consideration of architectural shading systems, such as external horizontal and/or vertical elements for different façade orientations and individual spaces.

Fenestration orientation is very important because it defines the incident direct solar radiation through the year and the related need for exterior and/ or interior shading devices. By observing the sun paths across India, it becomes evident that different fenestration orientations have very different relationships to the sun paths.

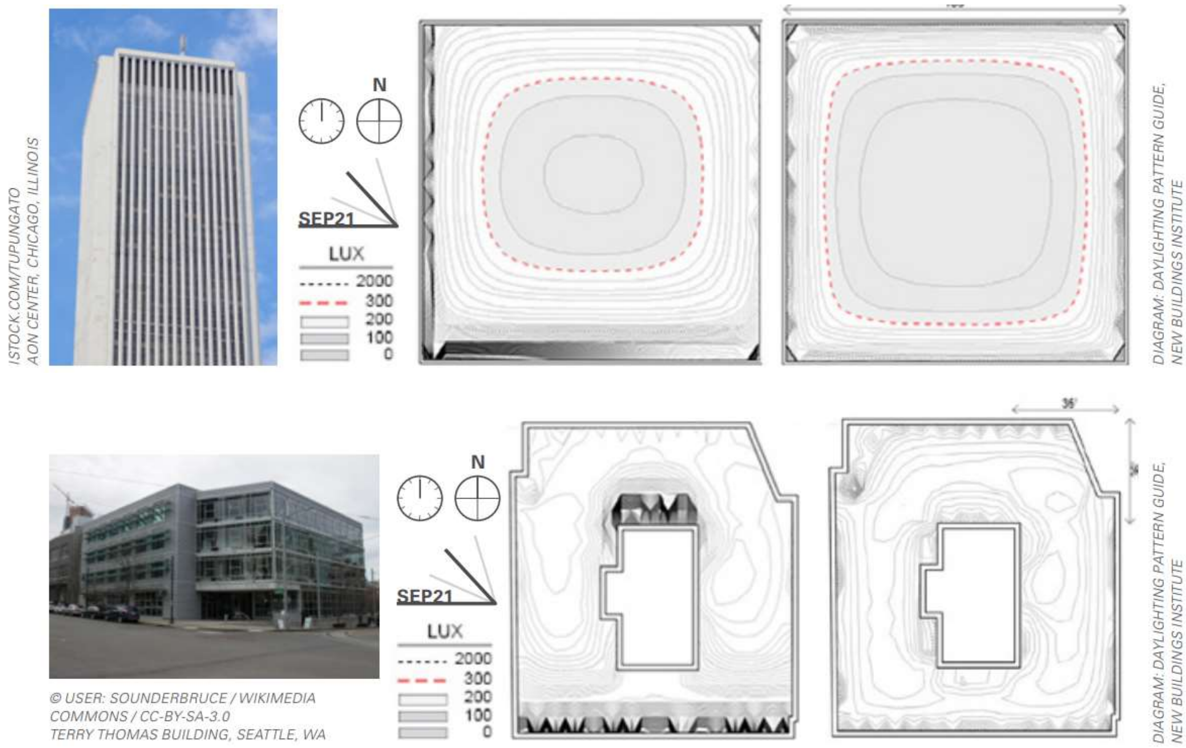


Fig 6.12 *Building Foot print vs Illumination Level in Building Core*

Material properties:

The colour and reflectance of room surfaces are part of the lighting system. Dark surfaces reflect less light than bright surfaces, and the result is likely to be an unsatisfactory luminous environment in which there is little in direct reflected light. Bright vertical surfaces inside the room are generally preferred to dark ones, but shading devices used to control sunlight should use darker materials in order to limit the risk of glare (e.g. grey awning blinds).

6.06 Fenestration Design:

Fenestrations are the most common daylight apertures, with potential to illuminate interior spaces at depths of two window-head heights. While the main function of skylights is to introduce daylight into architectural spaces, the main function of the fenestration is to provide view and connection to the outdoors. The daylight distribution through windows is very uneven, with comparatively very high levels next to the window that drop significantly as we move away from it. [Fig 6.13]

Schematic diagram showing the daylight work-plane illuminance levels across the depth of a space with a window. The daylight levels close to the window are very high and drop significantly with distance from the window. Daylight through windows can provide daylight illumination at distances of up to two window head-heights from the window.

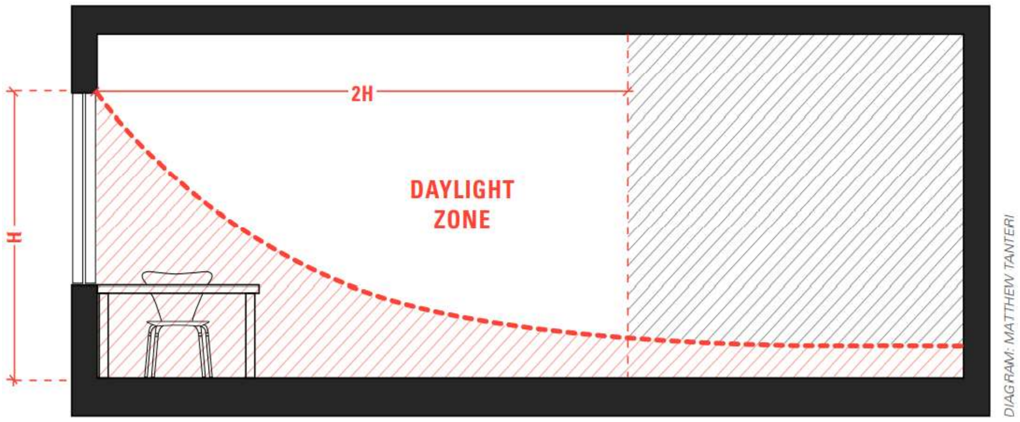


Fig 6.13 *Daylight work-plane illuminance levels across the depth of a space with a window*

The main objective in fenestration design is to maximize as many benefits—illumination, view and circadian health—and minimize negative performance effects such as glare and increased HVAC loads, especially for cooling. The main challenge is to thoughtfully consider the annual variation of daylight levels, sun paths, and cloud conditions at the building location, and also the outdoor terrain, neighbouring buildings and vegetation for each daylight aperture.

Fenestration design starts with architectural design decisions in terms of arranging the spaces of the building and the daylight apertures of each space. For more information on these design decisions, please read the Architectural Design section of these guidelines. Effective decisions on placement, size and shape of daylight apertures require simultaneous consideration of glazing and shading decisions, which is the focus of this section. Fenestration design decisions are greatly affected by the local sun paths, which, along with the orientation of daylight apertures, dictate the incident angle [Fig 6.14] of direct solar radiation through the year. The smaller the incident angle, the more challenging the shading from direct solar radiation, as blocking small incident angles significantly compromises view.

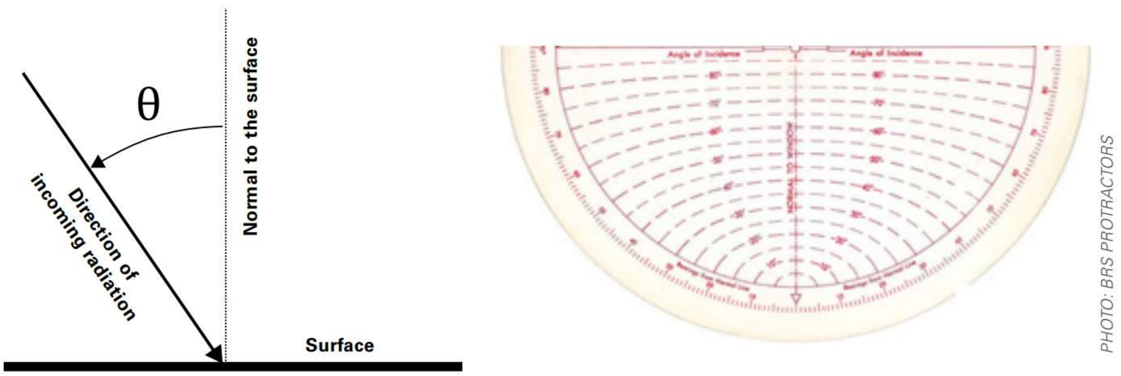


Fig 6.14 *The incident angle of radiation and iso-contours*

6.07 Building Form & Massing:

The depth of the floor plate, courtyard, and atriums plays an important role in designing a daylit building massing. A comparative analysis of potential daylight availability between different massing models is shown in [Fig 6.15] [19]

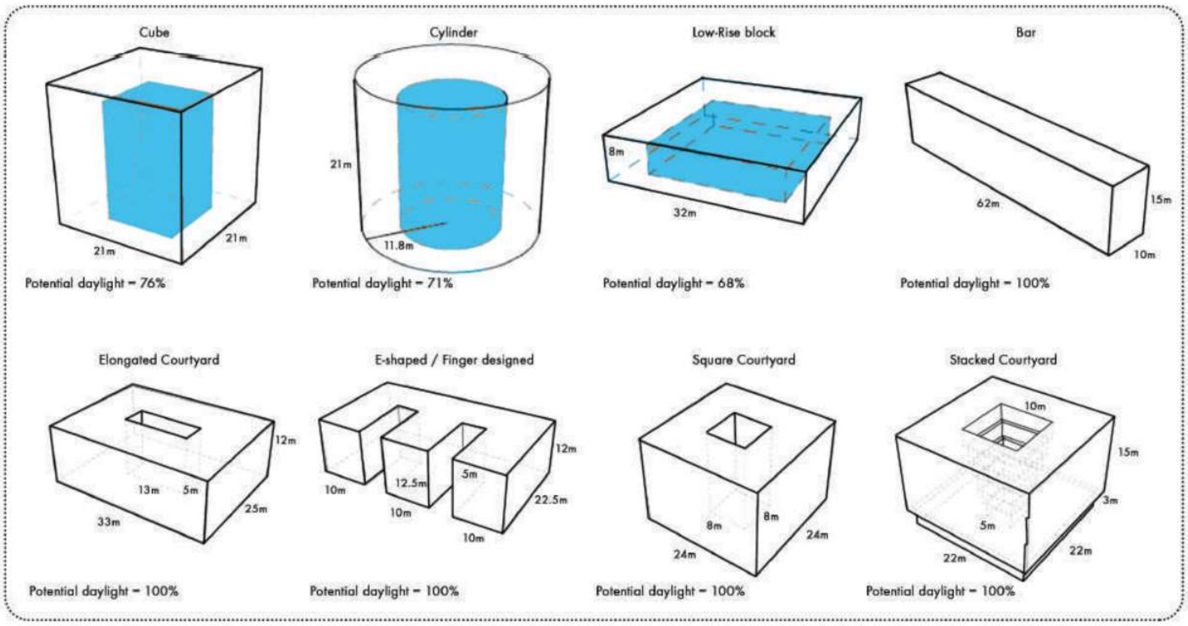


Fig 6.15 *Massing studies for daylight area*
(Adapted from MIT open course work – Sustainable Building Design)

6.08 Shading Design:

The use of fixed or movable devices to block, absorb, or redirect incoming light for purposes of controlling unwanted heat gains and glare is a function of the shading system. The main purpose to provide shading in a window is to obstruct, diffuse, or reduce the penetration of direct solar radiation majorly during summer days and provide shade to the indoor space and to reduce heat gain in a building thereby decreasing overall loads. Shading devices are important design elements of glazed facades to reduce energy consumption of buildings and to optimize thermal and visual comfort of occupants. Shading devices may be attached to the interior or exterior facade surfaces to control daylight, solar heat gains, glare, view, and heat loss through facades. External fixed shading can be categorized majorly into four typologies as mentioned in [Figure 6.16]:

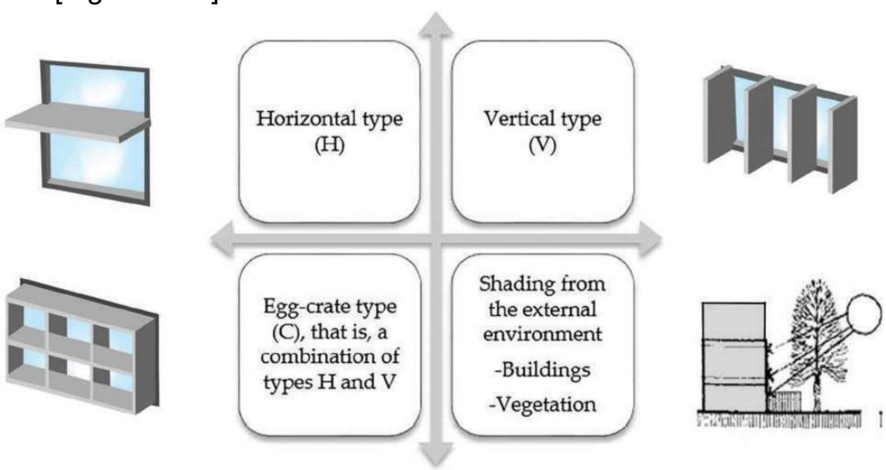


Fig 6.16 *Shading Technologies*

7.0 Daylighting Performance Metrics

The daylight performance metrics helps in determining the daylight availability and its performance in any indoor space with respect to the parameters discussed in the previous section. The parameters include site-specific conditions, dynamic interactions between buildings, use of the building by its occupants, and the surrounding climate considered on an annual basis.

7.01 Daylight Factor:

Daylight factor (DF) is defined as the ratio of interior illuminance to outdoor illuminance at the same time under an overcast sky condition. The DF is a commonly used measure for calculating the subjective daylight quality and availability in a room. The higher the DF, the more natural light is available in the room. The DF is depended upon the latitude; hence, DF is different for a same type of building constructed at different locations due to a change in outdoor illuminance. [19] It is expressed as,

$$DF = 100 * E_{in} / E_{ext}$$

E_{in} = inside illuminance at a fixed point
E_{ext} = outside horizontal illuminance under an overcast (CIE sky) or uniform sky

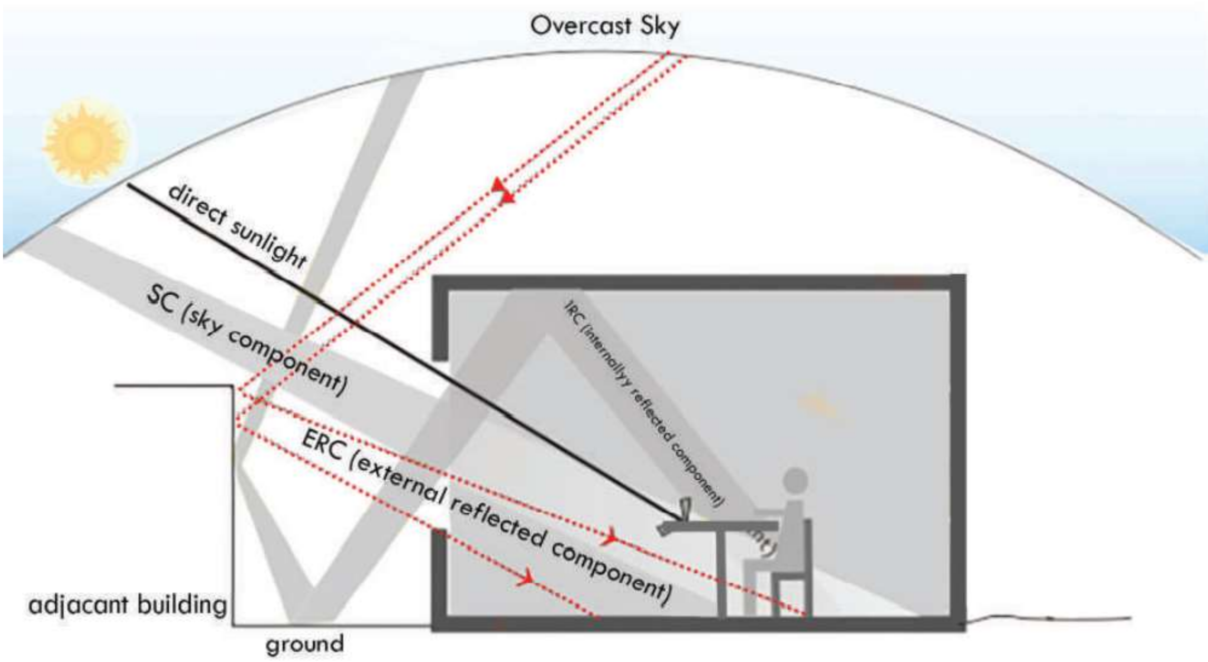


Fig 7.01 *Daylight factor illuminance*

Table 12 *Recommended value for illumination and daylight factor for residential space*

Recommended values of illumination for residential space (lux)		
1.	Kitchens	200
2.	Bathrooms	100
3.	Stairs	100
4.	Workshops	200
5.	Garages	70
6.	Sewing and darning	700
7.	Reading (casual)	150
8.	Homework and sustained reading	300
Recommended daylight factors for residential space (%)		
1.	Kitchen	2.5
2.	Living room	0.625
3.	Study room	1.9
4.	Circulation	0.313

7.02 Daylight Autonomy:

One of the metrics is the daylight autonomy (DA) which was first mentioned in 1989 by the Swiss norm and redefined by Reinhart and Walkenhorst in 2001. It is defined as the percentage of the occupancy time during the year when a minimum illuminance threshold is met by daylight alone considering overcast sky conditions throughout the year. [20]

In simpler terms, DA is the percentage of annual work hours during which all or part of a building's lighting needs can be met through daylighting alone. This helps in designing a space to maximize the amount of useful daylight, and thereby minimize or eliminate the need for supplemental electric light. Therefore, the higher the DA value, the lower the switching on time of electric lighting, which means higher the energy savings.

*Note**DA contains no upper limit on illuminance levels, so spaces with too much direct sunlight may also have higher sDA levels, but may not imply a comfortably lit space.* [20]

Continuous and Spatial Daylight Autonomy

Continuous daylight autonomy (DA_{con}) is an extension of the DA metric, which was proposed by Zack Rogers in 2006 [21]. This metric is defined as the percentage of the occupied time during the year when a minimum illuminance threshold is met by daylight alone, considering a partial credit linearly to values below the threshold defined [22].

Whereas, spatial daylight autonomy (sDA) is defined as the percentage of floor area that receives at least 300 lux for 50% of the annual occupied hours [23]. This concept does not refer to a given point and cannot be categorized under dynamic daylight performance metrics because it analyses daylight use for an entire surface. Generally, sDA (300 lux, 50%) >50% is accepted as already discussed but, sDA (300 lux, 50%) >75% is preferred and considered better.

There is a wide range of daylight metrics available with no link between them. This in turn makes it difficult for designers to choose a suitable metric when assessing the potential of natural light of an architectural space. To understand the daylight performance metrics better, a relation between the DF, the minimum DA, and the illuminance threshold is demonstrated further for different latitudes [Fig 7.02]. The daylight availability changes with the change in latitude for a constant DF and illuminance threshold. [20]

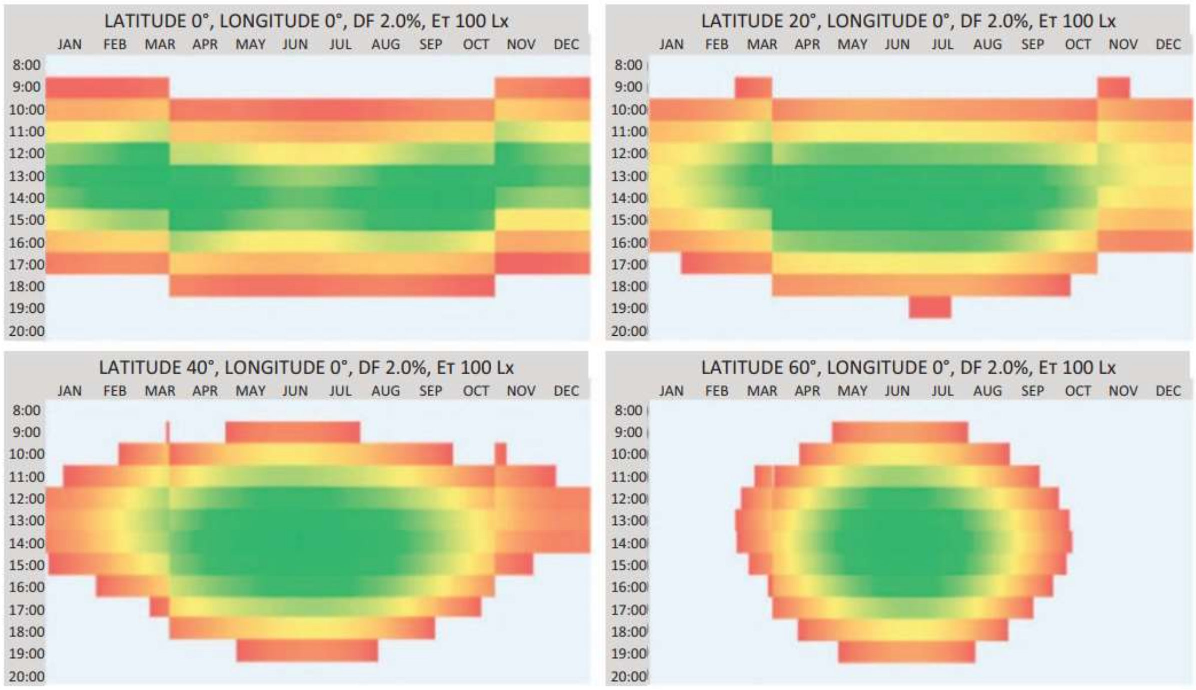


Fig 7.02 *Calculation of minimum daylight autonomy for different latitudes, a daylight factor of 2%, and an illuminance threshold of 100 lux*

7.03 Useful Daylight illuminance and Climate-based daylight modelling

The DF method for assessing the daylight performance is nearly 50 years old and has persisted in the market as one of the dominant evaluation metrics for daylighting because of its simplicity and direct approach.

Despite the lack of realism, designers have become accustomed to the DF method and design manuals following the calculation-based approach with a list of recommended minimum DFs for various settings or tasks. But, today the advances in computer simulation allow for the possibility of daylighting analyses that are based on hourly or sub-hourly predictions of internal illuminance for a full year. For these approaches, the hourly sun and sky conditions are derived from basic irradiance quantities found in meteorological datasets based on the sky model data collected with the help of simulation-based software.

For a calculation-based approach, the daylight illuminance uniformity that comes from using the standard overcast sky paradigm is inapplicable for realistic conditions where the contribution of direct sunlight leads to large differences between the maximum and the minimum daylight levels.

To overcome this issue, a new approach towards the evaluation came into practice known as the useful daylight illuminance (UDI). UDI is the percentage of time for which a space receives adequate daylight. Lux levels between 100 and 2000 are considered to be adequate lighting for visual comfort. Furthermore, instances when lux levels are below 100 may be classified as low daylight illuminance, and instances when lux levels are above 2000 lux may be classified as high daylight illuminance.

UDI = [[(X1*X2)*(Y+2)]/(Area of the Room)]*100

Where,
X1: Daylight extent factor,
X2: Head height of window, and
Y: Width of the fenestration.

Key Points

- The illuminance is considered at the point in a space between the lower and the upper threshold illuminance requirement of any space.
- If the daylight illuminance is too small (i.e., below a minimum), it may not contribute in any useful way to either the perception of the visual environment or in the carrying out of visual tasks.
- Conversely, if the daylight illuminance is too great (i.e., above a maximum), it may produce visual or thermal discomfort, or both, causing the occupant(s)
- The higher value of the useful daylight illuminance contributes to the availability of daylight and reflects in its performance.

7.04 Annual Sunlight Exposure

It is a percentage of the analysis area (space) that exceeds a specified direct sunlight illuminance level for more than the specified number of hours for the course of the experiment. Annual sunlight exposure (ASE) $_{1000/250h}$ = Percentage of a space that exceeds 1000 lux for 250 (~10%) of the occupied hours.

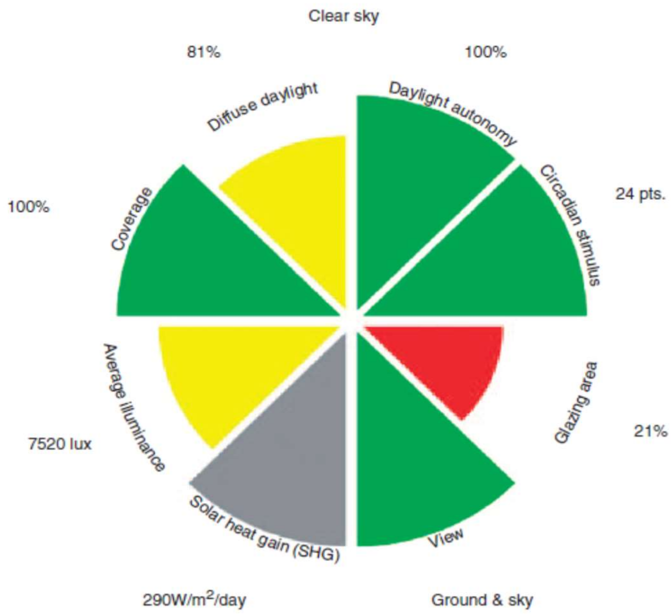
7.05 Conceptual design metrics for daylighting

by RP Leslie, LC Radetsky and AM Smith

"Daylight is a key component of green building; however, no prevailing metric has emerged to help identify buildings that are well-daylit buildings. This paper proposes a 'daylighting dashboard'; a visual representation of a design's potential to meet eight design goals: average illuminance, coverage, diffuse daylight, daylight autonomy, circadian stimulus, glazing area, view and solar heat gain. This metric allows for informed decisions to be made early in the conceptual phase of design, and highlights aspects of design that may need further development, while there is still the opportunity to make modifications. These eight goals should be prioritized as appropriate for individual projects, rating systems or code requirements. This early indication of performance of conceptual design alternatives is likely to guide architects to better daylit buildings." [20]

The most critical decisions for capturing daylight for building interiors come during the conceptual phase of architectural design, when the building’s site, configuration and fenestration are formulated. These decisions affect lighting quality and quantity, cost, view, solar heat gain and energy use. Simple metrics, applicable during conceptual design, can help designers choose among alternative configurations to be further developed and forewarn designers when further attention will be needed during design development to improve the final building performance. This study introduces a daylighting dashboard [Fig 7.03], a visual representation of a design’s potential of meeting eight design goals:

- **Average illuminance**: Provide sufficient daylight to perform tasks.
- **Coverage**: Avoid under-lit areas by distributing ambient light throughout the space.
- **Diffuse daylight**: Control glare by minimizing direct sun in all spaces with critical visual tasks.
- **Daylight autonomy**: Save energy by maximizing the time when electric lights can be turned off.
- **Circadian stimulus (CS)**: Provide sufficient light to promote circadian stimulation.
- **Glazing area**: Control construction costs by minimizing the area of windows or skylights.
- **View**: Provide views to the outside.
- **Solar heat gain**: Reduce building energy requirements and improve comfort by monitoring solar heat gain through glazing.



	Clear sky											
	Mar			Jun			Sep			Dec		
Time	9 a.m.	12 p.m.	3 p.m.	9 a.m.	12 p.m.	3 p.m.	9 a.m.	12 p.m.	3 p.m.	9 a.m.	12 p.m.	3 p.m.
Avg. illuminance (lux)	4337	12 731	11 149	1517	2314	2088	5069	12 968	10 622	7889	20 265	6059
Coverage (%)	100	100	100	100	100	100	100	100	100	100	100	100
Diffuse daylight (%)	87	83	83	100	100	100	87	83	83	50	40	50
Daylight autonomy (%)	100	100	100	100	100	100	100	100	100	100	100	100
Circadian stimulus (pts.)	2	2	2	2	2	2	2	2	2	2	2	2

[a]Glazing area: 24%, View: ground and sky, SHG (W/m^2/day): March, 366; June, 303; September, 394; December, 262.

Fig 7.03 *Simplified graphic developed from the Daylight Metric data*

7.06 Green Building Benchmarks for Daylighting

There are various daylight performance assessment benchmarks for residential buildings by various green rating system in India, like; GRIHA, IGBC, LEED etc. [Table 13].

***Table 13** Daylight performance assessment benchmarks for residential buildings by various green rating system in India*

S. No.	Rating System	Daylighting Benchmarks
1	GRIHA V. 2015	▪ Maximum WWR% = 60% ▪ Maximum SRR% = 5% ▪ The mean DA requirements (100* lux or more) should met over the total living area for at least 25% of total annual analysis hours ▪ The mean DA requirements (3000 lux or more) should never exceed over the total living area for across the total annual analysis hours
2.	IGBC Rating System for green affordable housing (2017)	▪ Achieve minimum glazing factors for at least 50% of the regularly occupied spaces in each dwelling unit ▪ Glazing Factor = $\frac{\text{Window Area (sqm) X Actual VLT of glass X Constant X 100}}{\text{Floor Area (sqm)}}$ *Where, constant values for windows on wall = 0.2 and window on roof (skylight) = 1.0* ▪ Glazing factor values for: ✓ Living/Bedroom = 1 ✓ Multi-purpose room = 1 ✓ Kitchen = 2 ▪ Simulation approach: Daylight illuminance measurement for 50% of the regularly occupied spaces in the building should achieve daylight illuminance levels for a minimum of 110 lux
3.	WELL Building Standard-Multifamily Residential	▪ Spatial daylight autonomy (sDA300, 50%) is achieved for at least 55% of the regularly occupied space. In other words, at least 55% of the space receives at least 300 lux of daylight for at least 50% of the operating hours each year. ▪ Annual sunlight exposure (ASE1000, 250) is achieved for no more than 10% of the regularly occupied space. In other words, not more than 10% of the area can receive more than 1000 lux for 250 hours each year ▪ Window/wall ratio, as measured on external elevations, is: ✓ Between 30% and 60% in living rooms ✓ Between 20% and 40% in bedrooms
4.	LEED V4. Residential-Multifamily	▪ **Minimum access to daylight in each living space:** Achieve a minimum of 10 lux of daylight for at least 90% of the floor area of each regularly occupied space in all residential units ▪ **Adequate daylight for the building:** Achieve levels between 150 and 5000 lux for at least 50% of the regularly occupied floor area ▪ Spaces that incorporate blinds or shades for glare control may demonstrate compliance for only the minimum 150 lux level. ▪ **Quality views:** For at least 50% of the regularly occupied spaces in each residential unit, have one window that includes one of the following: (1) flora, fauna, or sky; or (2) objects at least 25 feet from the exterior of the window ▪ Views into interior atria may be used to meet up to 30% of the required spaces in the building

8.0 Daylighting: Rule of Thumb

The design professional frequently depends on rules-of-thumb to estimate the area of windows that allows good utilization of daylight. These rules-of-thumb are the (1) 2.5 rule, (2) one tenth rule, and (3) 15/30 rule. None of these rules-of-thumb is tailored to a specific building type fitted with a specific glass type in a specific climate. Rules-of-thumb are meant to be simple in order to be user-friendly.

8.01 Window head height: The rule of 2.5:

The higher the window head, the deeper will be the penetration of daylight. As a general rule of thumb, the depth of daylit zone is typically 2-times the window head height [Fig 8.01]. If a space does not require the use of a shading device, the ratio range can increase up to 2.5 times.

The rule of 2.5 assumes that, for office tasks, side-lighting (windows) can provide effective illumination for depths up to approximately 2. 5 times the height of the window head above the work-plane (Allen et al, 2002).

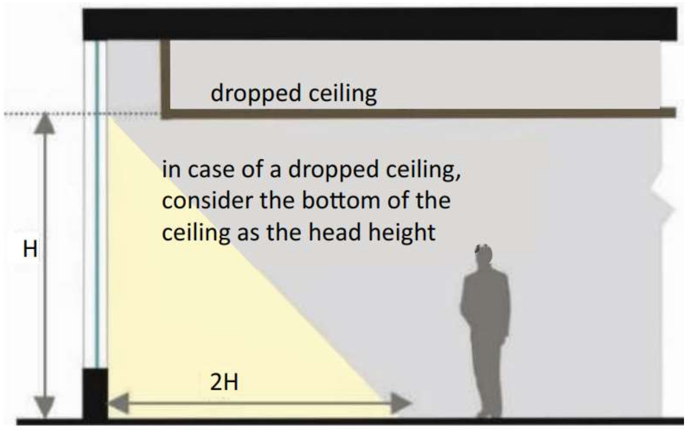


Fig 8.01 *Daylight area window head height thumb rule*

In addition to this rule, the daylit area for vertical fenestrations, majorly rectangular and square-shaped windows, can be easily evaluated by taking an offset of 1 m along the width of the window and two-times the height of the window on the floor plan. As shown in Figure 8.02, the daylit area extends ‘a horizontal dimension equal to the width of the window plus either 1 m (3.3 ft) on each side of the opening, the distance to the opaque partition, or one-half the distance to an adjacent skylight or window, whichever is least.

8.02 Atrium rule of thumb

To daylit all spaces bordering an interior atrium with diffuse daylight, the maximum atrium height should be about 2.5-times its width. [Fig 8.03]

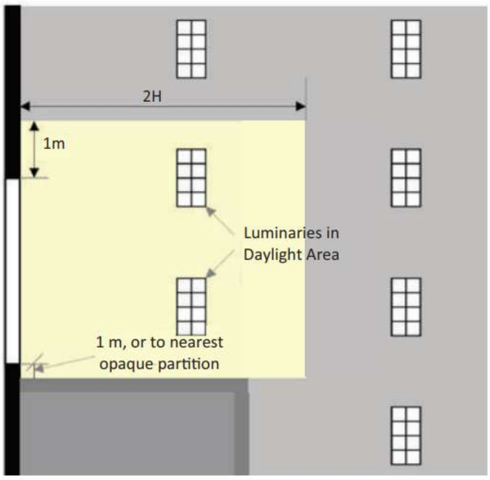


Fig 8.02 *Daylight evaluation thumb rule for rectangular or square windows*

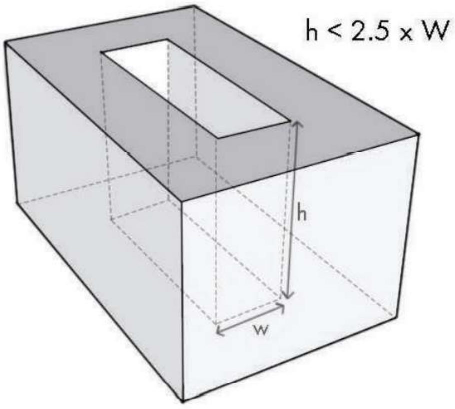


Fig 8.03 *Atrium rule of thumb*

8.03 The 15/30 rule of thumb

As per the 15/30 rule, illumination level due to daylight is sufficient for the tasks within the first 15 feet from the window, and 50% benefit of daylight happens within the next 15 feet, while areas deeper than 30 feet receive no benefit of daylight. (Moore, 1993).

8.04 The One Tenth rule

As per the 15/30 rule, illumination level due to daylight is sufficient for the tasks within the first 15 feet from the window, and 50% benefit of daylight happens within the next 15 feet, while areas deeper than 30 feet receive no benefit of daylight. (Moore, 1993).

The one-tenth rule states that the minimum DF in a daylit space is approximately one tenth of glass ratio, which is defined as the area of the glazed window divided by the gross area of the exterior wall (Moore, 1993). For example if the minimum desired DF is 3%, the glass ratio should be ten-fold, i.e., 30%.

8.05 Discussion

None of these rules-of-thumb is tailored to a specific building type fitted with a specific glass type in a specific climate. Their use most likely results in downsizing or oversizing windows for the visual task performed in the space. Indeed, rules-of-thumb are meant to be simple in order to be user-friendly, however, in this case, they are rather simplistic and ignore many crucial factors that influence the performance of daylighting systems. The experiment performed by *Khaled Mansey* performed a series of experimental studies in which he tested several physical models under an artificial sky dome in order to obtain accurate results due to the use of the rules-of-thumb under consideration. [20]

Indeed, the rules-of-thumb are seen as the simplest and easiest design-assisting type of tools to use. However, they may be misleading. In case of rules-of-thumb for daylighting design, they are not accustomed to a specific building type, visual task, glass type, or a specific climate. Availability of daylight, both in terms of light intensity and duration per time, experience wide variations in different climates due to sun position and cloud cover. Rules-of-thumb for daylighting design ignore the following factors[20]:

- Building location which, in return, determines the apparent sun movement (daily and seasonal) and the available intensity of daylight.
- Sky condition that may range from clear sky (no cloud cover) to overcast sky (100% cloud cover).
- Ground reflection that may affect the reflected light components off the ground into bottom floors of the building.
- Space orientation which determines which side of the sky dome the space may receive light from. For example, is the space facing the bright south sky or the less bright north sky (assuming a location in the Northern Hemisphere)?
- Glass ratio, which is the area of glazed windows to the gross area of the exterior wall.
- The visual task performed in the space, since different visual tasks require different intensities of light on the work-plane.

9.0 Simulation & Analysis on Daylighting Parameters:

A sample case analysis of "The Kolkata Municipal Corporation Building Rules, 2009" through software simulation.

Kolkata, the capital of state West Bengal, is one of the densely populated metro-city of India and as per the report of Census of India,2011, the total urban non-institutional / residential household under the Kolkata Municipal corporation (KMC) is hovering around one million with population over 4.4 million. As per the byelaws of 'The Kolkata Municipal Corporation Building Rules, 2009', there are specific guidelines to erect or renovate or alter the buildings, like, Ground coverage, FAR, Height of the buildings, etc. and along with the growth of urban population and economic wellbeing of society, KMC has altered the guidelines along with the times with relaxed Ground coverage, maximum FAR & more permissible height.

In this chapter, an analysis has been performed through software simulation, and the variation of daylighting metrices with the variation of daylighting tools has been observed. For the simplification of the analysis, a symmetric rectangular build form with identical floor at each level has been opted as the 'Test Residential Building Enclosure' with the identical volume of neighbourhood or surrounding building. [Fig 9.01]

9.01 Test Consideration:

- Location: Kolkata Metropolitan Area, with coordinates 22.57° N, 88.36° E
- Sample Plot: 200 Sq.m. (20m x 10m) with 3.6m Road in front
- Simulation Time: 21st March, 12 p.m.
- Modelling Software: AutoCAD & Trimble SketchUp
- Simulation Software: VELUX Daylight Visualizer, validated against CIE 171:2006 Test cases.
- Building Regulation: The Kolkata Municipal Corporation Building Rules, 2009
- Building Dimension: 15.6m(L)x7.4m(B) with height of 11.2m, including 1.2m parapet. 3nos of floor, each of Floor Area 115.44 Sq.m or 120Sq.m apx, Which complies with the permissible residential building parameters of Ground coverage of 60% as per A-45, point 70, maximum FAR of 1.75 as per A-43, point 69, and minimum open spaces of 1.2m each side with 3m in rear as per A-39, point 62 and permissible height of 10m (exemption of 1.2m height for parapet) as per A-47, point 74 &76, and total 10nos of windows of each size 1.2m(H) x 1.0m(W), symmetrically distributed as per NBC 2016 with minimum 10% area of aggregated floor area as per A-62, point 121.(3). Width of Chajja or Weather shed has been considered 450mm (maximum permissible 600mm).
- Opening Condition: Closed Door and Open Window.

- Plinth Height: 600mm
- Window Sill: 900mm from finished floor level of each floor
- Working Plane: 800mm from finished floor level of each floor
- Sky Consideration: CIE Standard Overcast sky

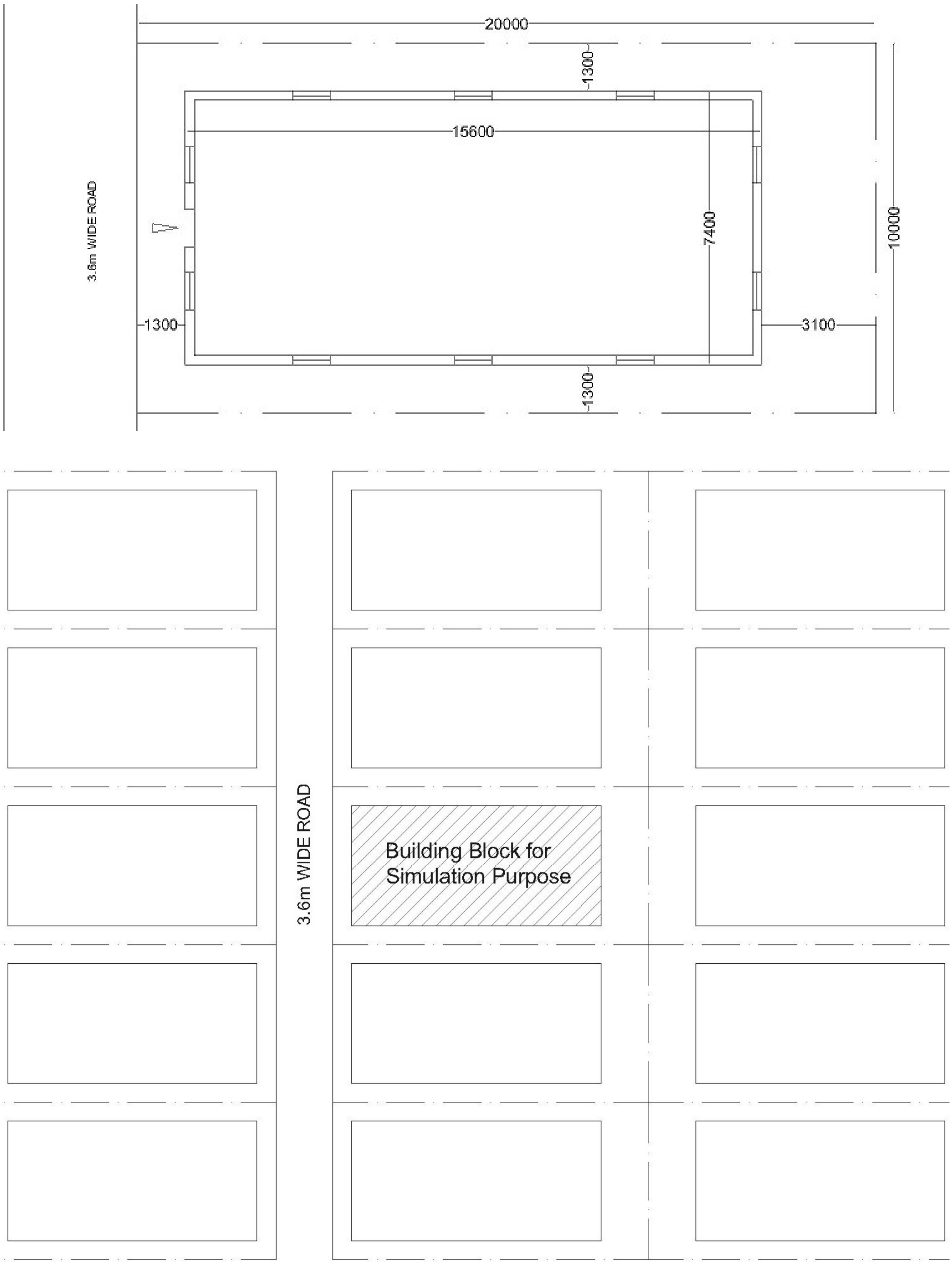


Fig 9.01: *Building and Site Layout*

9.02 Simulation with varying Window to Floor Area Ratio:

As per the KMC, *"in no case, the minimum aggregate area of the openings of habitable rooms and kitchen, excluding doors, shall not be less than one tenth of the floor area."* In this part, the variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the varying Window -Area Ratio for every 5%, from 10% to 25%, have been observed and comparative test results has been shown in Table 14.

10% Window-Area Ratio:

Total 10 Nos. of window, each of size 1.2m (H) x 1.0m (W). Total 12Sq.m against total Floor area of approx. 120 Sq.m. [Figure 9.02]

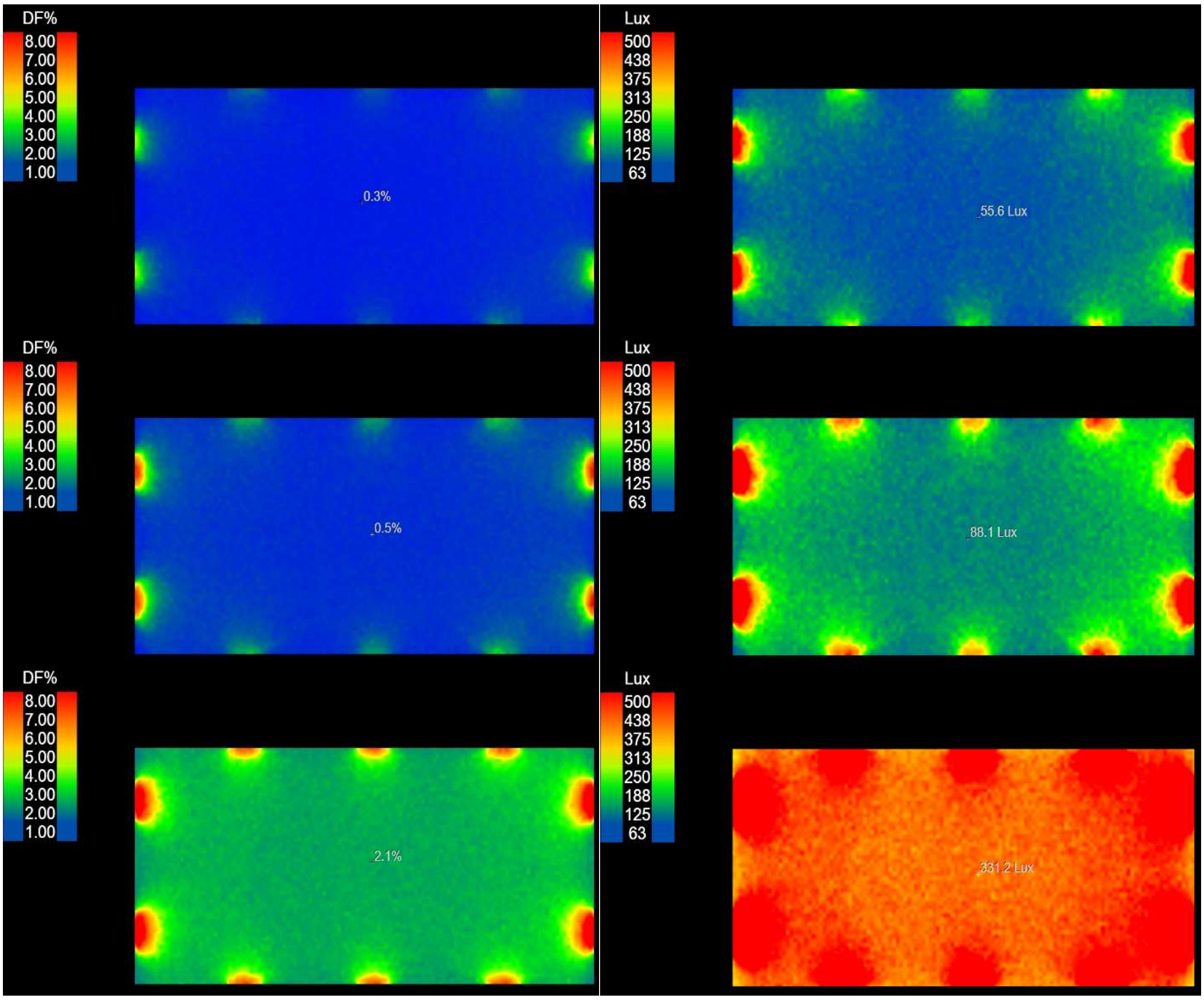


Figure 9.02*: Simulation Output at 10% Window Floor Area Ratio (From top to bottom; G Floor, 1st Floor & 2nd Floor)*

15% Window- Area Ratio:

Total 10 Nos. of window, each of size 1.2m (H) x 1.5m (W). Total 18 Sq.m against total Floor area of approx. 120 Sq.m. [Figure 9.03]

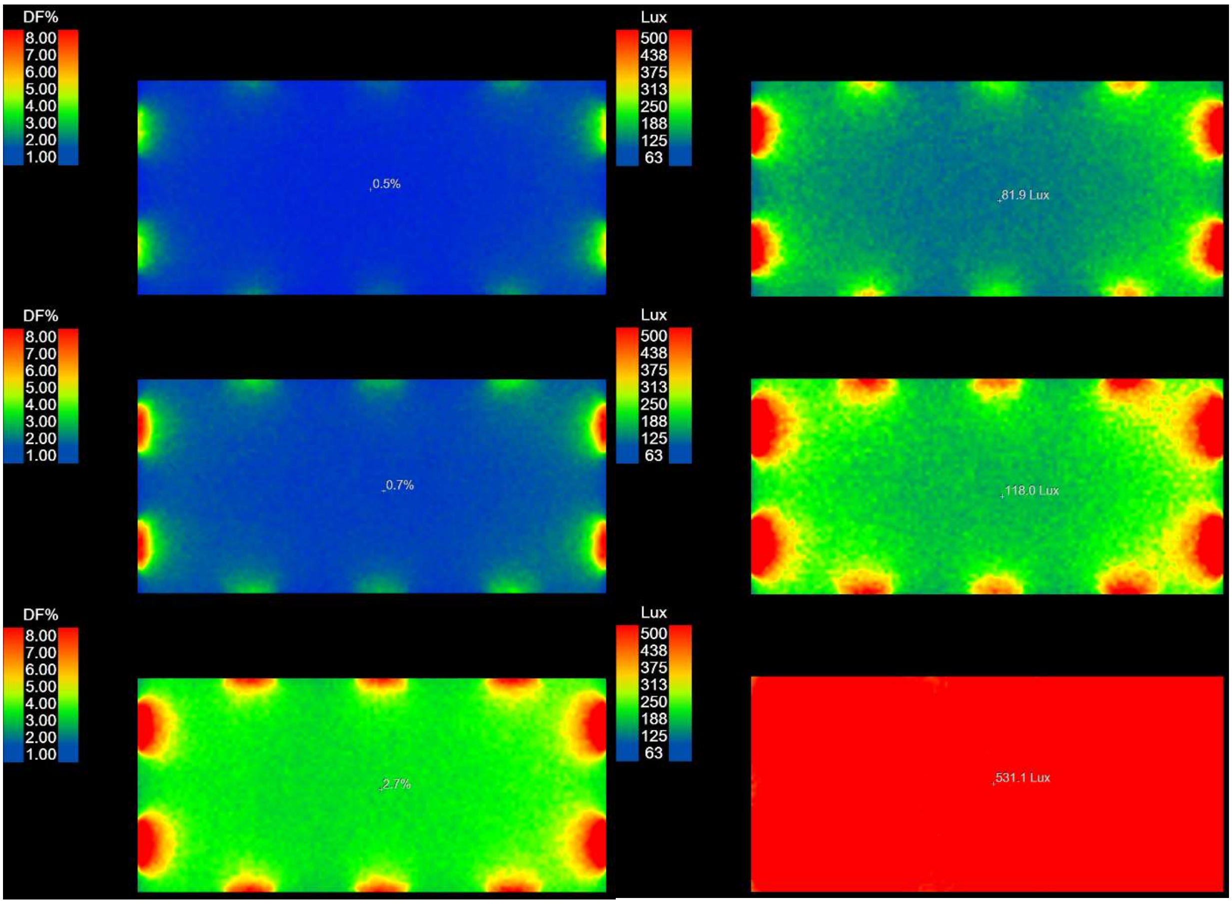


Figure 9.03: *Simulation Output at 15% Window Floor Area Ratio (From top to bottom; G Floor, 1st Floor & 2nd Floor)*

20% Window-Area Ratio:

Total 10 Nos. of window, each of size 1.2m (H) x 2.0m (W). Total 24 Sq.m against total Floor area of approx. 120 Sq.m. [Figure 9.04]

25% Window-Area Ratio:

Total 10 Nos. of window, each of size 1.2m (H) x 2.5m (W). Total 30 Sq.m against total Floor area of approx. 120 Sq.m. [Figure 9.05]

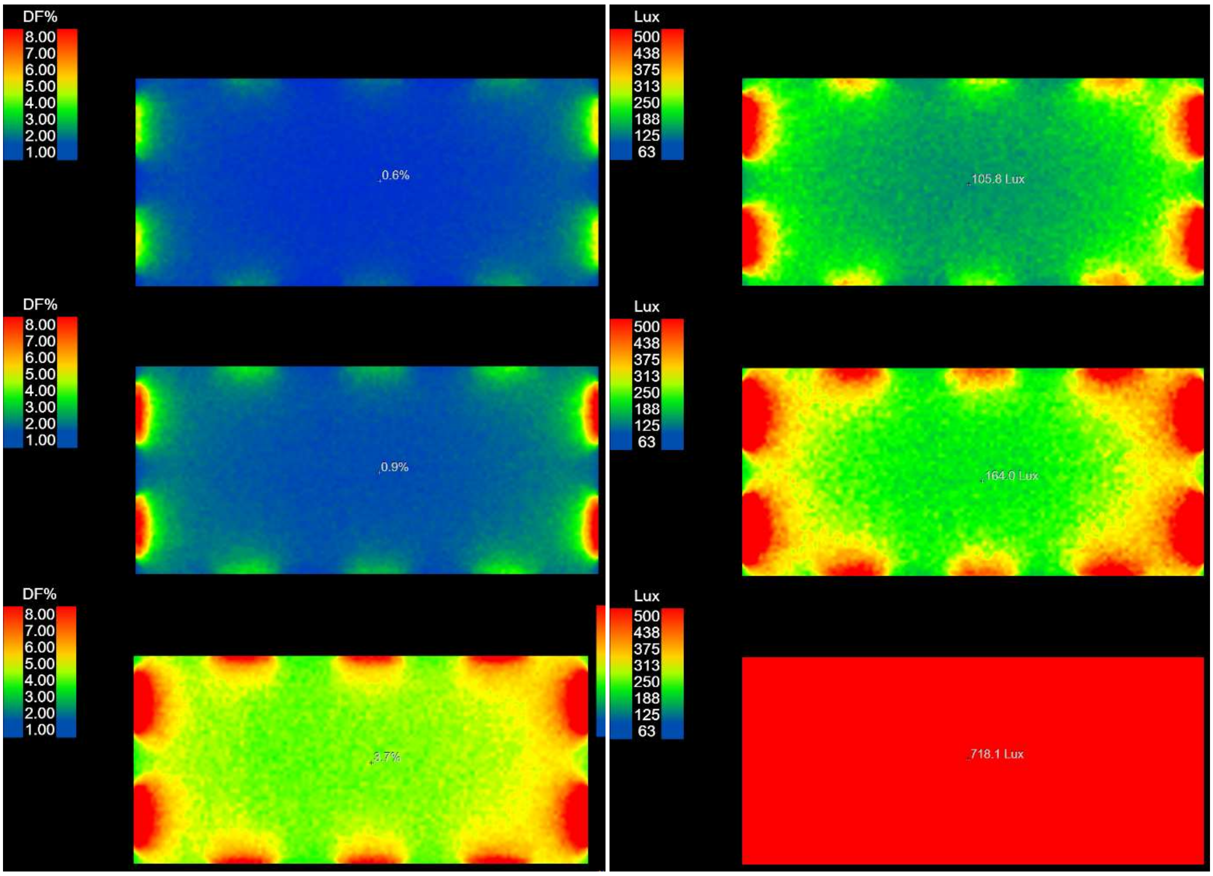


Figure 9.04: *Simulation Output at 20% Window Floor Area Ratio (From top to bottom; G Floor, 1st Floor & 2nd Floor)*

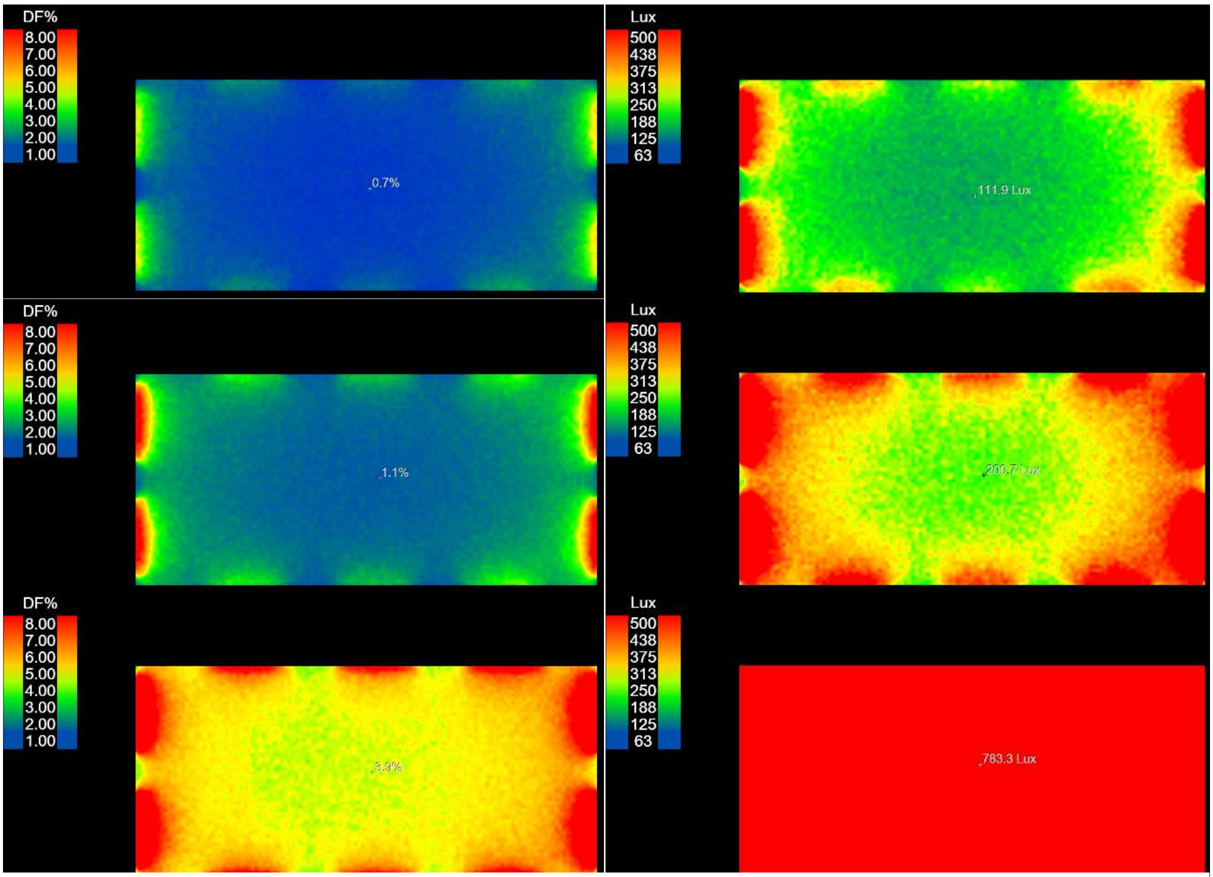


Figure 9.05: Simulation Output at 25% Window Floor Area Ratio (From top to bottom; G Floor, 1st Floor & 2nd Floor)

Table 14: *Daylighting Metrices Comparison with varying Window Floor Area Ratio*

Daylight Factor Parameters	GROUND FLOOR				FIRST FLOOR				SECOND FLOOR			
	W 10%	W 15%	W 20%	W 25%	W 10%	W 15%	W 20%	W 25%	W 10%	W 15%	W 20%	W 25%
$D_{average}$ [DF%]	0.55	0.8	1.04	1.22	0.9	1.3	1.65	2.03	2.61	3.63	4.69	5.43
D_{median} [DF%]	0.44	0.65	0.87	1.01	0.71	1.04	1.32	1.63	2.29	3.17	4.12	4.76
D_{min} [DF%]	0.22	0.31	0.48	0.55	0.33	0.54	0.76	0.98	1.43	2	2.84	3.1
D_{max} [DF%]	4.87	5.49	4.95	5.15	8.36	9.26	9.27	9.43	12.21	13.9	14.99	15.22
D_{min}/D_{avg}	0.40	0.39	0.46	0.45	0.37	0.41	0.46	0.48	0.55	0.55	0.61	0.57
D_{min}/D_{max}	0.04	0.06	0.10	0.11	0.04	0.06	0.08	0.10	0.12	0.14	0.19	0.20

Illuminance Parameters	GROUND FLOOR				FIRST FLOOR				SECOND FLOOR			
	W 10%	W 15%	W 20%	W 25%	W 10%	W 15%	W 20%	W 25%	W 10%	W 15%	W 20%	W 25%
$I_{average}$ (lux)	104.26	151.70	197.68	231.39	170.19	246.45	311.43	383.14	494.39	687.57	886.35	1027.19
I_{median} (lux)	84.15	123.81	164.26	192.03	133.96	197.18	250.04	310.09	432.57	599.18	778.81	901.47
I_{min} (lux)	41.26	58.68	82.47	100.93	62.66	104.62	145.90	183.85	270.69	377.84	531.64	592.81
I_{max} (lux)	920.90	1014.67	969.56	982.72	1581.71	1751.04	1722.66	1802.98	2309.54	2629.16	2826.59	2878.78
$F_{plane,\%} \geq 40\%$ (lux)	92.25	136.04	181.31	212.35	145.98	214.75	274.68	343.05	448.26	624.33	811.77	947.93
$F_{plane,\%} \geq 50\%$ (lux)	84.15	123.81	164.26	192.03	133.96	197.18	250.04	310.09	432.57	599.18	778.81	901.47
$F_{plane,\%} \geq 60\%$ (lux)	77.61	114.05	151.38	175.02	124.60	180.50	229.27	283.76	420.56	579.74	755.15	868.36
$F_{plane,\%} \geq 70\%$ (lux)	72.25	106.70	140.23	162.37	116.46	168.13	213.49	264.89	409.20	562.43	733.81	842.61
$F_{plane,\%} \geq 95\%$ (lux)	57.43	86.16	115.55	133.05	96.26	139.48	177.75	222.95	370.24	512.86	674.27	771.79
$I_{min}/I_{average}$	0.40	0.39	0.42	0.44	0.37	0.42	0.47	0.48	0.55	0.55	0.60	0.58
I_{min}/I_{max}	0.04	0.06	0.09	0.10	0.04	0.06	0.08	0.10	0.12	0.14	0.19	0.21

Graphical Representation

The variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the varying Window -Area Ratio for every 5%, from 10% to 25%, have been observed and comparative test results has been shown. [Figure 9.06], [Figure 9.07]

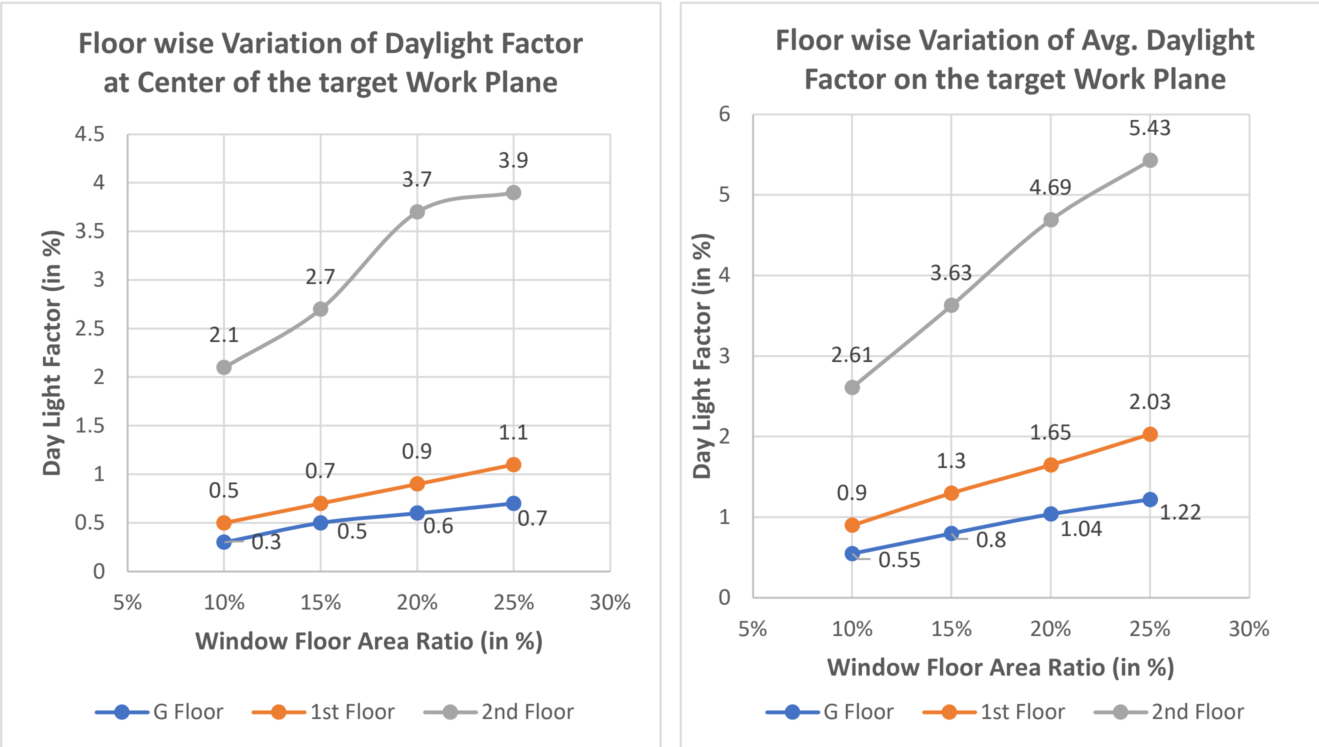


__Figure 9.06__: Graphical Comparison of Daylight Factor output w.r.t. Window Floor Area Ratio

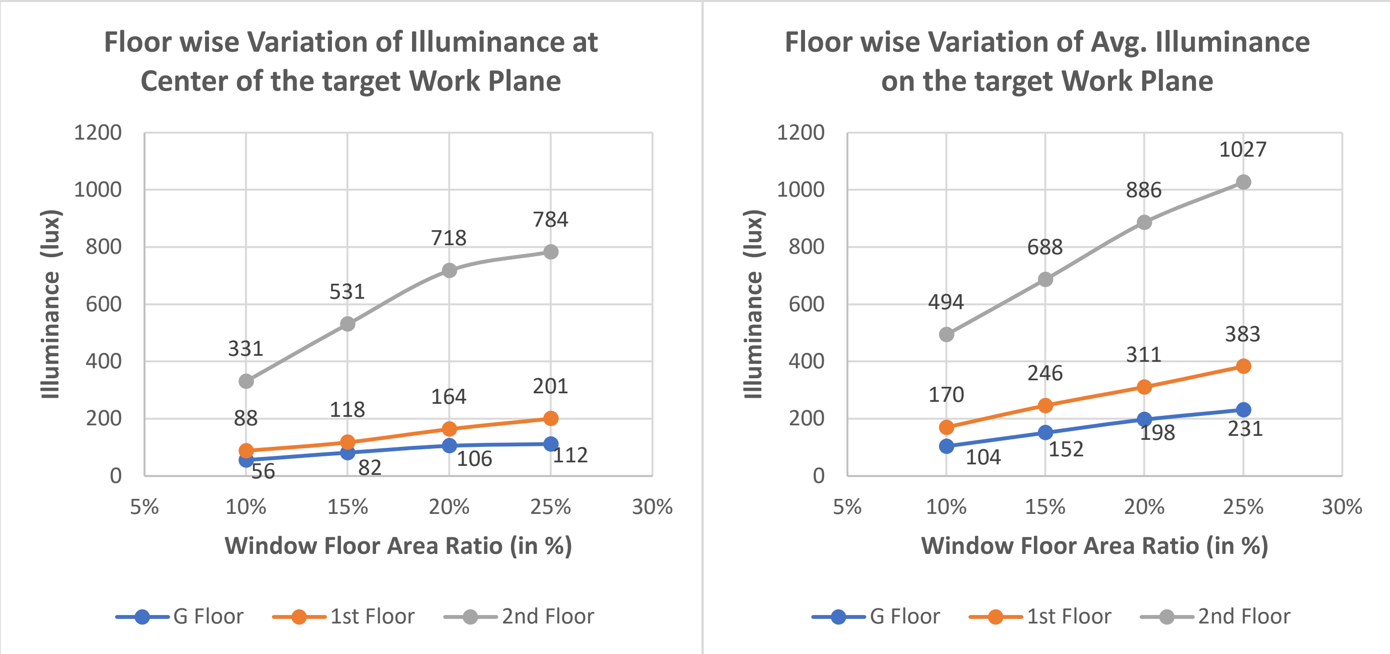


***Figure 9.07**: Graphical Comparison of Illuminance output w.r.t. Window Floor Area Ratio*

9.03 Simulation with minimising Height of Adjacent Building:

In this part, the variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the varying height of adjacent Building or obstruction etc. for every 1 meter, up to 3 meter, have been observed and comparative test results has been shown [Figure 9.11].

Minimising Height by 1 meter:

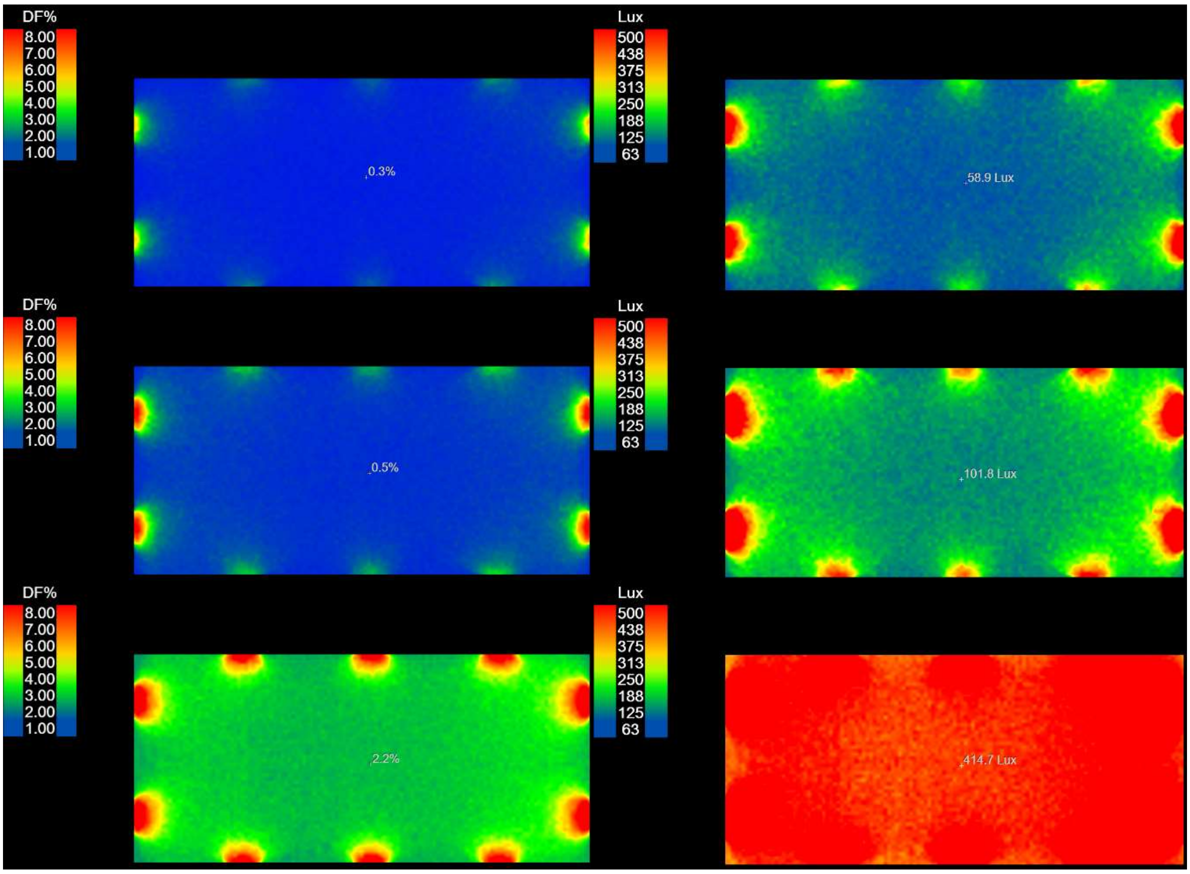


***Figure 9.08** Simulation after minimising 1m height of each adjacent building (Top to bottom; G Floor, 1st Floor & 2nd Floor)*

Minimising Height by 2 meter:

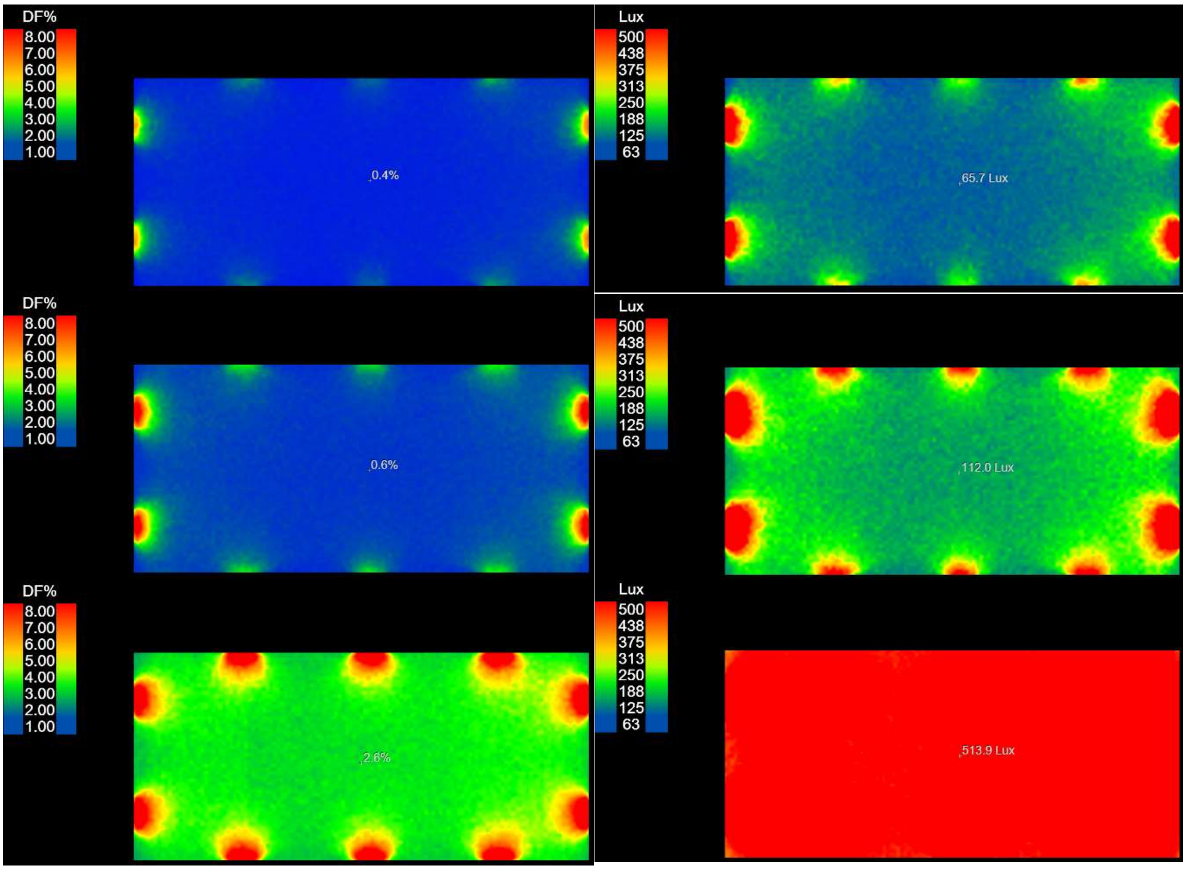


Figure 9.9 *Simulation after minimising 2m height of each adjacent building (Top to bottom; G Floor, 1st Floor & 2nd Floor)*

Minimising Height by 3 meter:

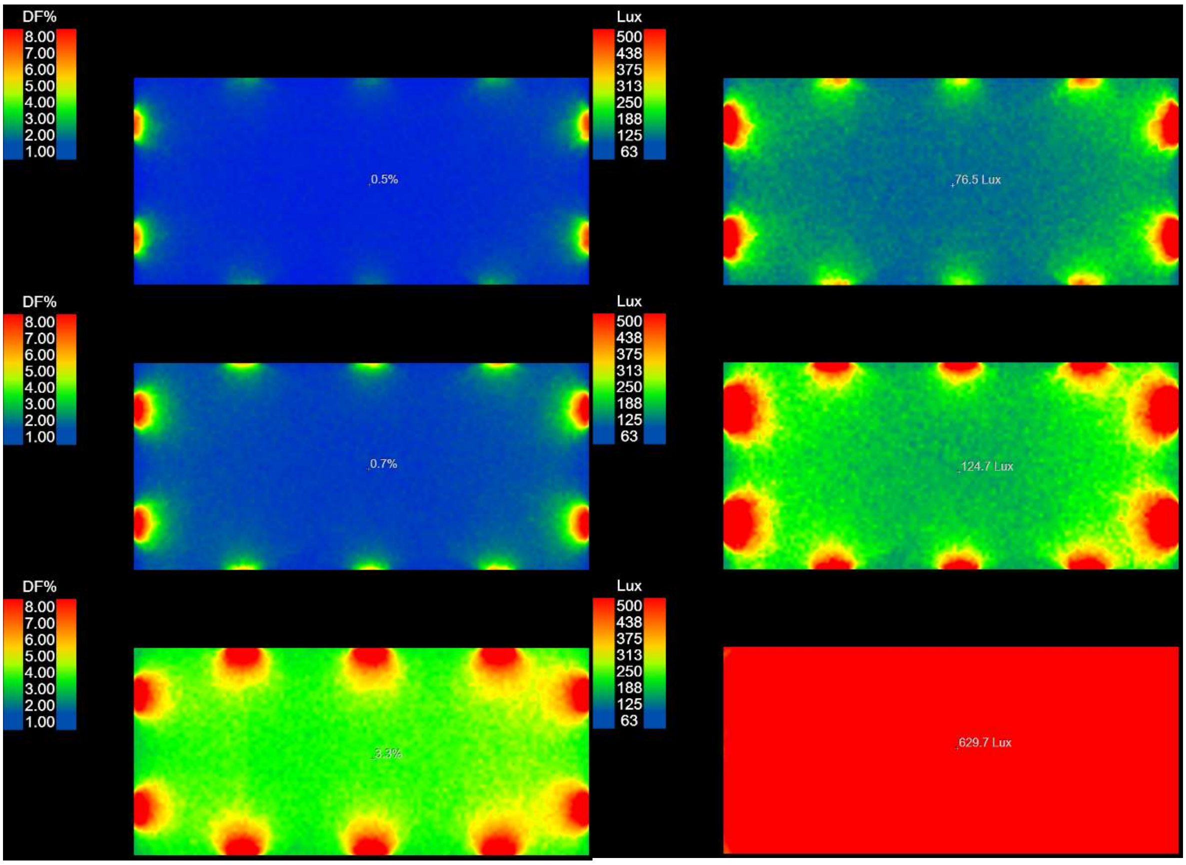


Figure 9.10 *Simulation after minimising 3m height of each adjacent building (Top to bottom; G Floor, 1st Floor & 2nd Floor)*

Graphical Representation

The variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the minimized height of the adjacent building block for every 1.0 meter, from 0-3 meter, have been observed and comparative test results has been shown. [Figure 9.11]

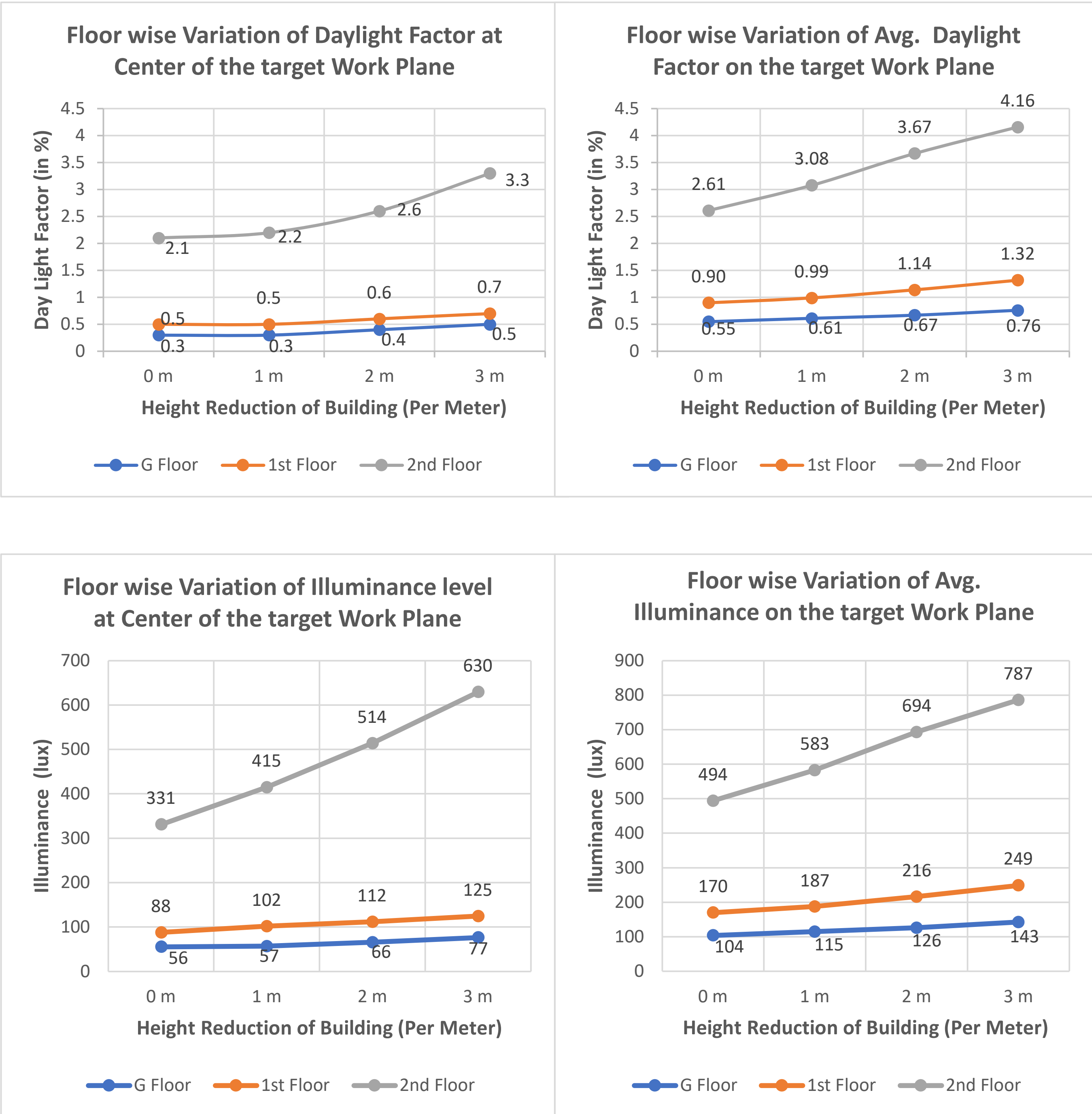


Figure 9.11 *Graphical Comparison of Daylight Factor and Illuminance w.r.t the variation of height of adjacent building*

9.04 Simulation with maximizing Sill Height of Windows:

In this part, the variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the varying height of window sill for every 100mm, from 0.9 meter up to 1.2 meter from finished floor at 1st Floor level of the Building, have been observed and comparative test results has been shown [Figure 9.13].

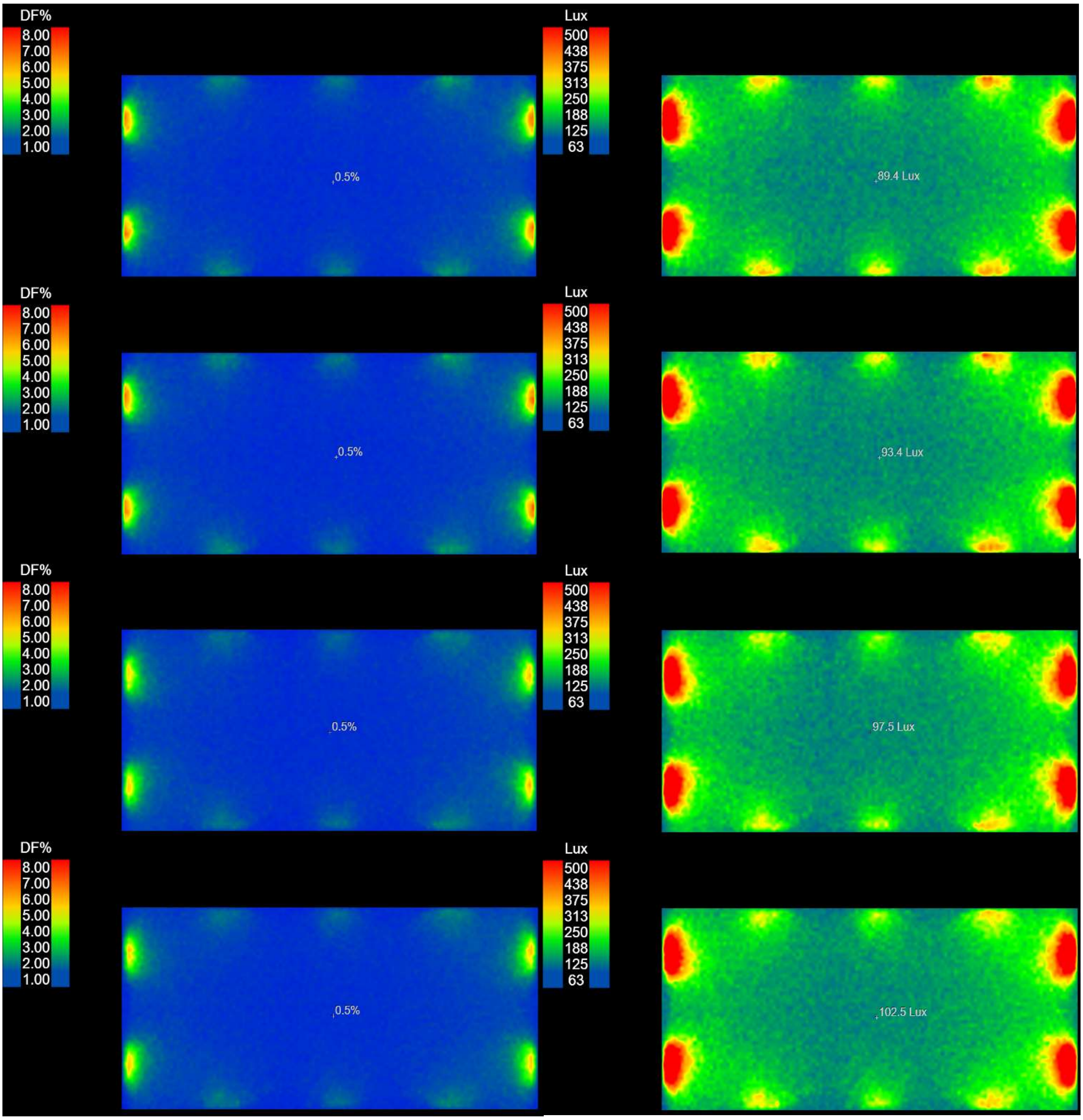


Figure 9.12 *Simulation with varying Window Sill Height (On Left: Daylight Factor, On Right: Illuminance, Top to bottom; 900mm, 1000mm, 1100mm, 1200mm)*

Graphical Representation

The variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the increasing window sill height for every 100 mm, from 0.9 meter to 1.2 meter, have been observed and comparative test results has been shown. [Figure 9.13]

Table 15: *Daylighting Metrices Comparison with varying Window-Sill Height*

Day Light Factor (%)			**Illuminance Factor (lux)**	
Sill Height	Day Light Factor at Center (%)	Avg. Day Light Factor (%)	Illuminance at Center (lux)	Avg. Illuminance Level (lux)
0.9m	0.50	0.90	88.00	170.00
1.0 m	0.50	0.89	89.40	168.47
1.1 m	0.50	0.89	93.40	168.85
1.2 m	0.50	0.90	97.50	170.26
1.3 m	0.50	0.90	102.50	170.95

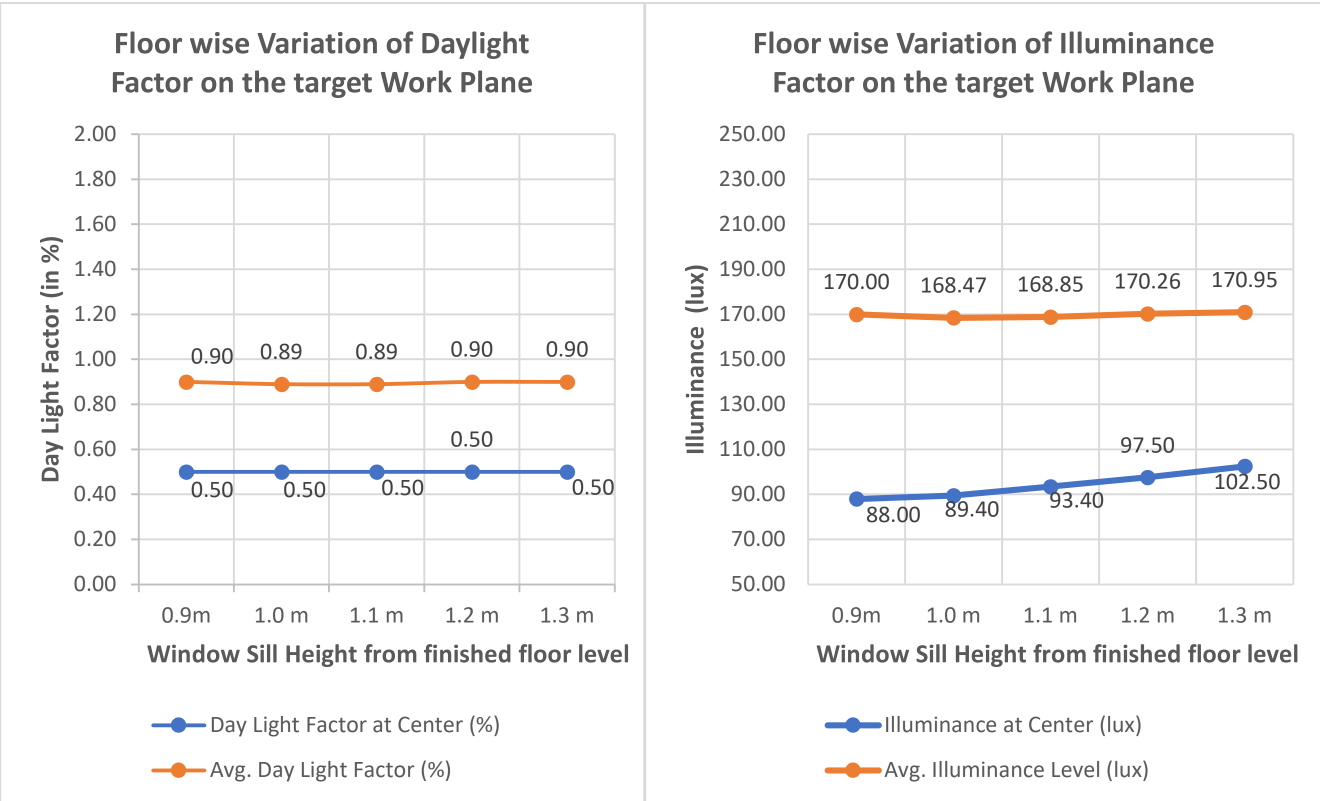


Figure 9.13 *Graphical Comparison of Daylight Factor and Illuminance w.r.t the variation of window sill height*

9.05 Simulation with varying depth of Window Chajja:

In this part, the variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the varying depth of window chajja for every 75mm, from 300mm up to 600mm at 1st Floor level of the Building, have been observed and comparative test results has been shown [Figure 9.14].

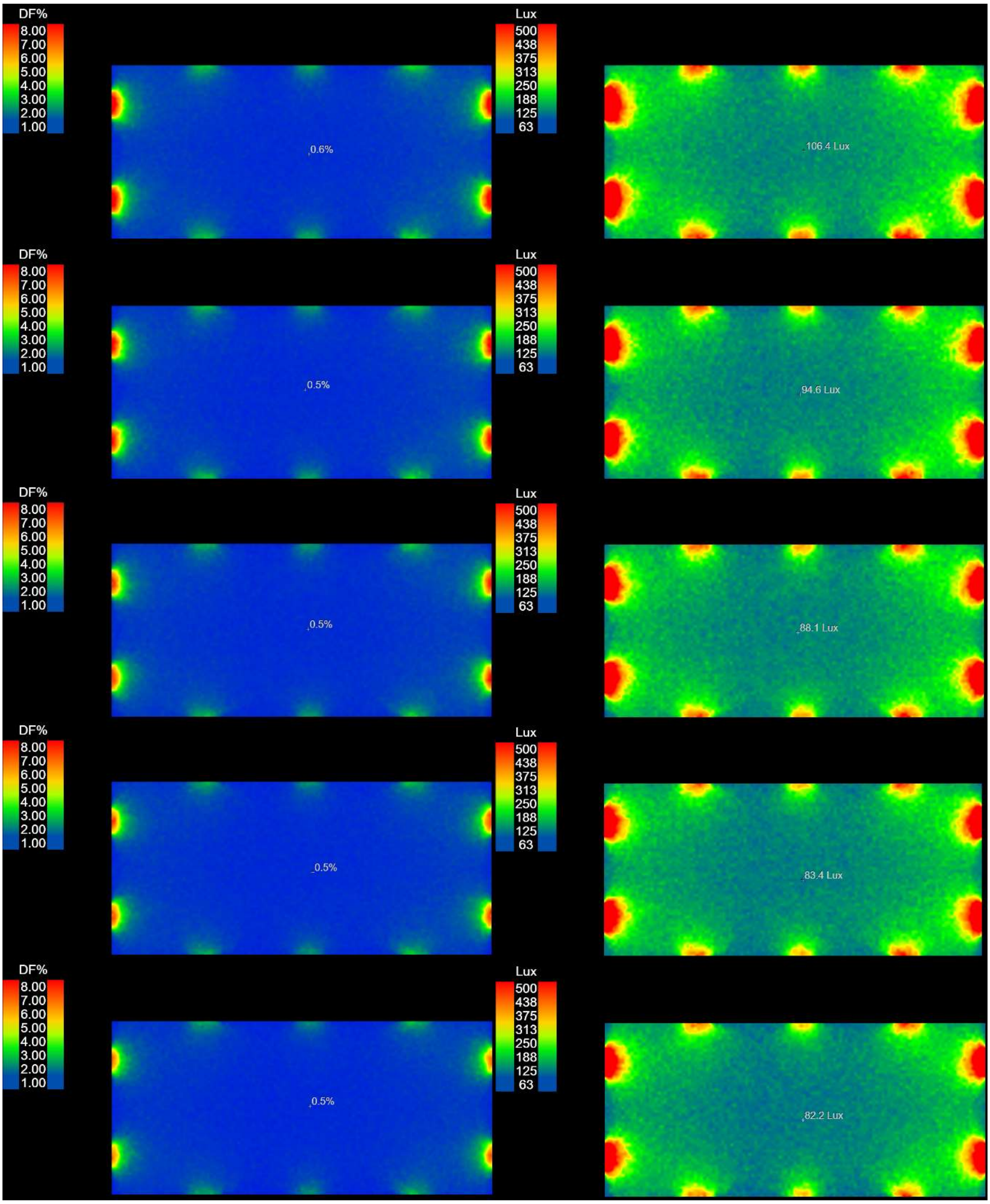


Figure 9.14 Simulation with varying Depth of Window Chajja (On Left: Daylight Factor, On Right: Illuminance, Top to bottom; 300mm, 375mm,450mm,525mm and 600mm)

Graphical Representation

The variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the varying depth of window chajja for every 75mm, from 300mm up to 600mm, have been observed and comparative test results has been shown in Table 16 and [Figure 9.15].

Table 16 *Daylighting Metrices Comparison with varying depth of Window Chajja*

Day Light Factor			Illuminance	
Chajja Depth	Day Light Factor at Center (%)	Avg. Day Light Factor (%)	Illuminance at Center (lux)	Avg. Illuminance Level (lux)
300mm	0.60	0.99	106.40	186.59
375mm	0.50	0.92	94.60	173.83
450mm	0.50	0.90	88.00	170.00
525mm	0.50	0.86	83.40	162.55
600mm	0.50	0.82	82.20	155.66

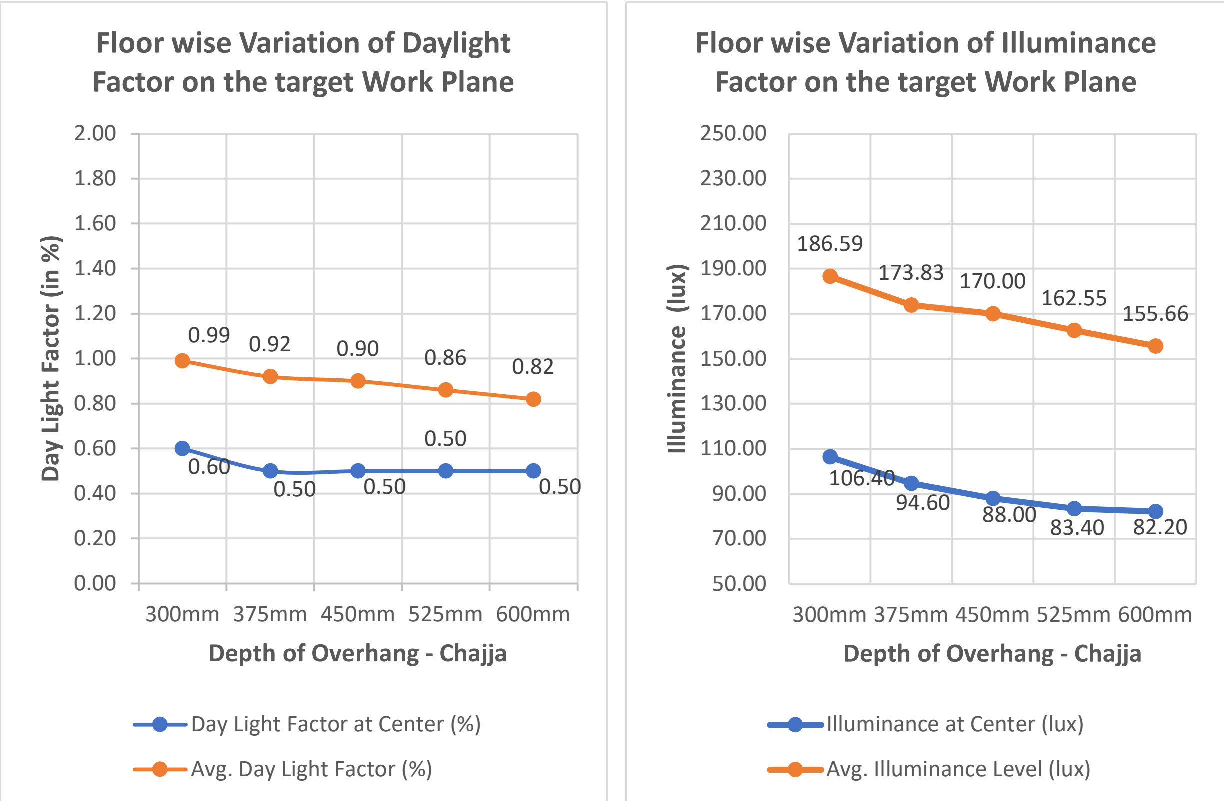


Figure 9.15 *Graphical Comparison of Daylight Factor and Illuminance w.r.t the variation of depth of Window Chajja*

9.06 Simulation with addition of Light shelve:

In this part, the variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the addition of Light shelve to the windows of the Building, have been observed for working plane of Ground floor and First Floor and comparative test results has been shown [Figure 9.16]. In this simulation, data comparison done with the Building with 15% window to Floor area ratio with window size 1.2m (H) x 1.5m (W) (without Light shelve) vs window size 1.8m (H) x 1.0m (W) with Light Shelve of depth 450mm, (where effective area of window is 10% and effective area of Light shelve is 5%) with material reflectance property not more than 0.55. [Table 17] [Figure 9.16]

Table 17 *Daylighting Metrices Comparison with inclusion of Light Shelve*

G FLOOR	Day Light Factor at Center (%)	Avg. Day Light Factor (%)		G FLOOR	Illuminance at Center (lux)	Avg. Illuminance (lux)
Window (10%) + LS (5%)	0.60	1.05		Window (10%) + LS (5%)	114.00	199.43
Window (15%)	0.50	0.80		Window (15%)	81.90	151.70
1ST FLOOR	Day Light Factor at Center (%)	Avg. Day Light Factor (%)		1ST FLOOR	Illuminance at Center (lux)	Avg. Illuminance (lux)
Window (10%) + LS (5%)	1.00	1.73		Window (10%) + LS (5%)	180.90	326.71
Window (15%)	0.70	1.30		Window (15%)	118.00	246.45

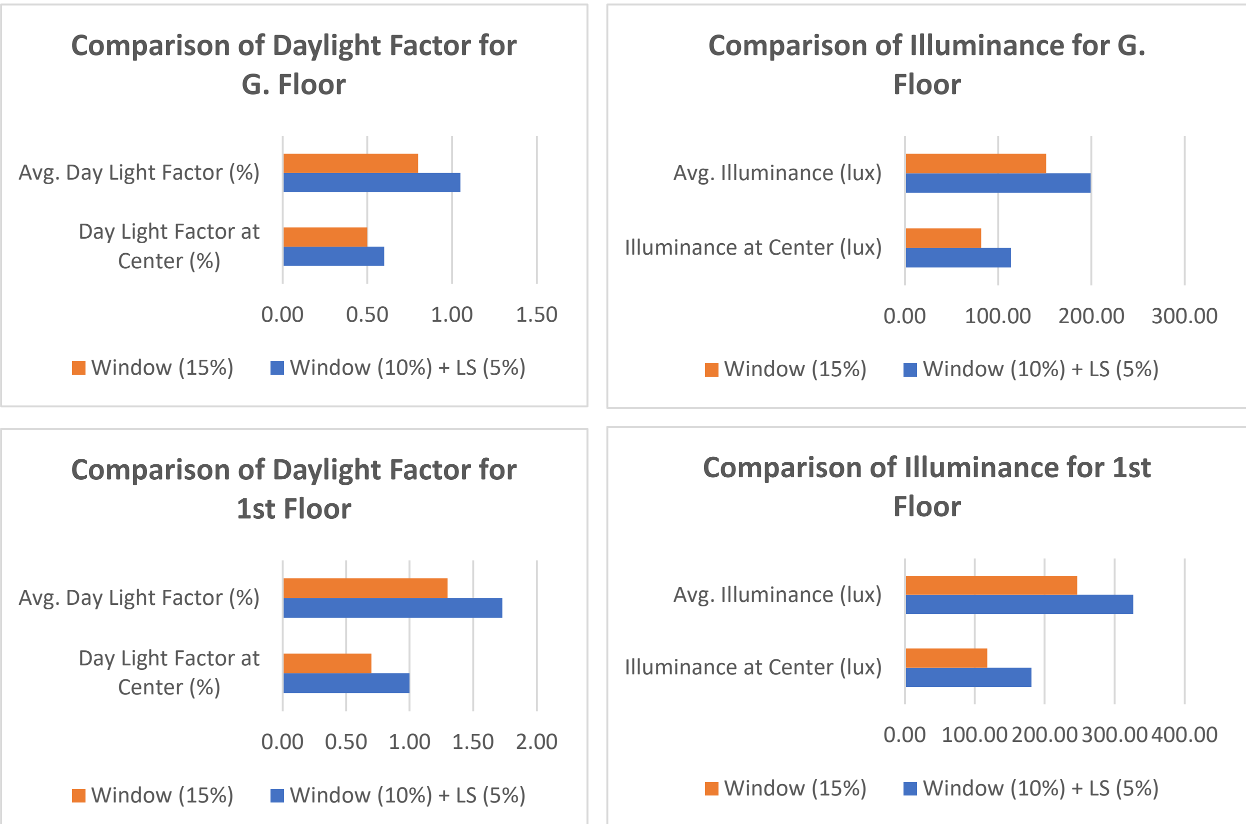


Figure 9.16 *Graphical Comparison of Daylight Factor and Illuminance with and without presence of Light Shelve*

9.07 Simulation with varying Orientation of Building:

In this part, the variation of daylighting parameters, like; Daylight Factors (%) & Illuminance (lux) with the change of orientation of the Building, from 0 degree to 180 degree, have been observed and comparative test results has been shown. [Table 17]. Simulation data were taken and plotted for the working plane of 1st Floor.

Table 18 *Daylighting Metrices Comparison with varying orientation of Building*

	Day Light Factor (%)		**Illuminance Factor (lux)**	
	Day Light Factor at Center	Avg. Day Light Factor	Illuminance at Center	Avg. Illuminance
0 deg	0.50	0.90	88.10	170.19
30 deg	0.50	0.89	84.50	168.06
45 deg	0.50	0.89	84.50	168.06
60 deg	0.50	0.89	90.20	168.06
90 deg	0.50	0.90	90.20	168.06
120 deg	0.50	0.89	89.00	168.06
135 deg	0.50	0.89	91.00	168.06
150 deg	0.50	0.89	89.40	168.06

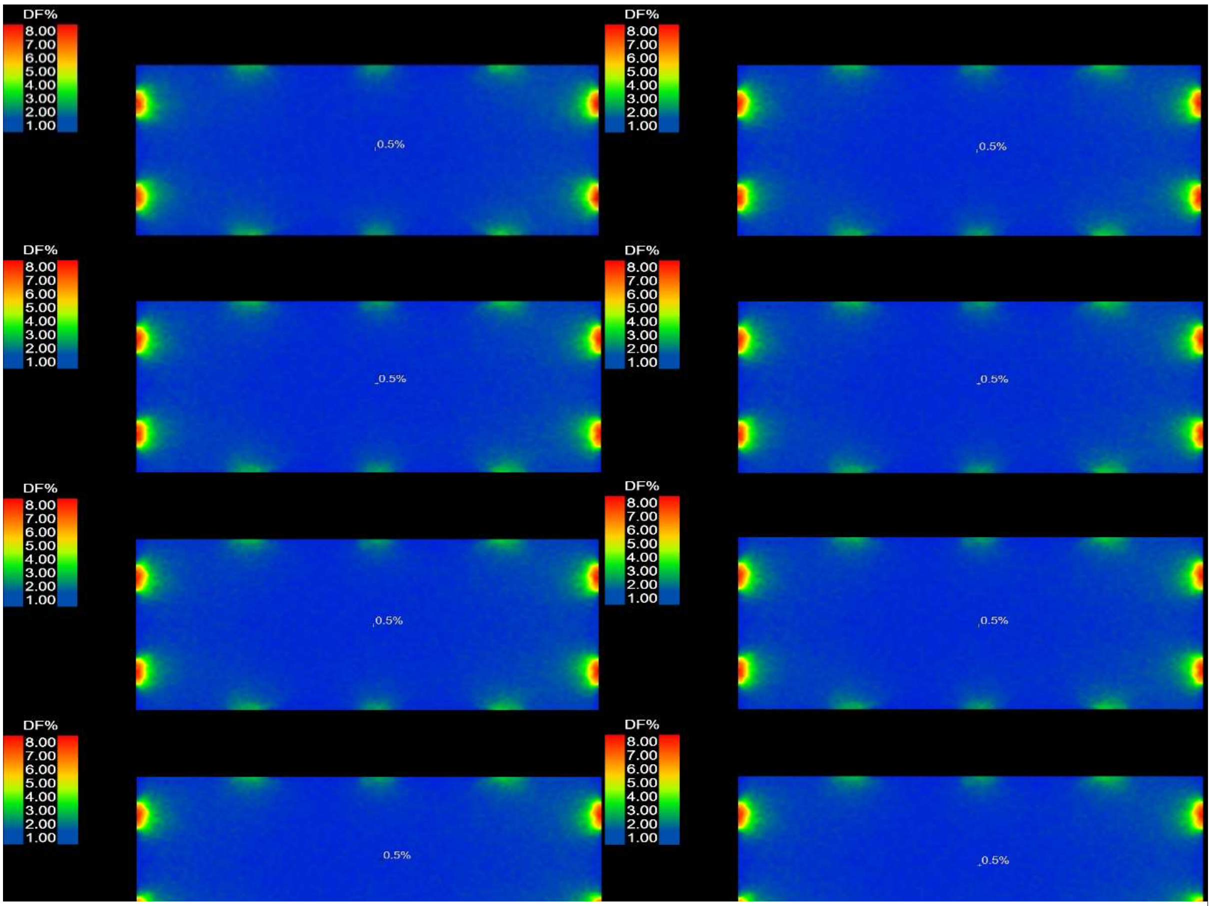


Figure 9.17 *Comparison of Daylight Factor at Work Plane of first floor with the changes in orientation. At Left, top to bottom, 0deg, 30deg, 45deg, 60deg and At Right, top to bottom, 90deg, 120deg, 135deg and 150deg.*

9.08 Observation and Analysis of Simulation Data:

- With every increase of window to floor area ratio, considerable increase in Avg. Daylight factor, Illuminance and both Quality and quantity of daylight at the farthest depth (centre of the enclosure) on working plane have been observed.

- With the gradual decrease of the height of the adjacent buildings or obstruction, both daylighting parameters; Daylight Factors (%) & Illuminance (lux), tends to increase at each floor level.

- The changes in orientation of building block with constant latitude and longitude, no such considerable changes have been observed in daylighting parameters (apart from shadow pattern) , like daylight distribution value and patterns.

- With the increase in sill height of the windows, there is no such considerable changes in values as well as patterns of Daylight Factor parameter have been observed. But gradual enhancement of the illuminance level at the centre point of the working plane is observed.

- Gradual increase in depth of the weather shade or window chajja causes gradual decrease of avg. illuminance through out the working plane. Daylight factor (%) at the centre of the working plane was not affected much, though the avg. Daylight factor throughout the working plane decreases at lesser proportion than the avg. illuminance.

- Inclusion of Light shelve tool, enhanced all the Daylighting parameters to a larger extent. With the same ratio of fenestration, there were increases of minimum 20% of daylighting metrices.

- With the increase in floor from Ground to top Floor, gradual increase in Illuminance Parameter and Daylight Factor have been observed for each test cases. As per the KMC byelaws, the lower floors, specially the Ground floor will receive extremely poor daylight penetration, where as the top floor is surpassed with the daylight.

10.0 Conclusion

In India, cumulative spent on indoor lighting needs is as large as 42% of total residential electrical energy. The energy consumption in building segment is rising at 8% per annum due to the rapid urbanization in India. However, from the research performed, it is possible to conclude that the optimized application of daylighting tools and energy efficient lighting technologies during design, can save a considerable percentage of the total residential electrical energy use.

- Though the National Building Codes of India 2016 (NBC), ECBC, IGBC, UDPFI, other research works provides some preference and some standards towards good practice of daylighting during building design, there was no specific mandate or enforceable guideline which needed to be followed.

- Model Building Bye-laws, published by Ministry of Urban Development, Government of India, 2016 or Building Bye-laws by different Urban Local Bodies (ULB) of India, like 'Kolkata Municipal Corporation Building Rules, 2009', also lack specific daylight-inclusive design guidelines, which need to provide policy support in reducing the energy consumption to formulate more comprehensive Building Bye-laws.

- Mandatory regulations of the minimum window sizes for different types of spaces need to be reviewed as it does not suffice the minimum illuminance and desired daylight distribution pattern within the building core.

- Mandatory regulations of the maximum permissible building height need to be reviewed in synchronisation with the mandatory open spaces between adjacent buildings, as the daylight penetration at building cores of lower-level floors is substantially being compromised and, in some cases, it does not meet the minimum illuminance and desired daylight distribution pattern to perform easier visual tasks.

- Regulations of the height of window sill can be proposed, as the increased height of window sill would allow maximum daylight penetration at building cores.

- Regulations of the lower depth of weather shade can be proposed at lower-level floors near to ground as it would allow maximum daylight penetration at building cores. Use of reflective material like; light shelve could be promoted in this context.

- More research and evidence-based data, software based virtual simulation is required to support and design the premise with access of natural daylight which is necessary and advantageous for sustainable and healthy living.

- Due to the dynamic nature, the quantity and quality of daylight varies with time and individual location. For the country like India, with varying geography, topography and climate, one single Daylighting guideline might not be successful. Hence, zonal or regional specific guideline should to be formulated and followed by individual Urban Local Bodies or Development Authorities.

11.0 Future scope of research

- In further it is possible to research various daylighting design metrices under different Sky condition and different geographical locations of India which can be used to formulate the guideline of daylight inclusive building byelaws in Indian Context. It is also possible to formulate several algorithm with the test data to achieve the optimum design solution.

- It is possible to perform further comparative parametric study with different daylighting performance metrices with the help of different software simulation; like thermal simulation of build environment, daylight uniformity, glare analysis, etc. with various static and dynamic design metrices input data to optimise the sustainable design guideline.

- To research and analyse the different geometry, architectural tools and related material property to enhance the daylight performance within build environment.

- The feasibility study should be performed before implementation of comprehensive building byelaws, which might be introductory with different incentive parameters, like; enhanced FAR, relaxation on permissible building height, discounted property tax, etc., for ease of acceptance to the society of developing countries.

12.0 Glossary

Absorption
Transformation of radiant energy to a different form of energy by the intervention of matter.

Adaptation
The process by which the state of the human visual system is modified by previous and present exposure to stimuli that may have various luminances, spectral distributions, and angular subtenses.

Altitude
The angular distance of the sun measured upward from the horizon on the vertical plane that passes through the sun. Altitude is measured positively from horizon to zenith from 0° to 90°.

Angle of Incidence
The angle between a ray of light falling on a surface and a line perpendicular to the surface.

Atmospheric Turbidity
The scattering of solar radiation caused by air molecules, the scattering and absorption of solar radiation by larger particles known as aerosols, and the absorption of solar radiation by atmospheric gases and water vapour in the atmosphere. Atmospheric turbidity is usually expressed as the ratio of the total attenuation from molecules and aerosols in the atmosphere to that of molecules alone, using coefficients or optical thicknesses of molecular and particulate atmospheres. Atmospheric turbidity values of 3 to 6 are common even on days described as clear. A value of unity is equivalent to a Rayleigh atmosphere in which the size of particles is small compared with the wavelength of the radiation.

Atrium
An interior light space enclosed laterally by the walls of a building and covered with transparent or translucent material that permits light to enter interior spaces through pass-through components.

Azimuth
The azimuth of the sun is the angle between the vertical plane containing the sun and the vertical plane oriented to the north (direction of origin).

Brightness
The visual sensation by which an observer registers the degree to which a surface appears to emit or reflect more or less light. This subjective sensation cannot be measured in absolute units; it describes the appearance of a source or object.

Bye-Law
A regulation made by a local authority or corporation.

Candela
The unit of luminous intensity. The luminance of a full radiator at the temperature of solidification of platinum is 60 candelas / cm2.

Candela Per Square Meter
A unit of luminance in a particular direction recommended by the Commission Internationale de L'Éclairage (CIE).

CIE Standard Clear Sky
Cloudless sky for which the relative luminance distribution is described in Publication CIE No. 22 (TC 4.2) 1973 Commission Internationale de L'Éclairage (CIE).

Clerestory
Daylight opening in the uppermost part of an exterior wall.

Contrast
The subjective assessment of the difference in appearance of two parts of a field of view seen simultaneously or successively. It can be defined objectively as:
$(L1–L2) /L1$, where $L1$ and $L2$ are the luminances of the background and object, respectively.

Daylight
Visible global radiation. Daylight is the sum of sunlight and skylight.

Daylight Factor
Ratio, at a point on a given plane, of the illuminance that results from the light received directly or indirectly from a sky of assumed or known luminance distribution to the illuminance on a horizontal plane that results from an unobstructed hemisphere of this sky. The contribution of direct sunlight to both illuminances is excluded.

Daylight Opening
Area, glazed or unglazed, that is capable of admitting daylight to an interior.

Diffuse Illuminance From the Sky
Illuminance from the sky received on a horizontal plane from the whole hemisphere, excluding direct sunlight.

Diffuser
A device object or surface used to alter the spatial distribution of light.

Diffuse Reflection
The process by which incident flux is redirected over a range of angles.

Diffuse Transmission
The process by which the incident flux passing through a surface or medium is scattered.

Diffuse Transmittance
The ratio of the diffusely transmitted luminous flux leaving a surface or medium to the total incident flux.

Diffusion
The scattering of light rays so that they travel in many directions rather than in parallel or radiating lines.

Disability Glare
Excessive contrast, especially to the extent that visibility of one part of the visual field is obscured by the eye’s attempt to adapt to the brightness of the other portion of the field of view; visibility of objects is impaired.

Discomfort Glare
Glare that causes annoyance without physically impairing a viewer’s ability to see objects.

Emission
Release of radiant energy.

Fenestration
Any opening or arrangement of openings in a building for the admission of daylight or air.

Glare
A visual condition which results in discomfort, annoyance, interference with visual efficiency, or eye fatigue because of the brightness of a portion of the field of view (lamps, luminaires, or other surfaces or windows that are markedly brighter than the rest of the field). Direct glare is related to high luminance in the field of view. Reflected glare is related to reflections of high luminance.

Goniophotometer

Photometer for measuring the directional light distribution characteristics of sources, luminaires, media, or surfaces.

Integrating Sphere
Hollow sphere whose internal surface is a diffuse reflector that is as non-selective as possible.

Illuminance
The luminous flux incident on a surface per unit area. The unit is lux, or lumens per square foot.

Indirect Lighting
Illumination achieved by reflection, usually from wall and/or ceiling surfaces.

Latitude
Geographical latitude is the angle measured in the plane of the long meridian between the equator and a line perpendicular to the surface of the Earth through a particular point.

Light
Radiant energy evaluated according to its capacity to produce visual sensation.

Light Duct
An element of a building that carries natural light to interior zones. Duct surfaces are finished with highly reflective materials.

Longitude
The angular distance from the meridian through Greenwich, England, to the local meridian through a particular point. Longitude is measured either east or west from Greenwich through 180° or 12 hours.

Lumen
The unit of luminous flux. It is equal to the flux through a unit of solid angle (steradian) from a uniform point source of one candela or the flux on a unit surface all points of which are at a unit distance from a uniform point of one candela.

Luminaire
A complete lighting unit (fixed or portable) that distributes, filters, or transforms the light given by a lamp or lamps and that includes all the components necessary for mounting and protecting the lamps and connecting them to the supply circuit.

Luminance
The luminous intensity of any surface in a given direction per unit or projected area of the surface as viewed from that direction.

Lux
The International System (SI) unit of illumination. It is the illumination on a surface one square metre in area on which there is a uniformly distributed flux of 1 lumen.

Obstruction
Surfaces outside the building that obstruct direct view of the sky from a reference point.

Overcast Sky
Sky completely covered by clouds with no sun visible.

Radiation
Energy in the form of electromagnetic waves or particles.

Reflectance
The ratio of light reflected to incident light.

Reflection
Process by which radiation is returned by a surface or a medium without change of frequency of its monochromatic components.

Reflector
A device that returns incident visible radiation; used to alter the spatial distribution of light.

Refraction
Change in direction of propagation of radiation determined by change in the velocity of propagation as radiation passes through an optically non-homogeneous medium or from one medium to another.

Relative Sunshine Duration
Ratio of actual time to possible time when the sun is not obscured by clouds.

Shading
Use of fixed or movable devices to block, absorb, or redirect incoming light for purposes of controlling unwanted heat gains and glare.

Shading Coefficient
The dimensionless ratio of the total solar heat gain from a particular glazing system to that for one sheet of clear, 3-mm, double-strength glass.

Shading Device
Device used to obstruct, reduce, or diffuse the penetration of direct sunlight.

Skylight
An opening situated in a horizontal or tilted roof.

Top-lighting
Daylight that enters through the upper portion of an interior space such as a clerestory or skylight.

Translucent Glass
A glass with the property of transmitting light diffusely.

Transmission
Passage of radiation through a medium without change of frequency of its monochromatic components.

Transmittance
Ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions.

Veiling Reflections
Reflections that reduce the contrast between the task/object and the background when extremely bright reflections of light sources appear on the task object itself.

Window
Daylight opening on a vertical or nearly vertical area of a room envelope.

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