STUDY ON ENERGY-EFFICIENT SMART LIGHTING SOLUTIONS FOR MODERN OFFICE BUILDINGS USING DAYLIGHT INTEGRATION

A thesis submitted towards partial fulfillment of the requirements for the degree of

Master of Technology
in
Illumination Technology & Design

Submitted by

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Examination Roll No: - M6ILT24010

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CERTIFICATE OF RECOMMENDATION

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ACKNOWLEDGEMENT

At the very Beginning, with immense gratitude, I show my gratitude and acknowledge the support, help extended by my supervisor **Dr.Suddhasatwa Chakraborty** Associate Professor , Electrical Engineering Department, Jadavpur University whose encouragement and phenomenal supervision and visionary guidance from the preliminary to the concluding level enabled me to complete this project work.

I would like to acknowledge my sincere thanks to **Dr. ParthaSarathi Satvaya** , Director of School of Illumination Science, Engineering and Design, Jadavpur University, for providing me the opportunity to carry out my project work in Illumination Engineering Laboratory of Jadavpur University.

I would like to thank **Mr. Rohit Pyati** Manager of **Wipro Lighting** Bangalore location for his guidance during internship in Wipro Lighting.

I would also thank to all the staff member of Illumination Engineering Department for helping me in time of need.

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1. AIM & OBJECTIVE OF STUDIES:-

1.1 Introduction:-

Daylight Harvesting is an energy conservation term used to describe the process of actively managing the amount of artificial light in a room when natural sunlight is available. Daylight harvesting is the approach of using natural sunlight inside a building in order to reduce the electricity demand of artificial lighting. Daylight harvesting can substantially decrease lighting power consumption depending on the amount of natural light available. With the increasing demand for environmentally sustainable buildings on the rise, daylight harvesting has become a common feature of green buildings. It has the potential to achieve several goals, such as reducing electrical demand cutting costs of energy consumption, maintaining a level of comfort for the occupants and reducing the pollution levels. To do this, light that is produced by electricity is reduced in proportion to the available daylight. This tactic is generally used in commercial buildings where major amount of energy is utilized for lighting purpose. Over a few decades, daylighting has been perceived to possess good potential for energy conservation. The efficient and effective use of daylight can offer major energy and cost saving. This approach holds particular promise for commercial areas such as office buildings, schools & college buildings and other government & non-government buildings because they are primarily occupied and being operated during daylight hours. In this perspective, there have been significant advances in research methodologies and technologies for optimizing energy consumption through daylight harvesting in commercial buildings by combining natural daylight and window shades that reduces artificial light levels as well as the energy consumption when more natural light is available.

1.2 Objective of Studies:-

The present study explores the utilization of daylight in conjunction with sustainable building design and the challenges of assessing daylight into the building in a proper way. Daylight is an available resource that adds value both architecturally and economically. Successfully designing of daylighting into buildings leads to high levels of visual comfort and also reducing energy consumption. Qualitative daylighting design has the capacity to increase user satisfaction and productivity. Moreover, when consciously exploited and used together with energy-efficient lighting and controls, daylighting can reduce energy consumed by electric lighting by up to 60% (approx.) with immediate results on decreasing overall building energy use. In this context, this research effort intends to describe a systematic approach toward obtaining and assessing daylight performance data from high-rise commercial buildings. This approach is currently being applied to explore balancing daylight harvesting and energy demands in a particular climate zone in India. The main objective of this paper is to present a methodology to predict & assess the potential for lighting energy savings due to the integration of daylight. The methodology is then applied to a case study to optimize potential for lighting energy savings within a Office Building in Kolkata, India.

Furthermore, in relevance to this study, by means of computer simulations using DIALux software, the interaction between natural daylight and artificial light and the related illumination conditions expected in a commercial sector, i.e., a office building in Kolkata, India have been simulated and analyzed. The main goal of this study is to show the potential of drastically reducing the electrical energy consumptions for illumination, by adopting day lighting harvesting solutions. Comparison need to be done by using two different lighting schemes followed by artificial lighting with LED Luminaires with and without daylight harvesting. The effectiveness of the system, drawbacks and further improvements on the system will be examined based on findings from various assessments. The structure of the thesis is outlined below.

1.3 Aim of Study:-

The global scenario of energy distribution reveals the fact that around (30%-40%) of the energy around the world is consumed by the commercial, residential and industrial buildings. In a fastest growing country like India, rapid rate of growth in the recent past increases the number of industries, service sectors (24x7); commercial complexes & residential units. In India, currently, the buildings (both Commercial & Residential) are the second largest consumer of electricity consuming approximately 40% of overall energy out of which a considerable part of energy [approx. 35%] is consumed by lighting load only. Lighting is responsible for approximately 28% of electricity consumption in the residential sector and approximately 60% in the commercial & industrial sector. Owing to the consistently growing demand, much effort has now been put towards reducing the demand for energy through various alternative sources of energy that not only complements electricity generation, but is also environmentally friendly.

This study provides a comprehensive overview of daylighting systems, design essentials, and an assessment of energy savings potential with maximum utilization of daylight of a building. This paper concerns an assessment of daylight availability in national and international level with an approach to build a scenario of the potential of daylight harvesting as well as reducing the demand of artificial lighting by utilizing daylight and make it sustainable by comparing with a case study at an ***OFFICE BUILDING, Kolkata, India***. The entire process is use to detect ambient daylight levels and automatically adjusts the artificial lighting output level to reach the desired illumination level that drastically reducing the electrical energy consumptions for illumination, by adopting daylight harvesting solutions which in turn reduce the cost of energy use.

2. DIFFERENT PERFORMANCE PARAMETERS FOR DAYLIGHT HARVESTING:-

In order to understand daylighting principles and its evaluation methods, it is important to start by defining certain frequently used lighting terms used in lighting engineering practice as per ***CIE*** [International Commission on Illumination] & ***IESNA*** [Illuminating Engineering Society of North America]. Performance parameters can be utilized to justify whether a lighting or daylighting solution is suitable for particular design objectives. The parameters can be also used to quantify the effectiveness of an innovative daylighting strategy or system. Additionally, certain independent variables such as building geometry, site location, surrounding obstacles etc. can also affect a daylighting performance evaluation.

2.1 Luminous flux [Ø]:-

Luminous Flux (Φ) is energy per unit time (dQ/dt) that is radiated from a source over visible wavelengths. The unit of luminous flux is *Lumen* and is expressed by the term candela.

$$1 \text{ lm (lumen)} = 1.464 \times 10^{-3} \text{ W at } 555 \text{ nm}$$

More specifically, it is energy radiated over wavelengths sensitive to the human eye, from about 330 nm to 780 nm. Thus, luminous flux is a weighted average of the Radiant Flux in the visible spectrum. The luminous flux is of particular importance, because it is the quantity that is used to describe the "brightness" of a light source. For example, a 100 watt incandescent lamp would produce about 1700 lumen. The luminous flux is therefore the light output of a light source.

2.2 Luminous intensity [I]:-

Luminous intensity is the quantity of visible light that is emitted in unit time per unit solid angle in a particular direction. The unit of luminous intensity is *lumen per steradian*, which is the unit of solid angle- there are 4π steradians about a point enclosed by a spherical surface. This unit of luminous intensity is also called the *standard candle, or candela* (cd).

2.3 Illuminance [E]:-

Illuminance is the measure of luminous flux incident at a point on a plane. It is the quotient of the luminous flux incident on an element of the surface containing the point by the area of that element and is expressed in terms of lumens per unit area. In SI units, illuminance is expressed in *lux (lx)*. Illuminance at a point may differ due to variation in visual tasks' size, contrast and time to observation of the object. Most often an average level of horizontal illuminance is required for most of the common task. But when considering the task of viewing from vertical surface, vertical illuminance is more important (Fig. 2.1).

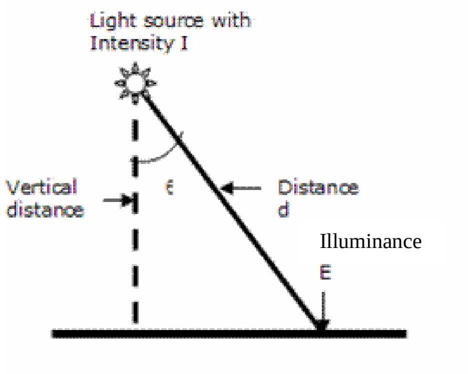


Fig 2.1 Illuminance at a point source

2.4 Luminance [L](cd/m²):-

Luminance is the luminous intensity of a surface in a given direction per unit projected area. It is measured by *candela/m$^{2.}$* It is a measure of the brightness of an illuminated surface. In addition to this, luminance is also described as the luminous flux per unit projected area per unit solid angle in a given direction. It is an inherent property of a ray of light. Luminance is the measurable quantity that most resembles a person's perception of brightness, although they are not quite the same.

2.5 Luminous Efficacy [lm/W]:-

Luminous Efficacy is the ratio of total luminous flux emitted by a source to the total power input to the source. It is expressed as *lumen/Watt (lm/W).* The luminous efficacy may help to judge the efficiency of different lamps. Nevertheless, as the luminous flux, the luminous efficacy is only a measure related to the "quantity" of light, not to the "quality". The larger the efficacy, the higher the light output with less power consumption.

2.6 Correlated Colour Temperature (CCT):-

The correlated color temperature ***[CCT]*** (K) is defined as the absolute temperature of a black body at which the closest possible color match with the given radiator is obtained. The correlated color temperature is obtained by comparing the light source under consideration to a black body radiator (Planckian radiator) of a given temperature and characterizing the light source by the temperature of the black body radiator which has the same chromaticity, i.e., which is closest 13 to it on the CIE chromaticity diagram (Fig. 2.2).

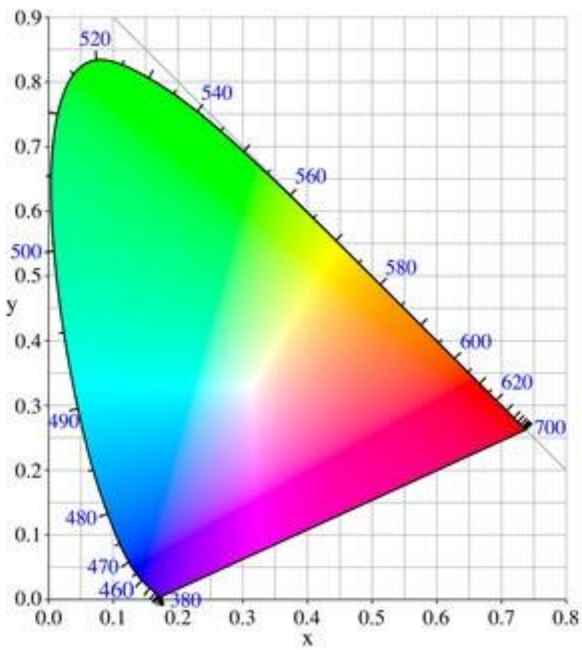


Fig 2.2 CIE chromaticity diagram or color space

That is, the CCT refers to the temperature to which a Planckian radiator is heated to produce light of the same visual color. Since the (continuous) spectral power distribution of a Planckian radiator depends only on its temperature, the CCT reduces the color to a single. The range of CCT is as follows:

CCT (in Kelvin)	CCT Class
CCT ≤ 3300	Warm
3300 < CCT ≤ 5300	Intermediate
5300 < CCT	Cold

The preferred CCT are between 2,500 and 7,500 K. Warm white light lies between 2,500 and 3,300 K, neutral white between 3,300 and 5,300 K, and daylight white between 5,300 and 7,500 K. The color of light is determined by the spectral power distribution, the color can still be summarized on a linear scale of the correlated color temperature (CCT). For classifying light sources for different fields of application (home, office, sports, etc.) or for specifying the right light source types in architectural lighting design. Nevertheless, light sources of the same CCT may vary widely in the quality of light emitted, i.e., in their color rendering. A low CCT implies warmer light (more red) while a high correlated color temperature implies a colder light (more blue). Daylight has a rather low CCT near dawn, and a higher one during the day. Nevertheless, a high CCT does not imply that the light source is actually at that temperature. Fluorescent lamps have, for example, a high CCT, but actually they are quite cool during operation compared to high-pressure discharge lamps. The correlated color temperature is obtained by comparing the light source under consideration to a black body radiator (Planckian radiator) of a given temperature and characterizing the light source by the temperature of the black body radiator which has the same chromaticity.

Various light sources with their typical correlated color temperature (CCT):

Light source	Correlated Color Temperature (CCT) (K)
Sunrise/Sunset	3,200
1 hr. before/after dusk/dawn	3,400
Sunny daylight noon time	5,800
Candlelight flame	1,900
Overcast sky	6500
Fluorescent lamp	2,700–6500
Incandescent lamp (40 W)	2,680
Incandescent lamp (200 W)	3,000
High-pressure mercury lamp	3,300–7,600

Table 2.1 Blackbody Radiator Temperature Approximation of Various Illuminants

2.7 Colour Rendering Index (CRI):-

Colours are perceived as natural in daylight. CRI deals with the appearance of coloured objects illuminated by a light source and how that appearance compares with the colour appearance of objects illuminated by a reference source. The general *color rendering index* (CRI) measures the ability of a light source to accurately display color as compared to a standard illuminant. The ability of a light source to render colour of surfaces accurately can be conveniently quantified by the colour-rendering index. This index is based on the accuracy with which a set of test colours is

CIE Colour Rendering Index

Colour renderin ggroups	**CIE general colour renderingindex**	**Typical application**
1A	$R_a > 90$	Wherever accurate colour rendering is required e.g., colour printing inspection
1B	$80 < R_a < 90$	Wherever accurate colour judgments are necessary or good colour rendering is required for reasons of appearance e.g. display lighting
2	$60 < R_a < 80$	wherever moderate colour rendering is required
3	$40 < R_a < 60$	Wherever colour rendering is of little significancebut marked distortion of colour is unacceptable
4	$20 < R_a < 40$	Wherever colour rendering is of no importance at all and marked distortion of colour is acceptable

reproduced by the lamp of interest relative to a test lamp, In assigning a numerical value to the colour rendering properties of a light source, the CRI system compares the shift in object colour that occurs when the object is illuminated by the test light source with the shift that occurs under the reference source. The reference source used depends on the correlated colour temperature of the test source. Generally the CRI is a scale from 0 to 100 which rates a light source by comparing the color appearance of eight different colors viewed under the light source to the color appearance of these eight colors viewed under a standard illuminant as defined by *International Commission on Illumination (CIE).* Color rendering describes how well the lights render. The higher the CRI, the better the color rendering. A CRI value of 100 means the source is identical to the standard illuminant. A CRI of more than 90 gives a very good color rendering, a CRI between 80 and 90 is good, a CRI between 60 and 80 gives a sufficient color rendering.

Some light sources having their typical colour rendering index (CRI) are as follows:

Light source	Colour Rendering Index(CRI)
Daylight	100
Tungsten Lamp	100
CFL	85
T8 Tri-phosphor Fluorescent Tube	80
Standard Metal Halide	65 - 85
White Sodium	80
LED	50 - 85

2.8 Luminance Contrast:-

Luminance contrast describes the physical quantity corresponding to the brightness of a surface in a specified direction. It can also be used to qualitatively analyze daylighting, especially glare. Luminance contrast depends not only on the illuminance on an object and its reflective properties, but also on its projected area on a plane perpendicular to the plane of view.

2.9 Glare:-

Direct glare is caused by excessive light entering the eye from a bright light source. The potential for direct glare exists anytime one can “see” a light source. With direct glare, the eye has a harder time seeing contrast and details. Mainly Glare can be classified into two categories:

2.9.1 Disability glare:-

This occurs when high luminance is present in a low luminance background. Light from the source is scattered in the eye thereby forming a luminous veil over the retinal image of parts of the scene adjacent to the source.

The magnitude of disability glare is quantified by the equivalent veiling luminance. For glare sources within an angular range of 0.1 to 30 degrees, this is given by the equation:

$L_v = 10 \sum (En / \theta n\hat{}2)$

Where L_v = equivalent veiling luminance (cd/m^2)

E_n = illuminance at the eye from the *n*th glare source (lx)

Q_n= angle of the *n*th glare source from the line of sight (degrees)

2.9.2 Discomfort Glare:-

The other form of glare is called discomfort glare. Discomfort glare is a sensation of annoyance or pain caused by high luminances in the field of view. By definition, discomfort glare does not affect visual performance but does cause discomfort. The following factors have been found to influence subjective judgments of discomfort glare:

a) Room size and shape
b) Room surface reflectances
c) Illuminances
d) Luminaire characteristics
e) Number and location of luminaires
f) Luminance of the entire field of view
g) Observer location and line of sight.
h) Differences in individual glare sensitivity.

Direct glare can be minimized with careful equipment selection and placement. In interior applications, indirectly light the walls and ceiling to avoid the veiling effects of glare. Discomfort glare is quantified by the **U**nified **G**lare **R**ating (UGR) as recommended by the CIE derived from the equation:

$$UGR = 8 \log_{10}\left(\frac{0.25}{L_b}\right)\sum_i \frac{L_i^2\, \omega_i}{P_i^2}$$

Where: UGR = Unified Glare Rating

L_b = Background luminance (cd/m^2), excluding the contribution of the glare sources.

L_i = Luminance of the luminaire (cd/m^2)

ω_i = Solid angle subtended at the observer's eye by the luminaire (in steradians).

p_i = Position index.

UGR values typically range from 13 to 30, the lower the value, the less the discomfort.

2.10 Irradiance [W/m^2]:-

Irradiance is the power of electromagnetic radiation per unit area (Radiative flux) incident on a surface. Radiant emittance or radiant exitance is the power per unit area radiated by a surface. The SI units for all of these quantities are watts per square meter *(W/m^2)*, often used in astronomy. These quantities are sometimes called intensity, but this usage leads to confusion with radiant intensity, which has different units. If a point source radiates light uniformly in all directions through a non-absorptive medium, then the irradiance decreases in proportion to the square of the distance from the object. Solar irradiance in a specific area may be measured as insolation, the solar radiation energy per unit area during a given time, or as direct insolation, insolation which reaches a location on Earth after absorption and scattering in the atmosphere. Total solar irradiance (TSI), is a measure of the amount of solar radiative energy incident on the earth's surface. This represents a fraction of the Solar constant, the total amount of electromagnetic radiation emanating from the Sun in all directions. Although the energy output of the Sun is fairly constant, solar irradiance varies significantly from one place to another and changes throughout the year. Sunlight only reaches the parts of the Earth that are facing the Sun at any given time, and the most intense irradiance is experienced by those parts that are not at an angle to the Sun as it passes over. The calculation of solar irradiance for a given area is useful for planning to obtain solar power.

2.11 Solar Insolation Level:-

Solar Insolation (***in***cident ***sol***ar radi***ation***) is the amount of electromagnetic energy (solar radiation) incident on a given surface area of the earth on a given time. Basically that means how much sunlight is shining down on us. It is commonly expressed as average irradiance in kWh/m^2/day and is the amount of solar energy that strikes per square meter of the earth's surface in a single day. The amount of insolation received at the surface of the Earth is controlled by (1) the angle of incident of sunlight, (2) the state of the atmosphere, altitude, and geographic location & (3) Duration of the day.

The insolation into a surface is largest when the surface directly faces the Sun. As the angle increases between the direction at a right angle to the surface and the direction of the rays of sunlight, the insolation is reduced. Insolation levels vary throughout the year depending on the weather variation, - lowest in winter and the highest in summer. In construction, insolation is an important consideration when designing a building for a particular climate. For a particular location value of solar insolation defines the amount of solar energy radiated for a particular period from which the average solar energy on that particular location can easily be estimated.

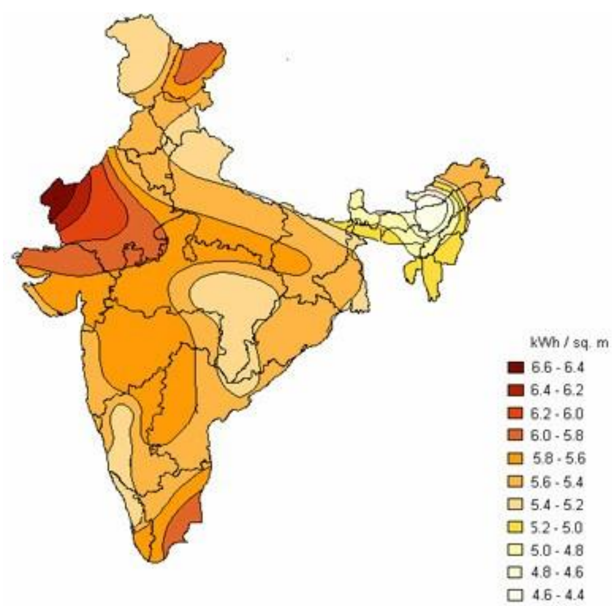


Fig 2.3 Solar Insolation Map showing Annual average Insolation

From the above figure one can easily determine the in India, the annual average solar insolation level lies in between 5.2 kWh/m^2/day to 6.4 kWh/m^2/day and that of West Bengal is in between 5.2 to 5.6 kWh/m^2/day.

2.12 Daylight Hour:

Daylight hour or Daytime is roughly the period on any given point of the Earth's surface during which it experiences natural illumination from indirect or (especially) direct sunlight. Daylight hour is a climatologically indicator, measuring duration of sunshine in given period (usually, a day or a year) for a given location on Earth, typically expressed as yearly average. It differs from insolation, which measures the total energy delivered by sunlight over a given period.

With the average Daylight hour, the annual available sunshine hour can be easily determined which further helps to measures the overall solar energy in a particular location, e.g. the annual average daylight hour for 2014 in New Delhi is 2685 Hrs, in Chennai it is 2762hrs, in Mumbai it is 2584hrs, where as in Kolkata it is only 2110hrs. In India it is highest in Ahmadabad [3000hrs]. The daylight harvesting process can easily be executed in the location having higher Daylight Hours.

2.13 Daylight Factor:-

A daylight factor (DF) is defined as the ratio of the indoor daylight illuminance to the simultaneous external illuminance on a horizontal plane and is normally given in per cent:

$$DF = \frac{\text{Indoor Illuminance at a point}}{\text{Outdoor Illuminance}} \times 100\%$$

$$\Rightarrow \quad DF = [\, E_{indoor} / E_{outdoor} \,] \times 100\,\%$$

where, E_{indoor} is the interior illuminance due to daylight at a point on a given plane in lux and $E_{outdoor}$ is the simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky in lux. It is usually measured at the height of the work plane, under a standardized CIE overcast sky.

For a given point in a room, the daylight factor is a permanent factor. The daylight factor is calculated under a standard overcast sky, which means that the calculation is per definition independent of window orientation and does not express anything about how much light there will be in the point under real sky conditions for a given orientation. Since the exterior illuminance varies constantly, the daylight factor is considered as a good measure of the available daylight in a space. A daylight factor below 1% is considered too low, a minimum of 2% has sometimes been used in building codes and between 2- 5% is considered as good daylighting factor.

Some examples of daylight factor requirements in different space types are listed below:

Space Type	**Target**
Office/Retail Building	2%
Classroom/Conference Room	3%
Circulation Area	1%

2.14 Uniformity:-

The uniformity of illumination of a given plane is calculated as the quotient of the lowest value for the illuminance of the plane (E_{min}) and the average illuminance of that plane (E_{av}.).

Where,

- Eav. = (E1 + E2 + ...+ En) / n ; [n - number of the measurement points]
- E1 ÷ En - results of measurements at the successive points.

Uniformity of lighting in space can be desirable or less desirable depending on the function of the space and type of activities. A completely uniform space is usually undesirable whereas too non-uniform lighting may cause distraction and discomfort. Lighting standards and codes usually provide recommended illuminance ratios between the task area and its surroundings. For continuous activities, it is assumed that the uniformity of illumination of the working plane should be at least 0.65. For irregular activities or those performed in staircases and corridors for sustainable buildings, it is assumed that the uniformity of illumination should be at least 0.4. Most indoor lighting design is based on providing levels of illuminances while the visual system deals with light reflected from surfaces i.e. luminances. For office lighting there are recommended luminance ratios between the task and its immediate surroundings.

3. VARIOUS INSTRUMENTS USED FOR MEASUREMENT OF SOLAR RADIATION

3.1 Solar Pyranometer:-

A **Pyranometer** (from the Greek word for fire) is used to measure global solar irradiance falling on a horizontal surface in the desired location in terms of *Watts per square meter* and solar radiation flux density from a field of view of 180° on that point. Generally a Pyranometer is standardized with respect to the **ISO 9060** standard as per The World Meteorological Organization (WMO) and are calibrated based on the World Radiometric Reference, which is maintained by World Radiation Center, Davos, Switzerland. Pyranometers are typically passive devices, requiring no power to operate. Its sensor has a horizontal radiation-sensing surface that absorbs solar radiation energy which is radiated into space uniformly in all directions from the sun within a solid angle of 2π sr. (steredian) and transforms this energy into heat energy. Global solar radiation can be ascertained by measuring this heat energy.

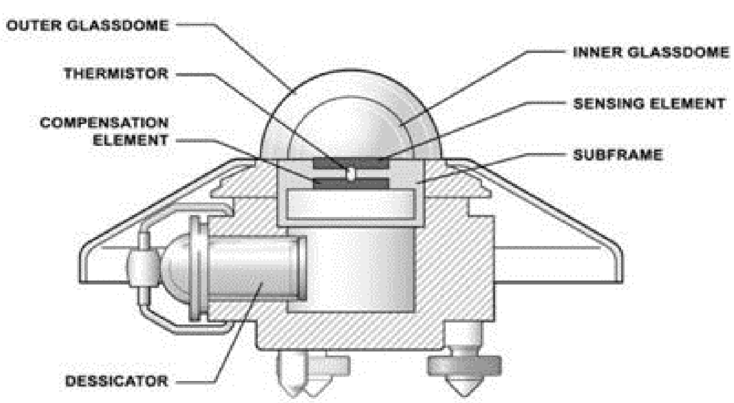


Fig.3.1 Different parts of a Solar Pyranometer

Most pyranometers in general use are now the thermopile type, although bimetallic pyranometers are occasionally found. In a standard high-quality thermopile type pyranometers, several pairs of thermocouples are electrically connected in series to form thermopiles that exhibits a flat spectrum that covers 300 nm to 50000 nm. A pyranometer is operated based on the measurement of temperature difference between a clear surface [reflects solar radiation] and a dark surface [absorbs the solar radiation]. The glass dome limits the radiation to the short wave range only. When sunlight strikes a thermopile, it creates a temperature difference across the junctions of the thermopile. This produced a potential difference [voltage] proportional to the amount of incident energy in the thermopile owing to the temperature gradient between the two

Fig. 3.2 Thermopile based Solar Pyranometer

surfaces is used for measuring the amount of solar radiation. However, the voltage produced by the thermopile can be measured using a potentiometer and the radiated energy is integrated by means of an electronic integrator. The main advantage of thermopile-based pyranometers is that they are designed to be precisely linear and also has a directional response, i.e., it produces maximum output when the Sun is directly overhead (at midday) and zero output when the Sun is on the horizon (at dawn or dusk) which is named as ***cosine response*** (or cosine correction), because the electrical signal from the pyranometer varies with the Cosine of the angle between the Sun's rays and the vertical. Also it responses across a very broad range of wavelengths, as required to measure solar insolation. A high-quality thermopile-based pyranometer is shown in Figure 3.2 .

3.2 Photometer:-

Lux is the unit of measurement of brightness, or more accurately, illuminance. A Photometer also referred to as light meter or lux meter is a device used to measure the illuminance at a point. It specifically measures the intensity with which the brightness appears to the human eye. It ultimately derives from the candela, the standard unit of measurement for the power of light. A candela is a fixed amount, roughly equivalent to the brightness of one candle. A lux meter works by using a photo cell to capture light.

Fig3.3 Digital Lux Meter

The meter then converts this light to an electrical current, and measuring this current allows the device to calculate the lux value of the light it captured.

4. OVERVIEW ABOUT DIFFERENT METHODS OF DAYLIGHT HARVESTING:-

Daylighting for energy savings and conservation has become common design practice. There are numerous ways to harvest sunlight, which involves capture and conversion of solar energy by different technique. Following are some common techniques for daylight harvesting.

4.1 Photovoltaic Cell:-

Solar capture and conversion is accomplished by existing photovoltaic cell (PVs), which turn sunlight into electricity. Comprised of tiny cells, the solar electric array absorbs energy from the sun and converts it to electricity without pollution. The cells are laid side by side into larger panels. Although, till time reliability cannot be made solely on the photovoltaic panels for electricity, it still provides a cleaner energy source. The energy from daylight especially solar thermal energy is to be captured from sunlight through various means to heat water and spaces.

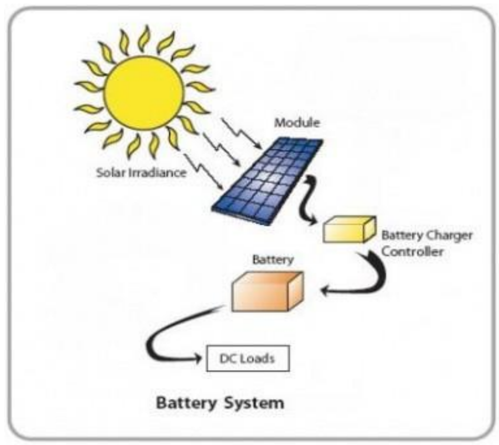


Fig 4.1 Photovoltaic Cell

4.2 Solar Tracker:-

A solar tracker is a device for orienting a daylighting reflector toward the Sun. The sun's position in the sky varies both with the seasons and time of day as the sun moves across the sky. Concentrating solar power using focusing mirrors track the movement of the sun throughout the day and are capable of harvesting energy from daylight. The main constraint is that the solar panels are operating at optimal parameters when they are at the perfect right angle to the sun.

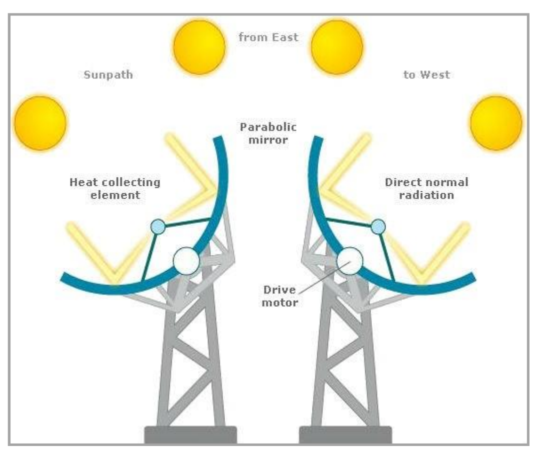


Fig 4.2 Solar Tracker

4.3 Skylights & Sun Tunnels:-

Skylights are openings cut through the roof of a building. Skylights can provide free natural light to transform any room or building into a more comfortable & attractive place. The amount of sunlight provided by skylights can depends directly on how much daylight is available outside, which varies with climatic conditions, the time of day, and the season of the year. Skylights may also be vented electrically or manually to provide fresh air & exhaust stale or hot air.

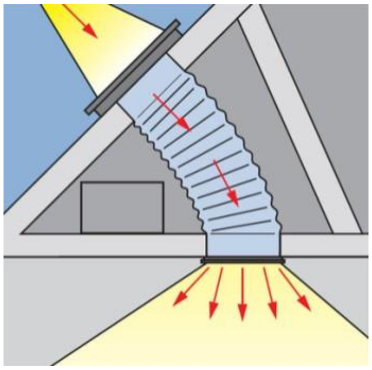


Fig 4.3 Skylight & Sun Tunnel

Sun Tunnels are also an economical way to add natural light when ventilation is not required. The Sun tunnel has a rigid light transmitting tube, made of aluminium [Al] and covered on its surface with a silver based and light reflective (in 98%) layer. The inside of the tube looks like a mirror. It channels daylight to the light transmitting tube through a dome mounted onto the roof. The sun’s rays are reflected off the walls of the flexible tube on to the light diffuser fitted into an internal ceiling. The diffuser spreads the daylight, evenly illuminating the whole interior of the room. This type of light transmitting tube secures that daylight is conveyed in huge quantities inside the interior.

4.4 Lightpipes:-

Lightpipes are hollow tubes with a highly reflective inner surface so that light can travel along the tube with little loss. Usually, daylight is coupled into the system by a beamer at one end of the lightpipe. An end mirror reflects the light that has not been coupled out back into the lightpipe. The lightpipe lead daylight into deeper building interiors that daylight usually does not reach. The maximum luminous flux of sun that can be harvested depends on the geographical location and the size of the surface of the pipe.

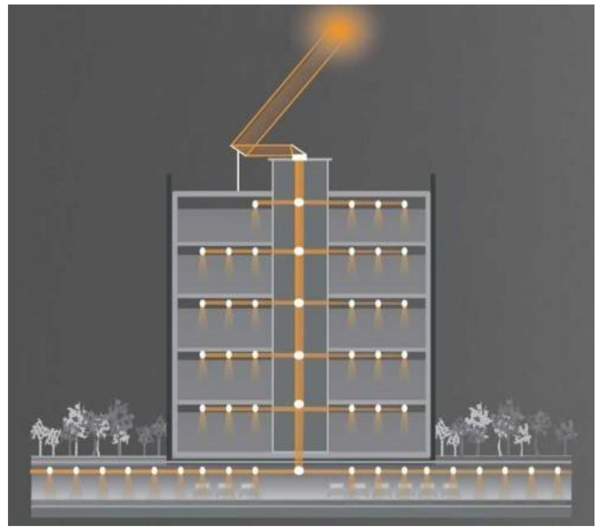


Fig 4.4 Light-pipes in a Modern Building

4.5 Automated Daylight Harvesting:-

Apart from these, a number of automated daylight harvesting solutions are available, consisting of dimmable luminaires, photo sensors, and lighting control software. The sensors have a photoelectric "eye" that measures the illumination in a specified zone. They transmit this information to lighting control software, which is programmed with acceptable threshold levels. If the illumination levels fall outside those thresholds, the software sends commands to dim or brighten the luminaires as required. It is possible to implement pseudo-daylight harvesting that uses timers to dim and brighten luminaires as per requirement. But the main problem is that Timers are not able to take into account things like whether the sky is clear or overcast, or whether people have closed the window coverings to reduce heat and glare, so often result in inappropriate levels of illumination.

5. CRITERIA FOR GOOD DAYLIGHTING PRACTICE:-

Daylight depends on amount of solar radiation reaching the Earth's surface which greatly varies with the different atmospheric conditions both during the day and throughout the year. The level and distribution of natural light within a building depends primarily upon the following external factors:

(1) Local geographical conditions

(2) Latitudinal and Longitudinal position of the building

(3) Orientation of the building

(4) The geometry of the building and

(5) Availability of daylight Hour on a particular area.

5.1 Effect of External Factors:-

The effect of external factors on which the good daylighting depends are discussed hereunder

5.1.1 Local Geographical Conditions:-

Local geographical features, such as mountains, forest, plain land, large lakes influence the solar radiation on a particular area; therefore, the amount of solar radiation received in these areas may be different from that received by adjacent land areas. Normally the amount of daylight differs according to the type of area where the building is located. The area is generally categorized as follows–*i]* ***Rural area, ii] Urban area, iii] Hilly area, iv] Forest area or v] Plane Land.*** Buildings located in ***Rural area*** can consume an adequate amount of solar radiation as in the rural area sufficient amount of open space is available surrounding the buildings.

In case of an ***Urban area***, Daylight strategies depend on the availability of natural light that depends on both man-made and naturally occurring events, e.g., air pollution, smoke and airborne ash from various sources, smog occurs mainly in winter season, immediate surroundings of the building, i.e., the presence of obstructions around the building. In urban area, the sky is usually obstructed to some extent by surrounding buildings and vegetation that can limit the amount of solar radiation at the earth's surface also which in turn has a larger impact on radiation coming in a direct line from the sun (direct beam) than on the overall solar radiation. ***Zoning regulations and floor area indexes*** that regulate the extent of urban density also affects daylighting design. Local zoning regulations limit a building's design (e.g., building size, height, etc.) The more the height is, the higher the chance of daylight availability. Also the aim of maximizing floor area in order to get the maximum daylight in a building is highly acceptable in case of commercial buildings in urban area.

For **Forest area,** trees are an important factor in daylight harvesting because they can starve the house of natural light when it is needed most. The geographical position of the forest area causes variation of daylight impact on a building. Trees planted on the south side will lose their leaves in the winter and allow natural light to enter the house, while trees planted on the

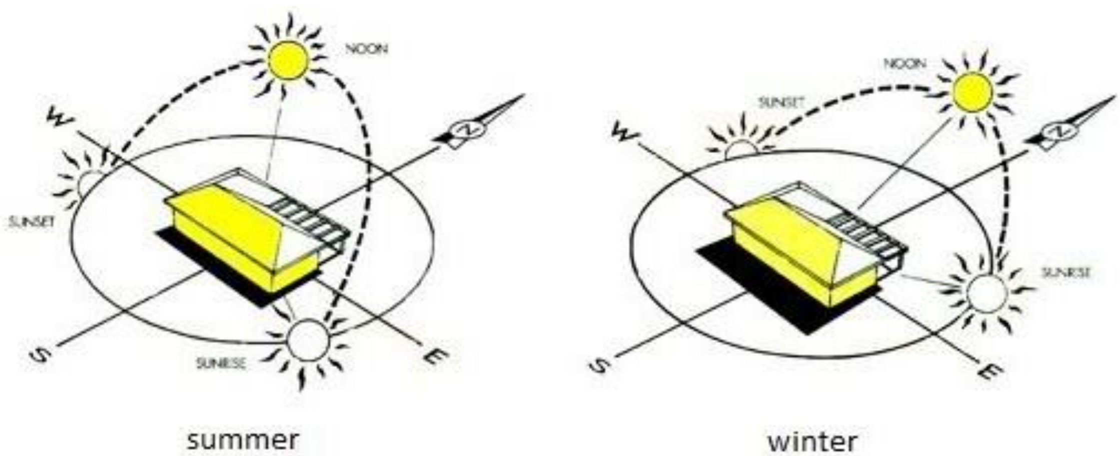


Fig 5.1 Effect of Geographical condition on daylighting

north side will make an obstacle from the summer sun. Builders need to be carefully considering these factors before deciding where to orient a structure on a building lot.

In case of ***mountains***, the north/south sun differential is exaggerated in ***hilly and mountainous regions***, where significant climatic differences can be seen over comparatively small areas .The slope of the mountain surface which restricts the sunlight will create obstacle in daylight harvesting. So, builders should considering the fact at the time of planning.

The most appropriate position for a building providing better daylight is one which located in ***plane land***, because it can receive equal amount of sunlight from all direction.

5.1.2 Latitudinal and Longitudinal position of the building:-

The entire Earth surface is sub divided into two parts namely Northern Hemisphere &

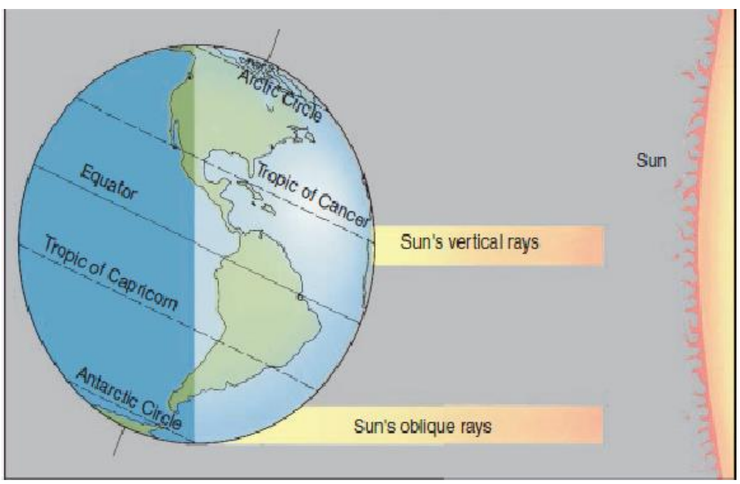


Fig 5.2 Effect of Latitude and longitude on daylighting

Southern Hemisphere. In Northern Hemisphere, the winter sun spends all of its time in the southern sky, and the summer sun spends much of its time in the northern sky (the sun crosses over into the southern sky during part of the day, depending on latitude) while in the Southern Hemisphere, all of these directions are reversed, so the winter sun rises and sets in the northeast and northwest, respectively, and the summer sun rises and sets in the southeast and southwest, respectively. The diagram represents the condition when solar radiation strikes the surface perpendicularly, creating summer conditions in the Northern Hemisphere. In the Southern Hemisphere, the sun's rays are more oblique and spread over larger areas, thus receiving less energy per unit of area, making this the winter. So, if the building has to remain under maximum daylight, the orientations of these building need to be also chosen to maximize north and south walls. East-west orientation should highly be avoided.

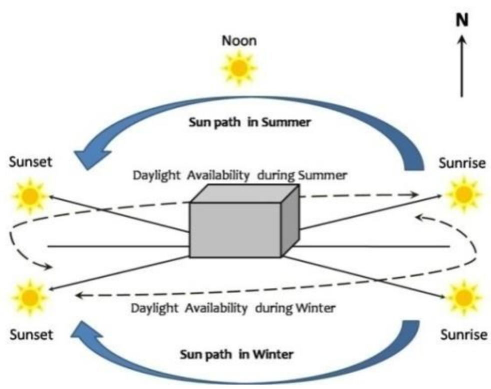
5.1.3 Orientation of the building:-

The relative position of the Sun is a major factor in receiving daylight in buildings, which makes accurate orientation of the building a fundamental consideration for proper daylight harvesting. Orientation of building determines the amount of radiation the building receives. A building on Earth will receive more insolation if

(1) The sun shines more directly

(2) The sun shines longer or

(3) Both.



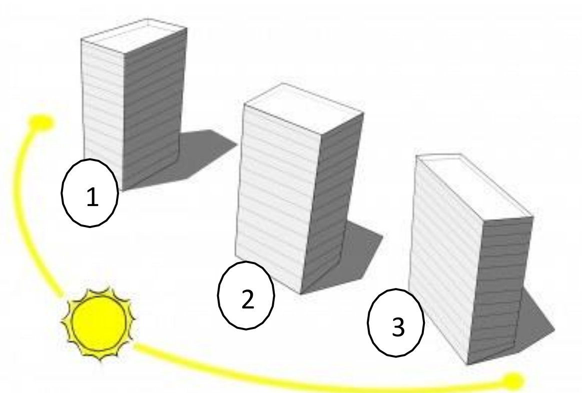


Fig 5.3(a) Daylight availability in a building depends on sun path and **(b)** Building Orientation to maximize daylight availability.

Orientation can be the most important step in providing a building for consistently harness daylight and control glare along the long faces of the building. It also lets you minimize glare from the rising or setting sun. Different faces of the building get very different amounts of light from the sun, i.e., the building orientation must be consider for proper daylighting. A building has been oriented in a particular direction to take advantage of the sun when it's wanted, but avoid overheating and glare. Normally an ideal building used to be oriented along east-west axis for better daylighting. For example, East facing rooms have benefit from early morning solar gain throughout the year and will be cooler in the late afternoon whereas a west facing room will suffer from excessive overheating and glare. Again a north facing room have good daylight & solar gain for most of the day throughout the year but a south facing room have receive lowest levels of daylight throughout the year. Here orientation position 1 is worst for daylighting, position (3) is good, and position (2) is best for Daylight harvesting on a particular building.

5.1.4 Geometry of the Building:-

The building geometry widely affects on the daylight distribution on that particular building. It is quite difficult to get consistent daylight throughout the daytime on a building. As India is located in the tropical region, it is undeniable that the high-rise building envelope

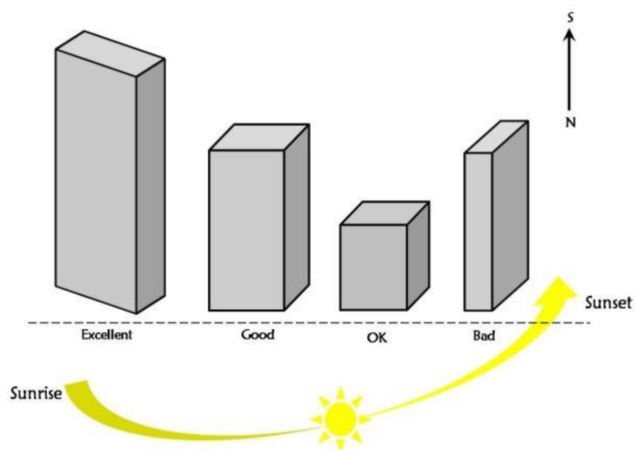


Fig 5.4 Effect of Building geometry on daylighting

experiences much greater impacts of solar radiation than low-rise building. Therefore it is very important to understand of the influence of incident solar radiation on high-rise building. For good daylighting, larger and taller buildings should have thinner profiles to maximize daylighting potential. Increasing the height of each storey to allow for higher windows also helps pull daylight further into the building. The single-storied buildings can also easily achieve good daylighting throughout, by using skylights, no matter how wide they are. On the other hand, the geometric shape can differ the amount of daylight penetration on a building. Different geometric shapes, e.g., square, rectangular or triangular shape building has different capacity to receive solar energy under the same conditions due to its geometric characteristics. Normally, square and rectangular is the regular form for a commercial building. It has been observed that the rectangular form collected lower amount of solar radiation than the square shape buildings.

5.1.5 Availability of Daylight Hour on an Area:-

We also know that the amount of daily insolation received at any one location on Earth varies with latitude (see Fig 5.5). The seasonal limits of the most direct insolation are used to determine recognizable zones on Earth. Three distinct patterns occur in the distribution of the seasonal receipt of solar energy in each hemisphere. These patterns serve as the basis for recognizing six latitudinal zones, or bands, of insolation and temperature that circle Earth. The area between the equator and the Tropic of Cancer can be called the north tropical zone. Here, insolation is always high but is greatest at the time of the year that the sun is directly overhead at noon. This occurs twice in a year, and these dates vary according to latitude (see Fig 5.5). The north middle-latitude zone is the wide band between the Tropic of Cancer and the Arctic Circle. In this belt, insolation is greatest on the June solstice when the sun reaches its highest noon.

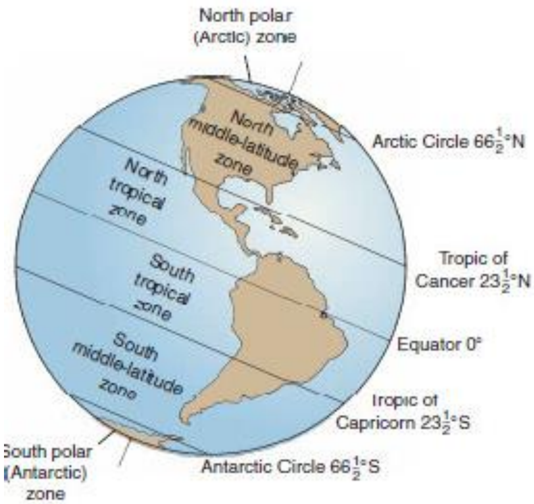


Fig 5.5 Zonal Daylight Availability

Following is a table of available daylight hour according to the Latitude (Globally)

Latitude (in Degree)	Available daylight Hour (Average)			Available Solar Insolation (Average)		
	Jan-Mar & Jul-Sept	Apr-June	Oct-Dec	Jan-Mar & Jul-Sept	Apr-June	Oct-Dec
0.0	12 hrs.	12 hrs.	12 hr.	6.72	6.567	6.75
10.0	12 hrs.	12hr. 35 min	11 hr. 25 min	6.18	6.88	6.08
20.0	12 hrs.	13 hr. 12 min	10 hr. 48 min	5.43	7.05	5.18
23.5	12 hrs.	13 hr. 35 min	10 hr. 41 min	5.14	7.12	4.85
30.0	12 hrs.	13 hr. 56 min	10 hr. 4 min	4.55	7	4.15
40.0	12 hrs.	14 hr. 52 min	9 hr. 8 min	3.58	6.68	3.1
50.0	12 hrs.	16 hr. 18 min	7 hr. 42 min	2.64	6.22	2.12
60.0	12 hrs.	18 hr. 27 min	5 hr. 33 min	1.83	5.63	1.23
66.5	12 hrs.	24 hr.	0 hr.	0.688	4.15	2.48
70.0	12 hrs.	24 hr.	0 hr.	0.47	3.77	1.65
80.0	12 hrs.	24 hr.	0 hr.	0.125	4.66	0.168
90.0	12 hrs.	24 hr.	0 hr.	0.05	5.48	0

Table 5.1 Global daylight hour availability throughout the year

6. THE RECOMMENDATIONS FOR DAYLIGHT ILLUMINANCE FOR INDOOR LIGHTING DESIGN:-

A Good lighting has three primary aims. The first aim is to promote work and other activities carried out within the building; the second aim is to promote the safety of the people using the building; and the third aim is to create, in conjunction with the structure and decoration, a pleasing environment conducive to interest of the occupants and a sense of their well-being. Illumination levels for different tasks are recommended to be achieved either by daylighting or by artificial lighting or a combination of both. Daylight, being non uniform and dynamic in nature, provides illumination that varies in intensity, both spatially and temporally. The outdoor light level is approximately *10,000 lux* on a clear day. In the building, in the area closest to windows, the light level is to be approximately *1,000 lux*. In the middle area it's may be as low as *250 - 350 lux* and at the far end of the room from window the measured value of light level can be approximately *25-40 lux*.

Earlier it was common with light levels in the range 100 - 300 lux for normal activities. Today the light level is more common in the range 500 - 1000 lux - depending on activity. For precision and detailed works, the light level may even approach 1500 - 2000 lux.

The table below is guidance for recommended light level in different work spaces:

Activity	Illumination *(lux, lumen/m^2)*
Easy Office Work, Classrooms	350 lux
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	500 lux
Supermarkets, Mechanical Workshops, Office Landscapes	750 lux

Table 6.1 Guideline of recommended Illumination level

The recommended values of daylight illuminance commensurate with the general standards of lighting related to many occupations and buildings; these are valid under most of the conditions whether the illumination is by daylighting, artificial lighting or a combination of the two. For specified requirements for daylighting of a particular area, reference may be made to good practice.

6.1 Daylight for General Room Lighting:-

In a tropical country, it is always preferable to use daylight during daytime hours. This can be achieved, if there is a significant amount of daylight is available depending on the availability of solar irradiance on that particular area during different daytime.

6.1.1 Interiors without Supplementary Electric Lighting during daytime:-

If artificial lighting is not used during daytime hours, the average daylight factor should be not less than 5 per cent. The internal reflectance and window position should be maintained properly to make symmetrical inter-reflected lighting in the room.

6.1.2 Interiors with supplementary electric lighting during daytime:-

If artificial lighting is being used during daytime, the average daylight factor should be not less than 2 per cent. If the average daylight factor is less than 2 per cent, daylight will be noticeable only on room surfaces immediately adjacent to windows. Artificial lighting may be required to increase the illumination level of the room far from the window. In this case, the average illuminance with artificial lighting in this area should not be less than 300 lux.

The interior illumination levels for Educational buildings are recommended in the following Table as per ***NATIONAL BUILDING CODE OF INDIA*** *[PART 8: BUILDING SERVICES]* and as per ***IS 3646 (Part-I):1992:*** *Code of Practice for Interior Illumination* by ***BUREAU OF INDIAN STANDARDS.***

Sl No.	Type of Interior or Activity	Range of Service Illuminance in Lux
21	**EDUCATION**	
21.1	**Assembly Halls**	
21.1.1	**General**	**200-300-500**
21.1.2	**Platform and stage**	**-**
21.2	**Teaching Space**	
	General	**200-300-500**
21.3	**Lecture Theatres**	
21.3.1	**General**	**200-300-500**
21.3.2	**Demonstration benches**	**300-500-750**
21.4	**Seminar Rooms**	**300-500-750**
21.5	**Art Rooms**	**300-500-750**
21.6	**Needlework Rooms**	**300-500-750**
21.7	**Laboratories**	**300-500-750**
21.8	**Libraries**	**200-300-500**
21.9	**Music Rooms**	**200-300-500**
21.10	**Sports Halls**	**200-300-500**
21.11	**Workshops**	**200-300-500**

Table 6.2 Code of Practice for Interior Illumination [IS 3646 :(Part-I): 1992]

6.2 The Lighting Recommendations by ECBC

6.2.1. General Design Consideration

For a good and energy efficient lighting design, sensitive integration of so many consideration that includes building orientation, building layout, daylight strategies, task illumination and type of Illumination system complies with the proper code, meeting both mandatory and perspective requirements. The lighting requirements in this section shall apply to:

(a) Interior spaces of buildings

(b) Exterior building features and

(c) Exterior building grounds lighting that is provided through the building's lighting.

Among these control code, some mandatory requirement for lighting related to interior & exterior control allows lighting to be dimmed or completely turned off for proper daylighting control as per requirements. These controls need to perform two basic functions---

a) Turn off lights when not in use

b) Modulate light output so that no more light beyond necessity to be produced.

According to this control code interior lighting system in buildings mainly all office room, school orcollege classrooms need to be equipped with occupancy sensor for proper dimming control.

6.2.2 Control in Daylighted Area

Luminaires in daylighted areas greater than 25 m (250 ft) shall be equipped with either a manual or automatic control device that:

(a) is capable of reducing the light output of the luminaires in the daylighted areas by at least 50%, and

(b) Controls only the luminaires located entirely within the daylighted area.

6.2.3 Interior Lighting Power

The installed interior lighting power for a building shall be calculated and shall not exceed the interior lighting power allowance limit determined by either

(i) Building area Method or (ii) Space Function Method as per ECBC.

The permissible value of ***Light Power Density as per ECBC guideline*** is given in the following table:

Building Area Type	LPD (W/m^2)	Building Area Type	LPD (W/m^2)
Automotive Facility	9.7	Multifamily Residential	7.5
Convention Centre	12.9	Museum	11.8
Court House	12.9	**Office**	**10.8**
Dining : Bar Lounge/Leisure	14.0	Parking Garage	3.2
Dining: Cafeteria/Fast food	15.1	Penitentiary (jail)	10.8
Dining : Family	17.2	Performing Arts Theatre	17.2
Dormitory	10.8	Police/Fire Station	10.8
Exercise Centre	10.8	Post Office	11.8
Gymnasium	11.8	Religious Building	14.0
Healthcare-Clinic	10.8	Retail	16.1
Hospital/Health Care	12.9	School/ University	12.9
Hotel	10.8	Sports Arena	11.8
Library	14.0	Town Hall	11.8
Manufacturing Facility	14.0	Transportation	10.8
Motel	10.8	Warehouse	8.6
Motion Picture Theater	12.9	Workshop	15.1

Table 6.3 [a] ECBC guideline as per Building area Method

Space Function	**LPD(W/m^2)**	**Space Function**	**LPD(W/m^2)**
Office - Enclosed	11.8	Library	
Office - Open Plan	11.8	For Card File & Cataloging	11.8
Conference/Meeting/ Multipurpose	14.0	For Stacks	18.3
Classroom/Lecture/ Training	15.1	For Reading Area	12.9

Table 6.3 [b] ECBC guideline as per Space Function Method

From the above database it has been found that the permissible LPD value for a Office building is 11.8 W/m^2 where as it is up to 15.1W/m^2 in case of individual room or conference hall.

7. DETAILS ABOUT PLACE OF STUDIES:

7.1 Building Details

The case study analysis has been performed in an Office building situated under nearly tropical region, i.e., this building located in Kolkata, India. The sample building is oriented along the north south axis having a latitude of 22°33' N and longitude of 88°41' E. The reference building is a multi-storied building having 6 numbers of floors. The building is square shaped.

The length of the building along the north south axis is about 28.425 m, and its east to west is 40 m. The building has no obstruction from sunrays for at least 50m- 80m within its surroundings. Nearly all the room are positioned in the north and south-facing sections. The east facing sections have mostly contained service spaces, server rooms, sick room , electrical room and washrooms. Each and every floor has a common corridor in the front side of the room. The all rooms is usually occupied from09:00 a.m. to 7:00 p.m. The building is needed to be designed as an energy-efficient building, by implementing active daylight harvesting technique to analyze the integration of strategies with artificial lighting with the help of incorporated data which greatly affects the overall energy performance of thebuilding and make it environmentally sustainable design strategies with artificial lighting

with the help of incorporated data which greatly affects the overall energy performance of thebuilding and make it environmentally sustainable design.

8. CLIMATIC ASSESMENT OF PLACE OF STUDIES:-

An attempt is made in this chapter to clarify the climate of Kolkata at various temperature, and weather condition. An attempt is also made to provide the design potential based on each of these climatic properties in addition to the solar radiation & overall illumination received from daylight. Depending on daily climate, an overview of an average day's patterns and the maximum and minimum hourly weather values for a full year is obtained. This case study analysis has been performed in an office building situated near the tropical region, i.e., located at Kolkata in West Bengal, India. The sample building is located having latitude of 22°33' N and longitude of 88°41' E.

8.1 Evaluation Method:-

The performance of both quantitative and qualitative assessments of daylight harvesting process in a building, some basic steps should be followed. The main steps involved in the performance assessment and comparison are as follows:

- Availability of Solar Insolation level for the specific location at different timeframe throughout the year.
- Quantity of daily contribution of daylight (hour basis) at different time period over the year.
- The yearly analysis of average temperature for the specified location.

8.1.1 Global Positioning of Kolkata & Sun-path:-

The sun-path diagram for Kolkata is presented in this section which is elongated from east to west.

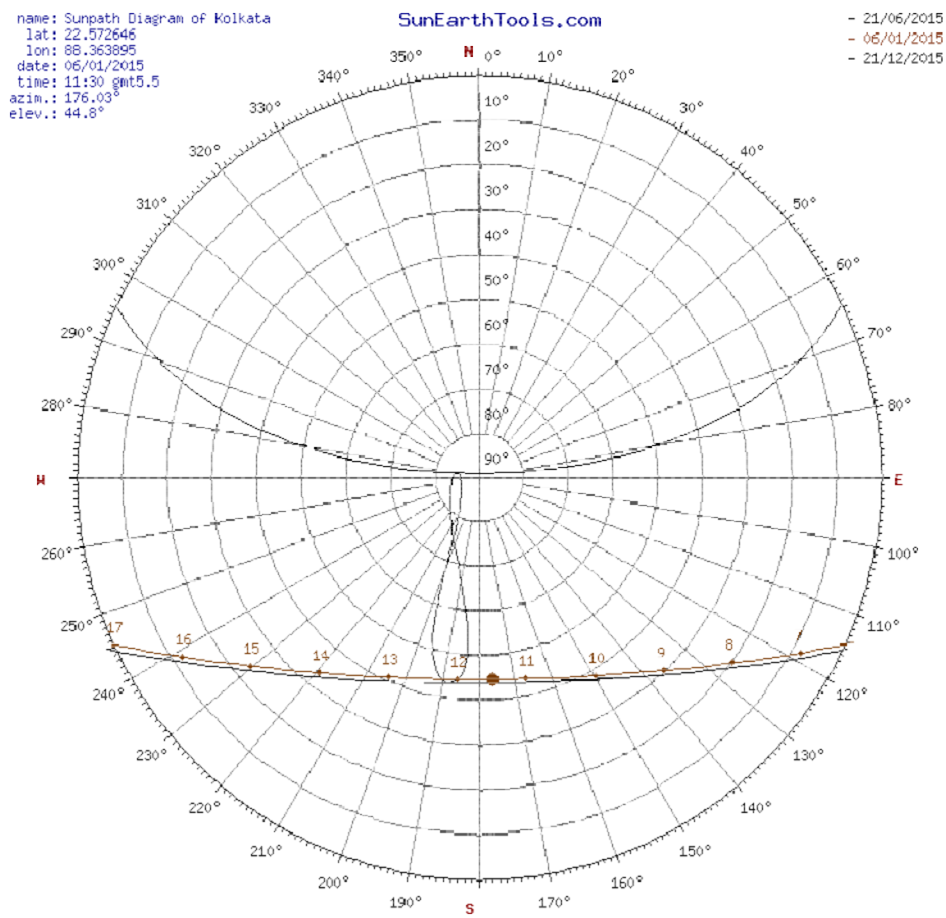


Fig 8.1 Sun-path diagram for Kolkata [***Source: NOAA ESRL***]

8.1.2 Study on Solar Irradiance:-

Based on the above criteria, background study has been carried out in the specified area i.e., in Kolkata of West Bengal, India in Northern hemisphere. Initially the performance analysis has been studied on the West Bengal region. Following is the solar insolation map of India showing the different solar irradiance area.

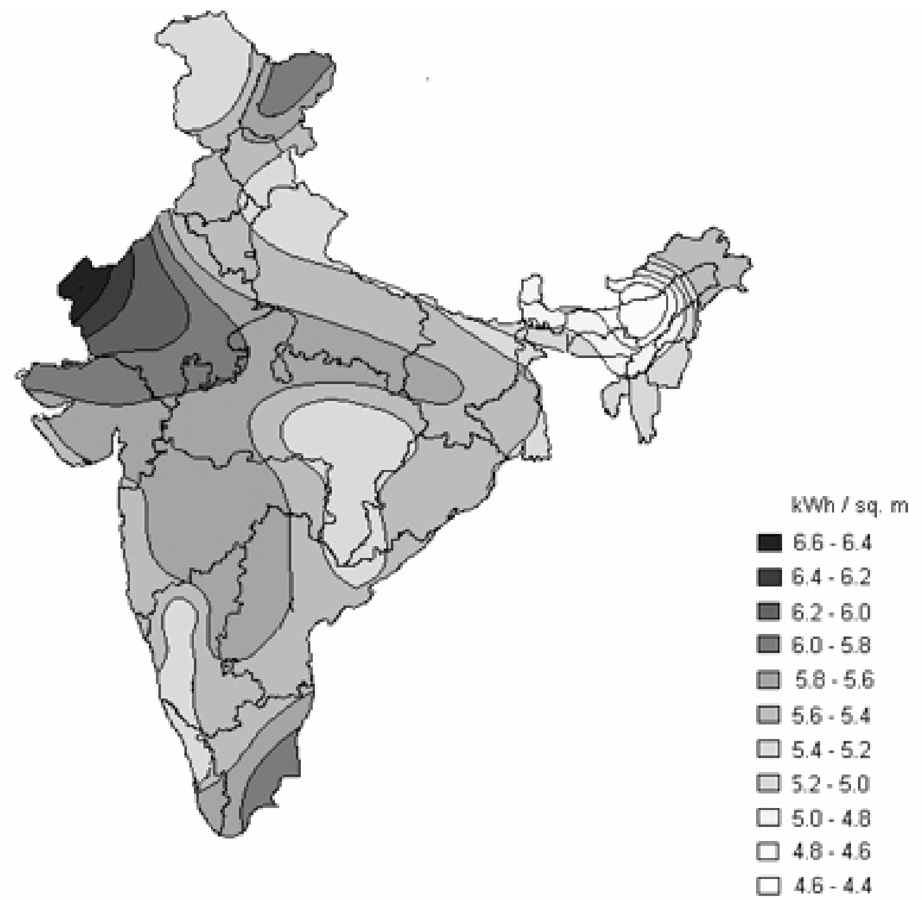


Fig 8.2 Solar Insolation Map showing Annual average Insolation **[Source: TERI]**

It has been analyzed from the above solar insolation map that the annual average insolation level of West Bengal is in between 5.2 to 5.6 kWh/m^2/day. The average solar energy West Bengal receives 1600 kWh/m^2 of per year. The detail status of annual solar insolation level in Kolkata can be found from the following assessment:-

Month	Solar Irradiance
Jan	4.67
Feb	4.92
Mar	5.54
Apr	5.51
May	5.5
Jun	3.51
Jul	3.56
Aug	3.73
Sep	3.43
Oct	4.04
Nov	4.5
Dec	4.43

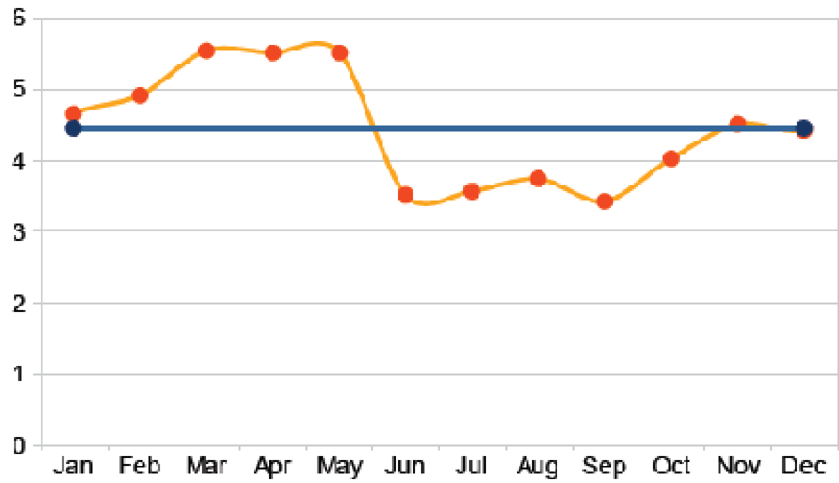


Fig 8.3 [a] Month wise Average Solar Irradiance of Kolkata in kW/m^2 **[b]** Graphical representation of average Solar Insolation in Kolkata, West Bengal. [**Source : SYNERGY Enviro Engineers**]

From the above data, it can easily conclude that the value of average solar irradiance is higher during March to May and have a lower value from June to September. Rest of the time it maintained a moderate value within the range of 4kW/m^2 – 5kW/m^2 which is standard for this region.

8.1.3 Study on Average daylight distribution:-

The amount of solar radiation also varies depending on the time of day and the time of year. In general, greatest insolation is obtained during midday or at solar noon. The amount of insolation is lesser during either the early morning or late afternoon. In the Northern Hemisphere, south-facing building receives more solar radiation during midday because the sun's rays are nearly perpendicular to that surface. In the Northern Hemisphere, one can experience more solar radiation during the summer than during the winter due to presence of more daylight hours in summer. Fig 8.4 shows how the illuminance on a particular location provided by daylight varies with the time of year and the time of day.

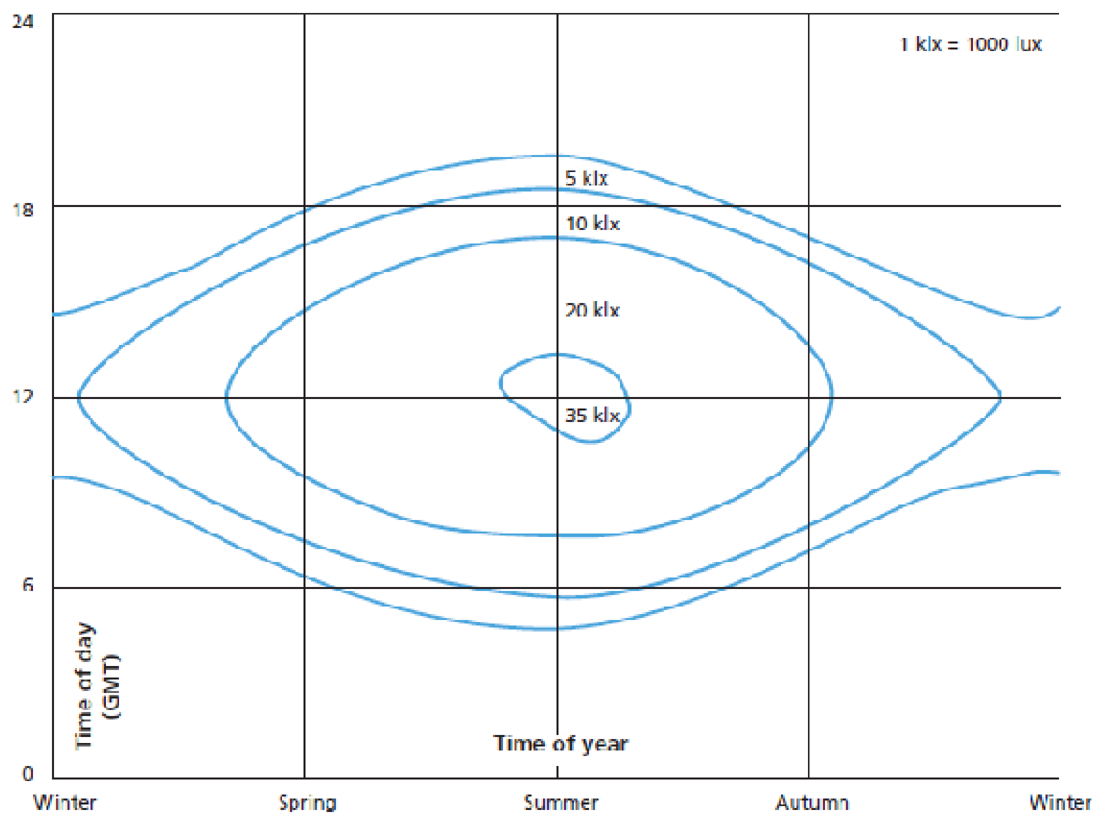


Fig 8.4 The illuminance provided by daylight on a area varies with the time of year and the time of day **[Source: SLL Lighting Handbook]**

It has been observe that during summer season the maximum illuminance can be up to 35000 lux at midday, whereas it drastically reduces to 10000 lux during winter. Obviously, these illuminances are measured on an unobstructed horizontal plane. But in a building, the amount of daylight available will depend on the position and size of the windows. The contribution of daylight inside a room is given by the daylight factor in conjunction with the daylight availability.

The quantity of daily contribution of daylight in Kolkata throughout the year can be studied from the following tabular and graphical assessment:

KOLKATA, WEST BENGAL, INDIA

Location: E 88° 22', N 22°34'

Duration of Daylight for a Year

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
01	10:47	11:09	11:42	12:23	12:59	13:26	13:29	13:09	12:35	11:56	11:18	10:52
02	10:47	11:10	11:43	12:24	13:01	13:26	13:29	13:08	12:33	11:55	11:17	10:51
03	10:48	11:11	11:44	12:26	13:02	13:27	13:29	13:07	12:32	11:54	11:16	10:50
04	10:48	11:12	11:46	12:27	13:03	13:27	13:28	13:06	12:31	11:52	11:15	10:50
05	10:48	11:13	11:47	12:28	13:04	13:27	13:28	13:05	12:30	11:51	11:14	10:49
06	10:49	11:14	11:48	12:30	13:05	13:28	13:28	13:04	12:28	11:50	11:13	10:49
07	10:49	11:15	11:49	12:31	13:06	13:28	13:27	13:03	12:27	11:49	11:12	10:48
08	10:50	11:16	11:51	12:32	13:07	13:29	13:27	13:02	12:26	11:48	11:11	10:48
09	10:50	11:18	11:52	12:33	13:08	13:29	13:26	13:01	12:25	11:46	11:10	10:48
10	10:51	11:19	11:53	12:35	13:09	13:29	13:26	13:00	12:23	11:45	11:09	10:47
11	10:51	11:20	11:55	12:36	13:10	13:30	13:25	12:59	12:22	11:44	11:08	10:47
12	10:52	11:21	11:56	12:37	13:11	13:30	13:25	12:58	12:21	11:42	11:07	10:47
13	10:53	11:22	11:57	12:38	13:12	13:30	13:24	12:57	12:19	11:41	11:06	10:46
14	10:53	11:23	11:59	12:40	13:12	13:30	13:24	12:56	12:18	11:40	11:05	10:46
15	10:54	11:24	12:00	12:41	13:13	13:30	13:23	12:55	12:17	11:39	11:04	10:46
16	10:55	11:26	12:01	12:42	13:14	13:31	13:22	12:54	12:16	11:37	11:03	10:46
17	10:56	11:27	12:03	12:43	13:15	13:31	13:22	12:52	12:14	11:36	11:02	10:46
18	10:56	11:28	12:04	12:44	13:16	13:31	13:21	12:51	12:13	11:35	11:01	10:45
19	10:57	11:29	12:05	12:46	13:17	13:31	13:20	12:50	12:12	11:34	11:00	10:45
20	10:58	11:30	12:06	12:47	13:18	13:31	13:20	12:49	12:10	11:33	10:59	10:45
21	10:59	11:32	12:08	12:48	13:18	13:31	13:19	12:48	12:09	11:31	10:59	10:45
22	10:59	11:33	12:09	12:49	13:19	13:31	13:18	12:47	12:08	11:30	10:58	10:45
23	11:00	11:34	12:10	12:50	13:20	13:31	13:17	12:46	12:07	11:29	10:57	10:45
24	11:01	11:35	12:12	12:52	13:21	13:31	13:16	12:44	12:05	11:28	10:56	10:45
25	11:02	11:37	12:13	12:53	13:21	13:31	13:16	12:43	12:04	11:27	10:56	10:45
26	11:03	11:38	12:14	12:54	13:22	13:31	13:15	12:42	12:03	11:25	10:55	10:45
27	11:04	11:39	12:16	12:55	13:23	13:30	13:14	12:41	12:01	11:24	10:54	10:46
28	11:05	11:40	12:17	12:56	13:23	13:30	13:13	12:39	12:00	11:23	10:53	10:46
29	11:06		12:18	12:57	13:24	13:30	13:12	12:38	11:59	11:22	10:53	10:46
30	11:07		12:20	12:58	13:24	13:30	13:11	12:37	11:57	11:21	10:52	10:46
31	11:08		12:21		13:25		13:10	12:36		11:20		10:47

Fig 8.5 [a] Annual Average Daylight Duration in Kolkata [Source*:* ***NREL*****]**

The graphical analysis of the daylight hour availability is as follows

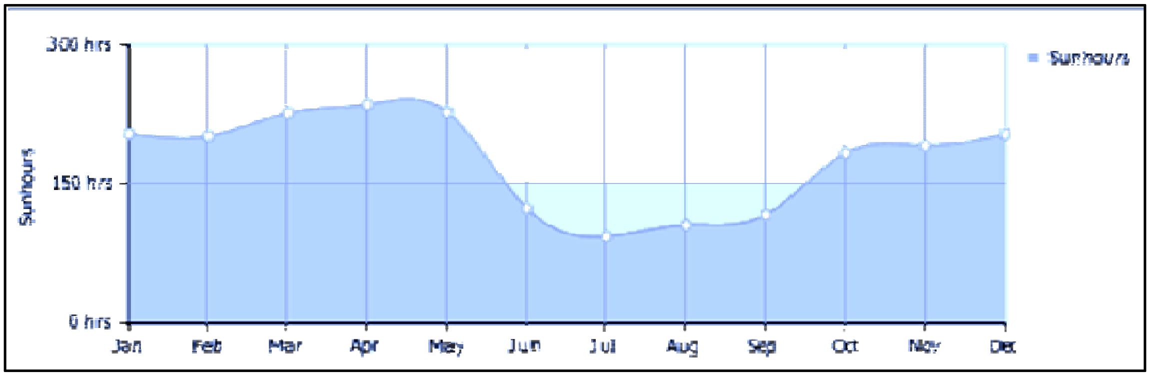


Fig 8.5[b] Average monthly daylight hours over the year in Kolkata, India [*Source : TERI*]

It has been observed from the Fig 8.5 [a] & Fig8.5 [b] that maximum daylight hours can be achieved (nearly 200Hrs/month) during the 2nd quarter of the year. It become lowest during June to Sept and then gradually increases to the maximum value.

8.1.4 Study of Yearly Average temperature at Different Location:-

This section provides supplementary information regarding annual average temperature at the assessed location of West Bengal. The collected data can be utilized for qualitative analysisof daylight harvesting.

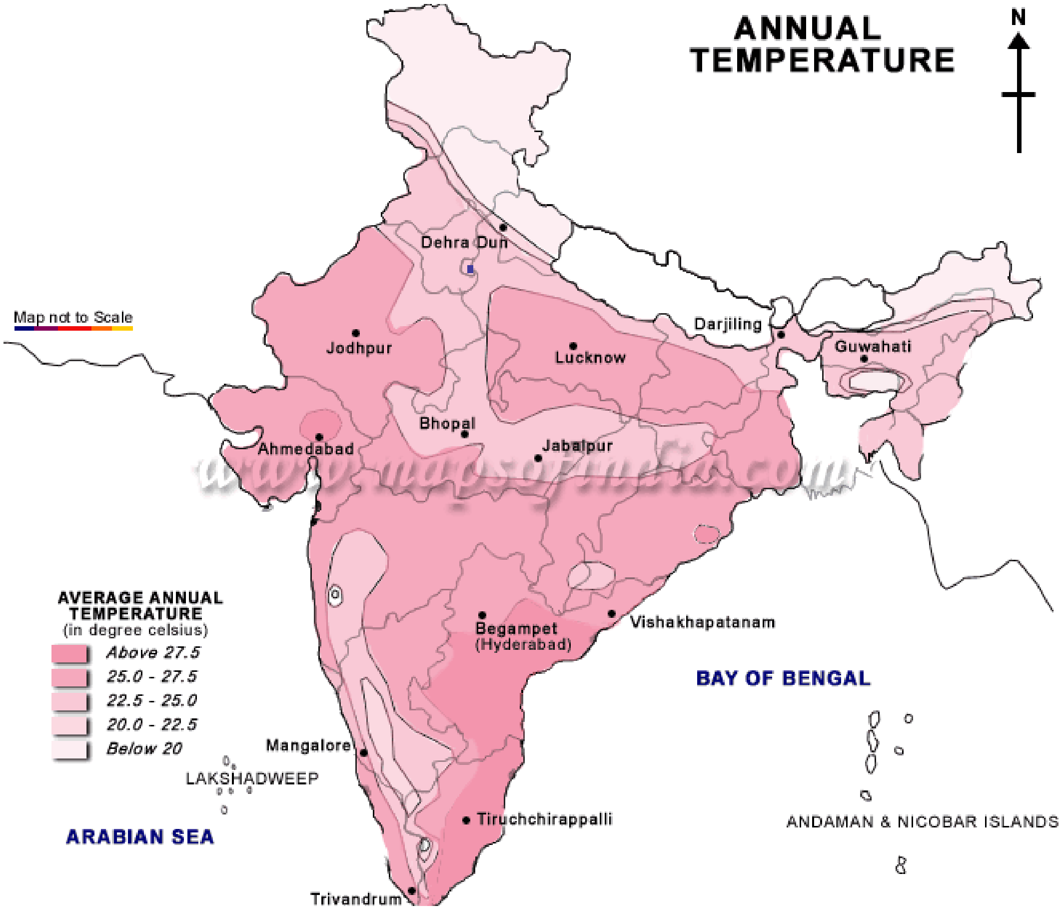


Fig 8.6 Annual Avg. Temperature (°C) Map of India [Copyright© Compare Infobase Pvt. Ltd. 2000-2001]

From the above map it is shown that the Annual temperature of Southern part of West Bengal is in between 25°C -27°C and of Northern part is in between 22°C-25°C. As the assessed location is situated in the southern region, the average temperature recorded in Kolkata.

The detail records of location wise temperature assessment are stated as follows

Month	Average Temp.in °C	
	max	min
January	25.6	12.4
February	29.3	16.4
March	33.4	21.1
April	35.8	24.3
May	36	25.4
June	34.3	26.2
July	33	26.1
August	32.9	26.2
September	32.9	25.7
October	32.2	23.7
November	29.9	18.9
December	26.7	13.8

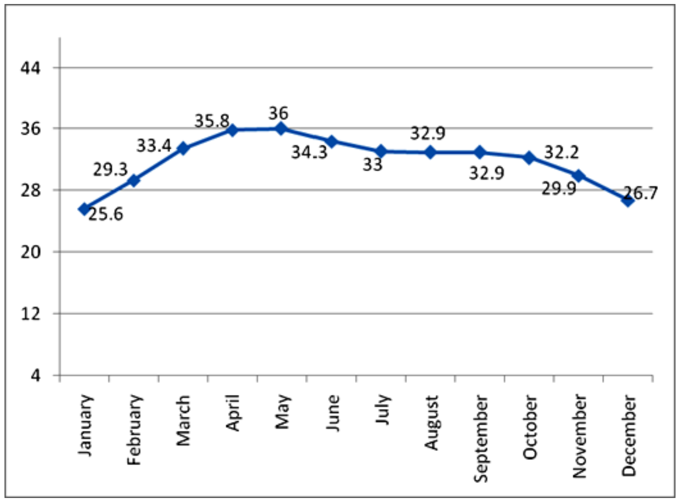


Fig 8.7 [a] Monthly Average Temperature of Kolkata, India **[b]** Graphical representation of annual average Temperature of Kolkata, India

From the above table it can easily be concluded that the annual average temperature can varies from 25°C to 36°C during daytime which become maximum at 2^{nd} quarter [April – June] of the year.

9. CASE STUDY:-

The case study analysis has been performed in an Office building i.e., located in Kolkata, India situated under tropical region; Fig 9.1 shows an isometric view of the whole case study building.

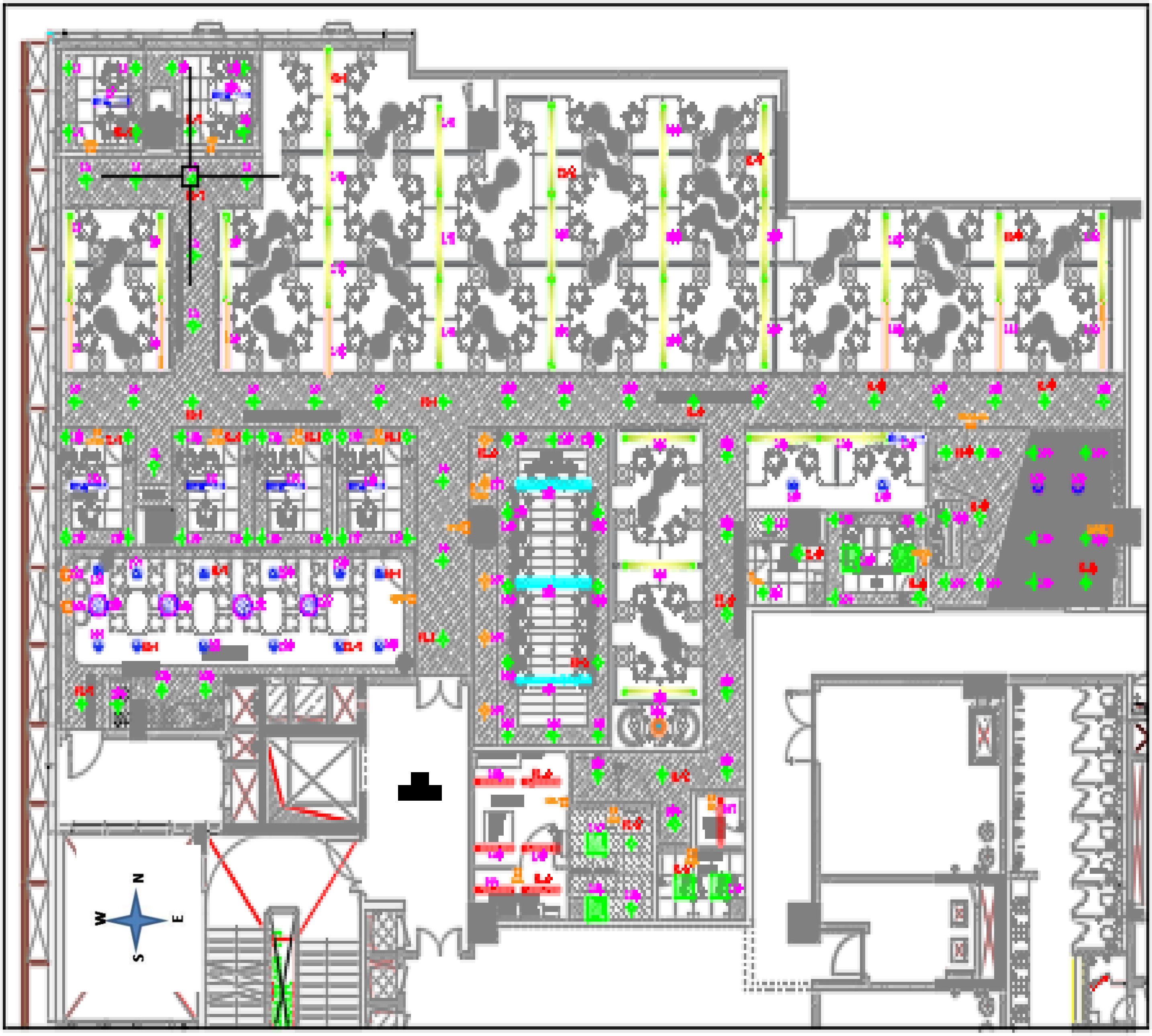


Fig 9.1 Isometric view of case study building

The building is orientated along the north-south axis to maximize daylight penetration. The building is symmetrical along east-west axis. So there exists similar type of rooms and cabins in both side of this building; for that reason measurement has been taken in one room for each specific type. The case study analysis has been done to calculate the value of overall illuminance within the different rooms of the building and also the exterior solar exposure of that location on a particular day to determine the daylight distribution. This study was conducted to derive a clear understanding of these relationships on the energy consumption within a building for the tropical climate zone. In particular, this study has been done for proper assessment of energy savings potential with maximum utilization of daylight in a building. The provision of daylight would reduce a building's energy consumption where electrical lights need to be switched off or controlled for spaces that are illuminated by daylight. To estimate the performance of a solar energy system it need to know how much solar energy is available on that particular location. This measurement has been done in two parts--

a) Measurement of exterior solar irradiance

b) Measurement of interior illumination

The solar irradiance in terms of W/m^2 has been measured in the study location throughout the year within a specific interval of time. The availability of daylight is measured at different area mainly at the office rooms and corridor area of the building considering all directions, i.e, North, South, East & West side of the building.

The performance assessment is as follows:

9.1 Solar Irradiance Measurement:-

Solar irradiance measurement has been carried out during a timeframe throughout the year for the assessment of solar energy on that location. The average annual solar insulation level in Kolkata can be found from this assessment.

9.1.1 Experimental Setup:-

The measurements of solar irradiance have been conducted with the help of **Global Solar Pyranometer** [*Serial No: 007159; Make: Weather Technologies (India) Pvt. Ltd*] in combination with a *Metravi make* **Multimeter.** The measured irradiance data have been collected at every half an hour interval. Each recorded solar irradiance value is the average data of 4 consecutive measurements taken within 2 minutes. The complete experimental setup is shown here under

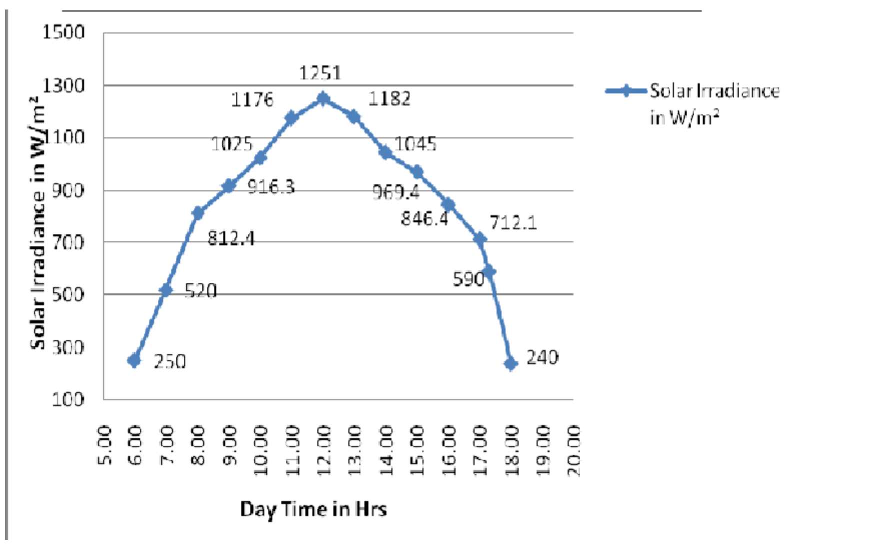
Fig 9.2 Measurement of Solar Irradiance with Global Pyranometer

9.1.2 Month wise (Seasonal) Report on Average Solar Insolation Level:-

The solar irradiance data has been recorded in a particular date of a month and is being plotted here under

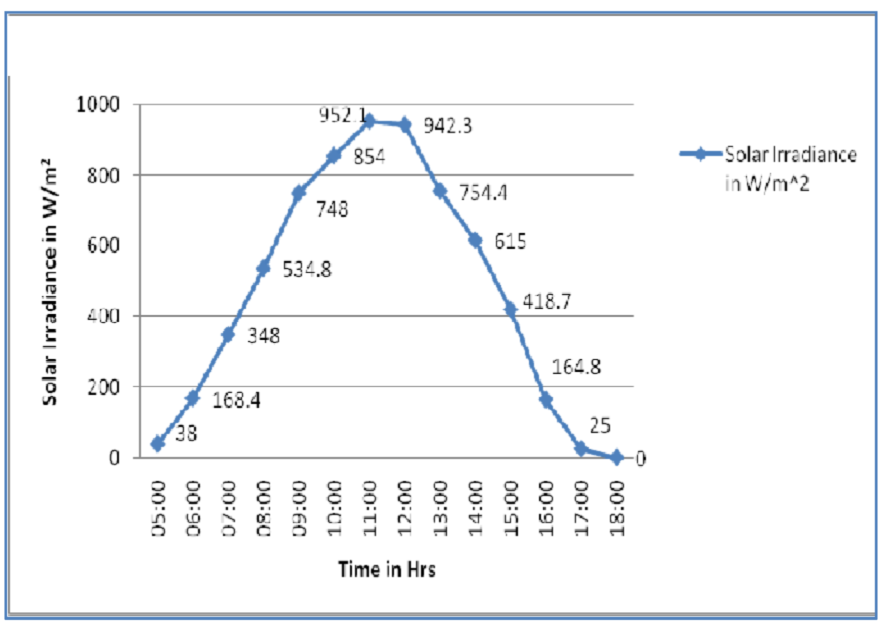
9.1.2.1 Solar irradiance data measured in the month of May (Summer):-

Time	Solar Irradiance in W/m²
6.00	250
7.00	520
8.00	812.4
9.00	916.3
10.00	1025
11.00	1176
12.00	1251
13.00	1182
14.00	1045
15.00	969.4
16.00	846.4
17.00	712.1
17.30	590
18.00	240



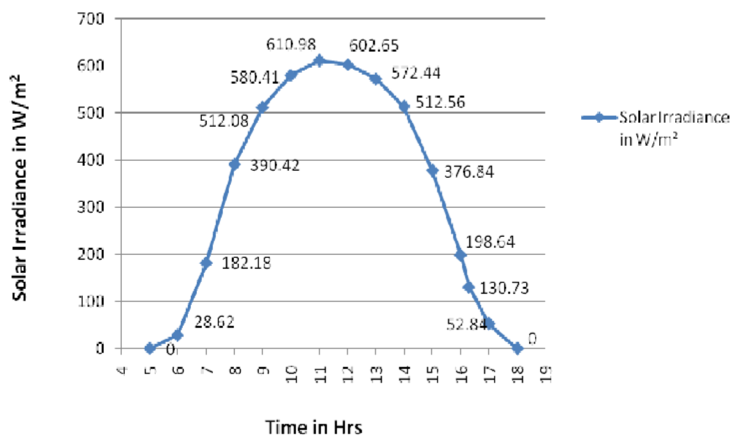
9.1.2.2 Solar irradiance data measured in the month of September(Autumn):-

Time	Solar Irradiance in W/m²
05:00	38
06:00	168.4
07:00	348
08:00	534.8
09:00	748
10:00	854
11:00	952.1
12:00	942.3
13:00	754.4
14:00	615
15:00	418.7
16:00	164.8
17:00	25
18:00	0



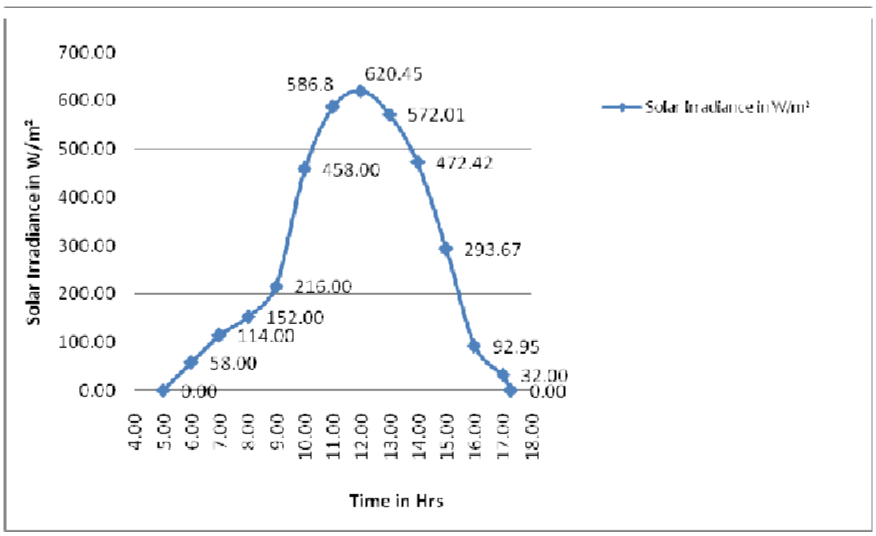
9.1.2.3 Solar irradiance data measured in the month of March (Spring):-

Time	Solar Irradiance in W/m²
5.00	0.00
6.00	28.62
7.00	182.18
8.00	390.42
9.00	512.08
10.00	580.41
11.00	610.98
12.00	602.65
13.00	572.44
14.00	512.56
15.00	376.84
16.00	198.64
16.30	130.73
17.00	52.84
18.00	0.00



9.1.2.4 Solar irradiance data measured in the month of December (Winter):-

Time	Solar Irradiance in W/m²
5.00	0.00
6.00	58.00
7.00	114.00
8.00	152.00
9.00	216.00
10.00	458.00
11.00	586.8
12.00	620.45
13.00	572.01
14.00	472.42
15.00	293.67
16.00	92.95
17.00	32.00
17.30	0.00



9.1.3 Standard Solar Insolation Data comprising Global Radiation:-

The measurement of hourly global solar radiation by means of ***Global Horizontal Irradiance*** **[GHI]** has been taken for a fixed date in every month, e.g., 6th day of each month and this data is being compared with the standard database for global hourly solar radiation of Kolkata. The standard solar radiation data comprising global radiation for Kolkata, India whose values have been collected from *Indian Meteorology Department (IMD) Pune, India* and incorporated hereunder:

Date	Time	GHI(W/m^2)
06/01/2024	06:00	4
06/01/2024	07:00	148
06/01/2024	08:00	333
06/01/2024	09:00	500
06/01/2024	10:00	616
06/01/2024	11:00	667
06/01/2024	12:00	645
06/01/2024	13:00	551
06/01/2024	14:00	401
06/01/2024	15:00	221
06/01/2024	16:00	49
06/01/2024	17:00	0

Table 9.1 [a]

Date	Time	GHI (W/m^2)
06/02/2024	05:00	0
06/02/2024	06:00	13
06/02/2024	07:00	177
06/02/2024	08:00	373
06/02/2024	09:00	560
06/02/2024	10:00	697
06/02/2024	11:00	766
06/02/2024	12:00	756
06/02/2024	13:00	675
06/02/2024	14:00	526
06/02/2024	15:00	332
06/02/2024	16:00	128
06/02/2024	17:00	0
06/02/2024	18:00	0

Table 9.1 [b]

Date	Time	GHI(W/m^2)
06/03/2024	05:00	0
06/03/2024	06:00	64
06/03/2024	07:00	275
06/03/2024	08:00	497
06/03/2024	09:00	689
06/03/2024	10:00	825
06/03/2024	11:00	890
06/03/2024	12:00	876
06/03/2024	13:00	781
06/03/2024	14:00	626
06/03/2024	15:00	420
06/03/2024	16:00	195
06/03/2024	17:00	5
06/03/2024	18:00	0

Table 9.1 [c]

Date	Time	GHI(W/m^2)
06/04/2024	05:00	2
06/04/2024	06:00	148
06/04/2024	07:00	370
06/04/2024	08:00	590
06/04/2024	09:00	774
06/04/2024	10:00	899
06/04/2024	11:00	950
06/04/2024	12:00	926
06/04/2024	13:00	825
06/04/2024	14:00	659
06/04/2024	15:00	449
06/04/2024	16:00	223
06/04/2024	17:00	26
06/04/2024	18:00	0

Table 9.1 [d]

Date	Time	GHI(W/m^2)
06/05/2024	05:00	30
06/05/2024	06:00	205
06/05/2024	07:00	418
06/05/2024	08:00	623
06/05/2024	09:00	792
06/05/2024	10:00	904
06/05/2024	11:00	946
06/05/2024	12:00	880
06/05/2024	13:00	813
06/05/2024	14:00	651
06/05/2024	15:00	336
06/05/2024	16:00	129
06/05/2024	17:00	46
06/05/2024	18:00	0

Table 9.1 [e]

Date	Time	GHI(W/m^2)
06/06/2024	05:00	34
06/06/2024	06:00	220
06/06/2024	07:00	418
06/06/2024	08:00	614
06/06/2024	09:00	771
06/06/2024	10:00	891
06/06/2024	11:00	933
06/06/2024	12:00	906
06/06/2024	13:00	812
06/06/2024	14:00	663
06/06/2024	15:00	469
06/06/2024	16:00	269
06/06/2024	17:00	82
06/06/2024	18:00	0

Table 9.1 [f]

Date	Time	GHI(W/m^2)
06/07/2024	05:00	33
06/07/2024	06:00	177
06/07/2024	07:00	298
06/07/2024	08:00	133
06/07/2024	09:00	477
06/07/2024	10:00	879
06/07/2024	11:00	933
06/07/2024	12:00	912
06/07/2024	13:00	684
06/07/2024	14:00	463
06/07/2024	15:00	495
06/07/2024	16:00	262
06/07/2024	17:00	18
06/07/2024	18:00	0

Table 9.1 [g]

Date	Time	GHI(W/m^2)
06/08/2024	05:00	10
06/08/2024	06:00	136
06/08/2024	07:00	214
06/08/2024	08:00	359
06/08/2024	09:00	211
06/08/2024	10:00	201
06/08/2024	11:00	241
06/08/2024	12:00	460
06/08/2024	13:00	568
06/08/2024	14:00	266
06/08/2024	15:00	148
06/08/2024	16:00	150
06/08/2024	17:00	29
06/08/2024	18:00	0

Table 9.1 [h]

Date	Time	GHI(W/m^2)
06/09/2024	05:00	2
06/09/2024	06:00	136
06/09/2024	07:00	356
06/09/2024	08:00	376
06/09/2024	09:00	747
06/09/2024	10:00	837
06/09/2024	11:00	897
06/09/2024	12:00	796
06/09/2024	13:00	663
06/09/2024	14:00	592
06/09/2024	15:00	244
06/09/2024	16:00	169
06/09/2024	17:00	9
06/09/2024	18:00	0

Table 9.1 [i]

Date	Time	GHI(W/m^2)
06/10/2024	05:00	0
06/10/2024	06:00	131
06/10/2024	07:00	310
06/10/2024	08:00	401
06/10/2024	09:00	653
06/10/2024	10:00	730
06/10/2024	11:00	440
06/10/2024	12:00	729
06/10/2024	13:00	246
06/10/2024	14:00	447
06/10/2024	15:00	231
06/10/2024	16:00	26
06/10/2024	17:00	0
06/10/2024	18:00	0

Table 9.1 [j]

Date	Time	GHI(W/m^2)
06/11/2024	05:00	82
06/11/2024	07:00	265
06/11/2024	08:00	456
06/11/2024	09:00	620
06/11/2024	10:00	723
06/11/2024	11:00	749
06/11/2024	12:00	701
06/11/2024	13:00	584
06/11/2024	14:00	411
06/11/2024	15:00	214
06/11/2024	16:00	36
06/11/2024	17:00	0
06/11/2024	18:00	0

Table 9.1 [k]

Date	Time	GHI(W/m^2)
06/12/2024	05:00	0
06/12/2024	06:00	31
06/12/2024	07:00	196
06/12/2024	08:00	379
06/12/2024	09:00	534
06/12/2024	10:00	636
06/12/2024	11:00	670
06/12/2024	12:00	633
06/12/2024	13:00	528
06/12/2024	14:00	371
06/12/2024	15:00	187
06/12/2024	16:00	17
06/12/2024	17:00	0
06/12/2024	18:00	0

Table 9.1 [l]

Table 9.1(a) - (k) Solar Insolation Data in Kolkata for a particular day (6^{th}) in Every Month

9.1.4 Comparison of Month wise Solar Irradiance Data:-

It is seen that the trend of the measured values are more or less similar with the standard values for all months throughout the year. Fig 9.3 – Fig 9.6 shows the comparison between calculated and measured hourly global solar radiation for a year [seasonal] in Kolkata.

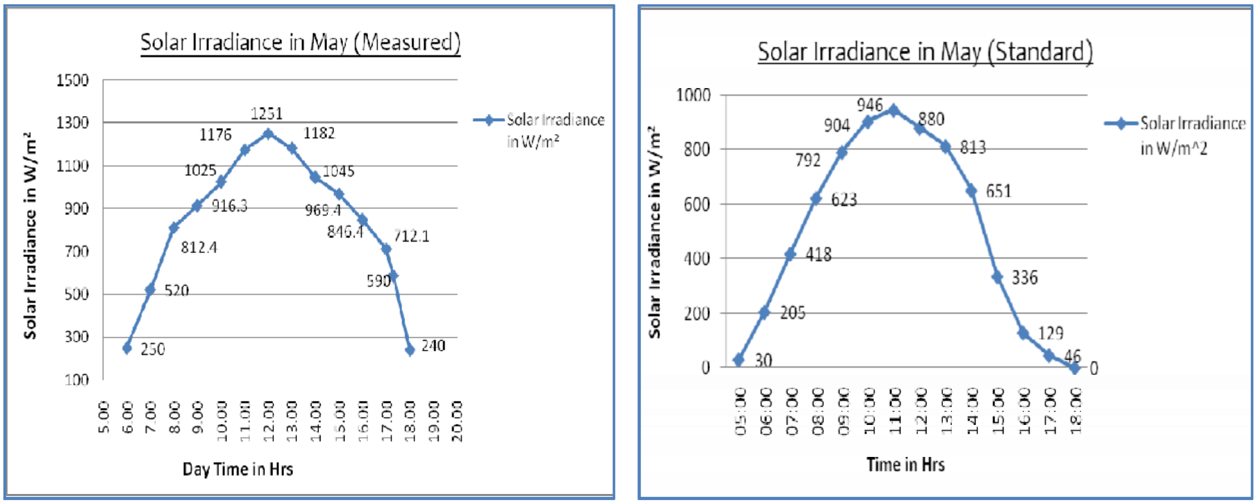


Fig 9.3 (a) Measured Value **(b)** Standard Value for the month of May in Kolkata

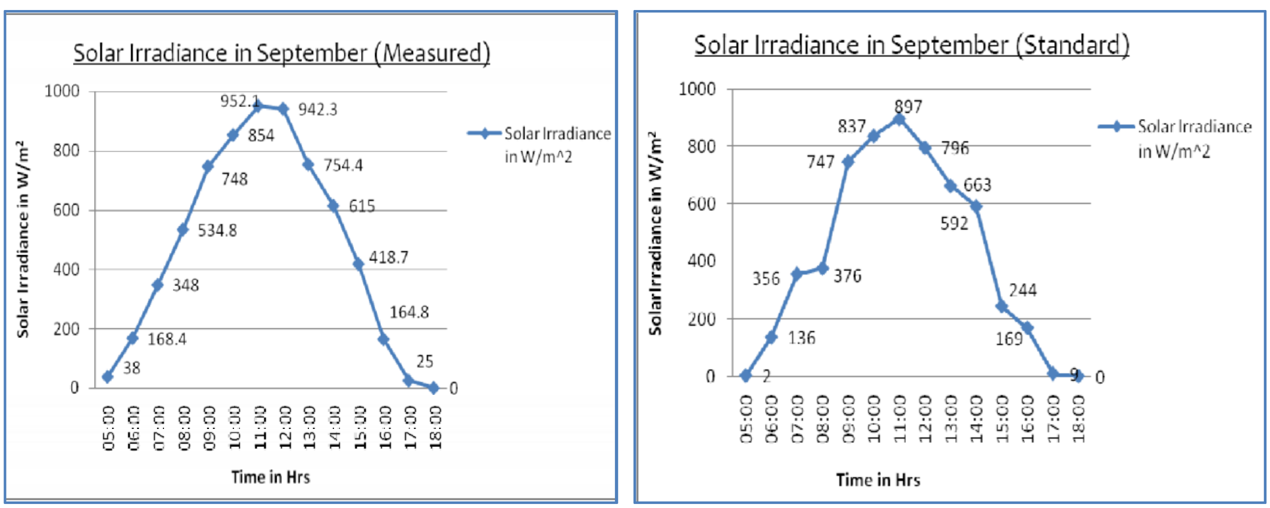
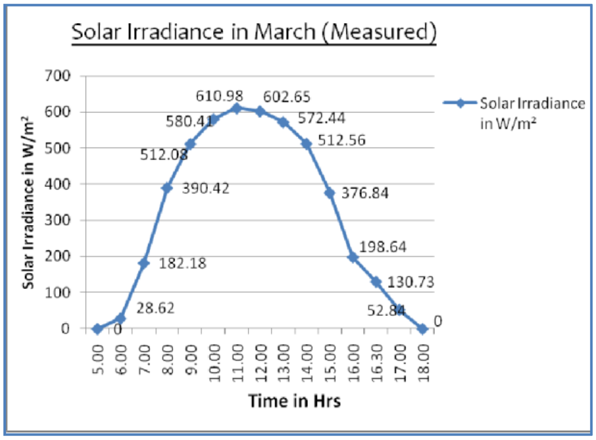


Fig 9.4 (a) Measured Value **(b)** Standard Value for the month of September in Kolkata

<u>Comparison of Month wise Solar Irradiance Data</u>



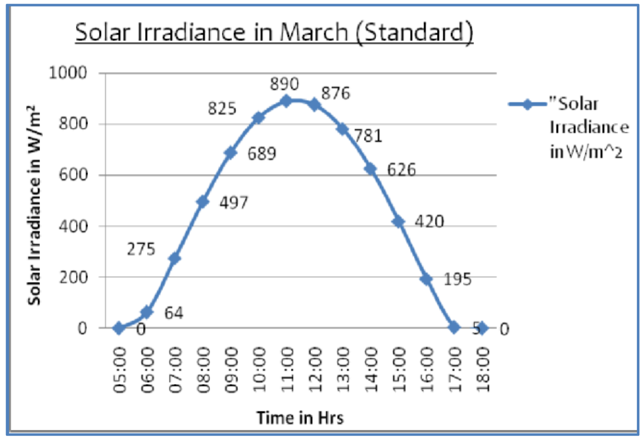
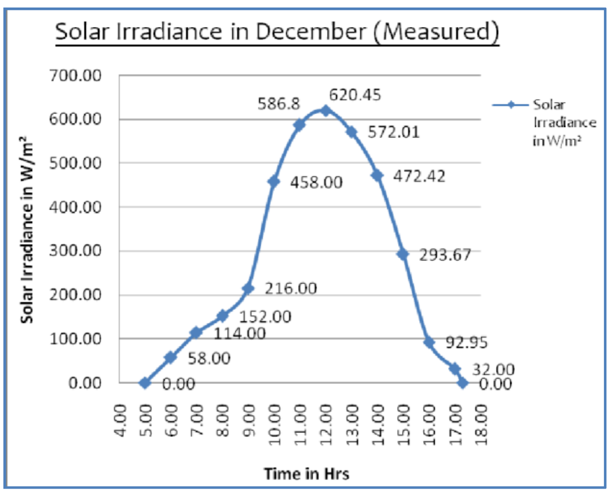


Fig 9.5 (a) Measured Value **(b)** Standard Value for the month of March in Kolkata



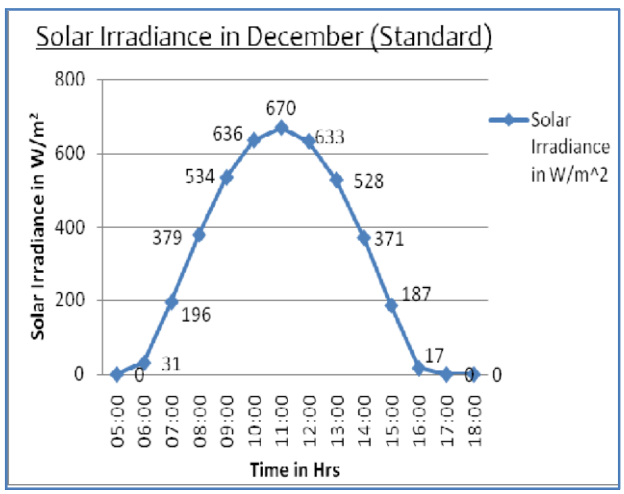


Fig 9.6 (a) Measured Value **(b)** Standard Value for the month of December in Kolkata

9.2 Measurement of interior illumination:-

The availability of daylight is measured at different area mainly at the rooms and work space area of the building considering all directions, i.e, North, South, East & West side of the building. Daylight levels of illumination will typically vary considerably over the room depth, due to distances from the window. For the artificial light, this means that the light, needed to supplement the lighting scene to maintain the required illuminance level, varies over the room depth.

9.2.1 Basic Consideration:-

The main steps involved in the performance assessment of interior illumination are as follows:

a) Investigate the quantity of the daylight contribution to a work plane level with the use of lighting measurements.
b) Investigate the correlation between indoor illuminance and outdoor weather conditions using statistical tools

For this experimental setup some basic scenario need to be followed based on following conditions -

- Room illuminate with daylight only
- Room illuminated with artificial light only
- Room illuminated with artificial light in combination with daylight

9.2.2 Experimental procedures:-

The measurements have been conducted on different months representing different season i.e., December (Winter in Kolkata), March (Spring in Kolkata), September (Autumn in Kolkata) and May (Summer in Kolkata) while sun position is different. Measurements are performed on a sunny day with mixed sky conditions between 09:00 A.M to 06:00 P.M. Artificial lighting in the sample rooms is switched off first and therefore only daylight illuminance is taken into consideration.

The hand-held illuminance level meter [*Digital Lux meter*] used to measure the light level. The meter allows quantitative (lux level) measurements to be taken simultaneously. Measurements were taken at floor level i.e., 0.0 mm high from the ground level and table top or work plane height is 0.76mm from the ground level. The measurements have been taken at different point in the room and are plotted.

9.2.3 Daylight Contribution Analysis:-

Daylight Availability Study for CAFÉ 35 PAX time 12.00pm

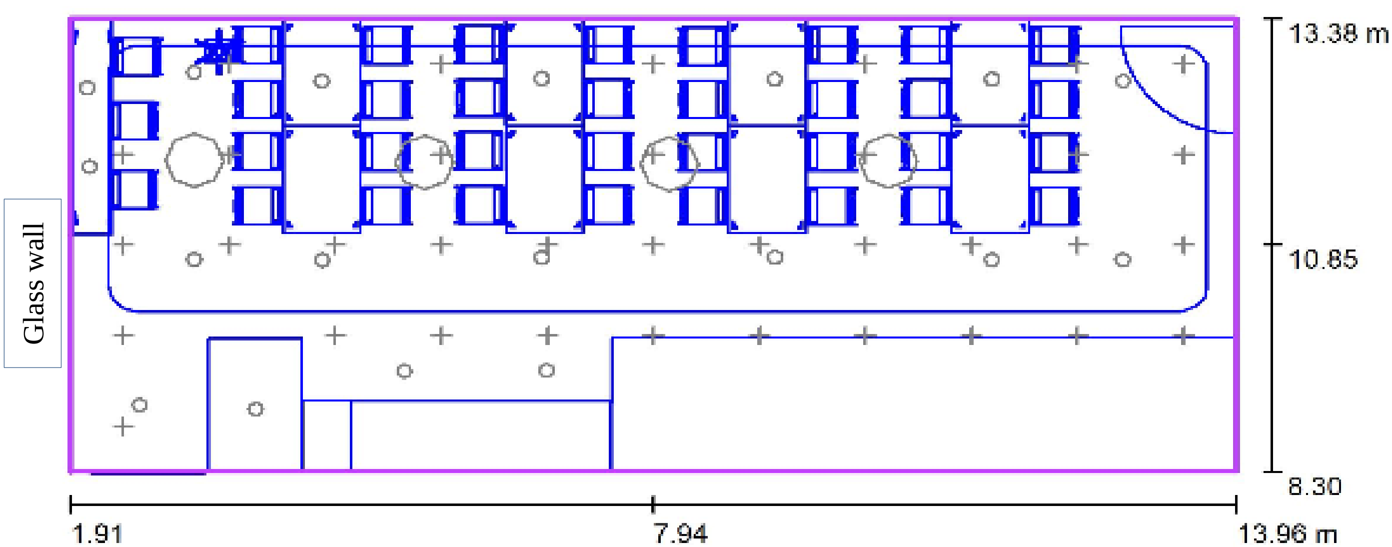


Fig. 9.7 CAFÉ 35 PAX with object

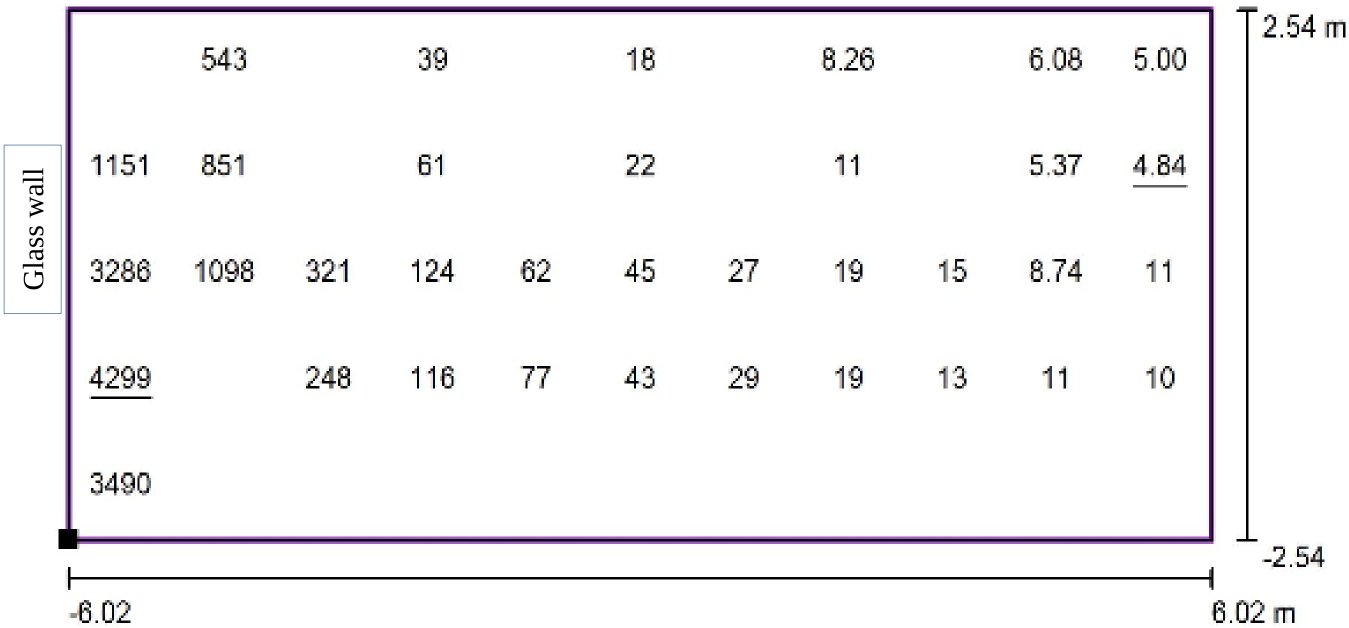


Fig.9.8 Point wise daylight lux level (summer time)

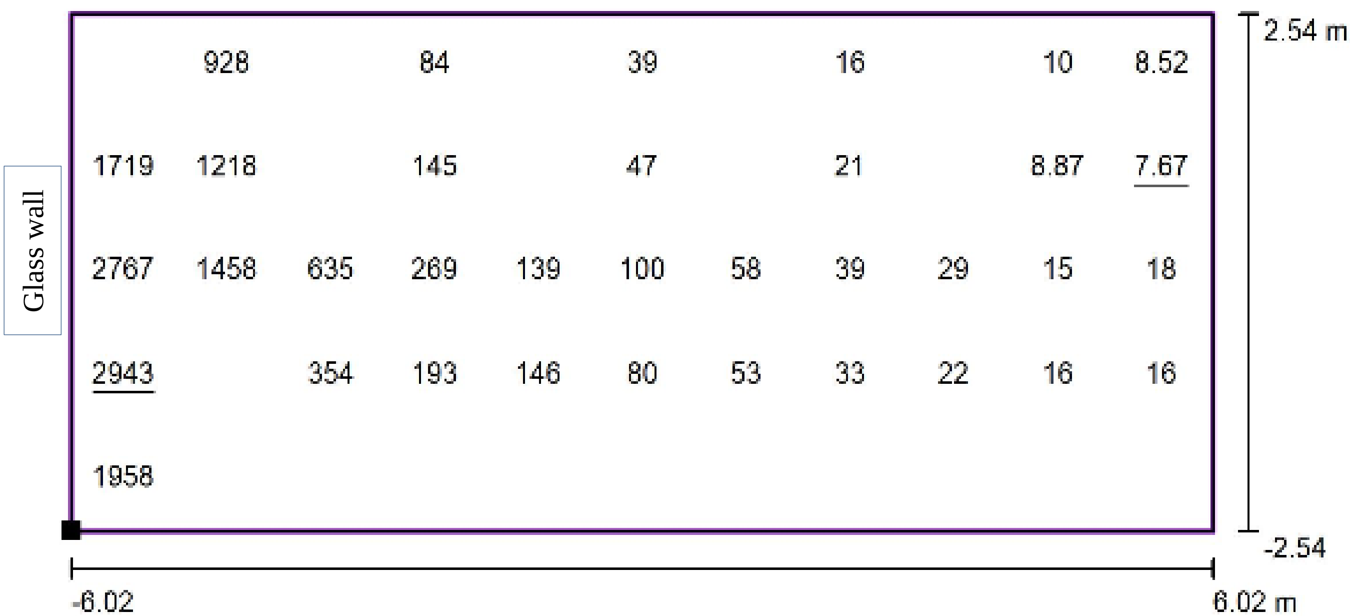


Fig.9.9 Point wise daylight lux level (winter time)

Daylight Availability Study for CABIN 1 time 12.00pm

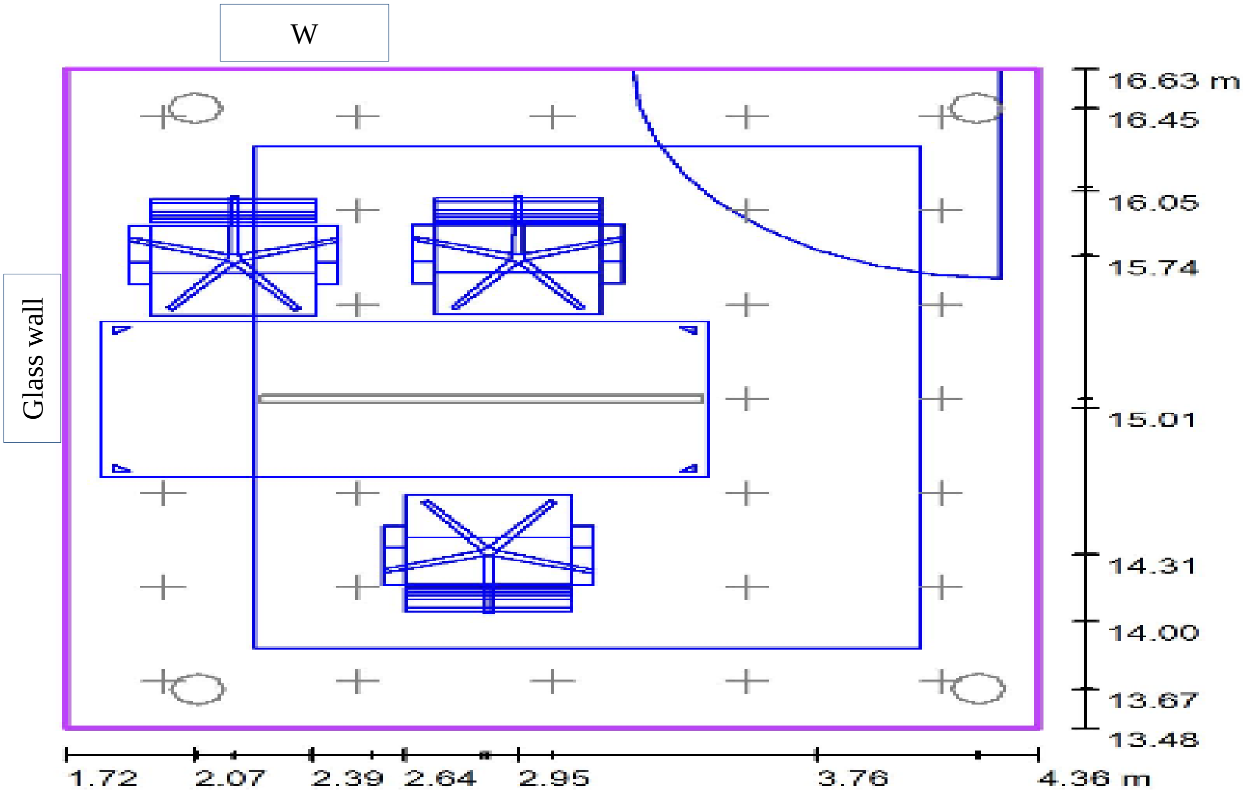


Fig. 9.10 CABIN 1 with object

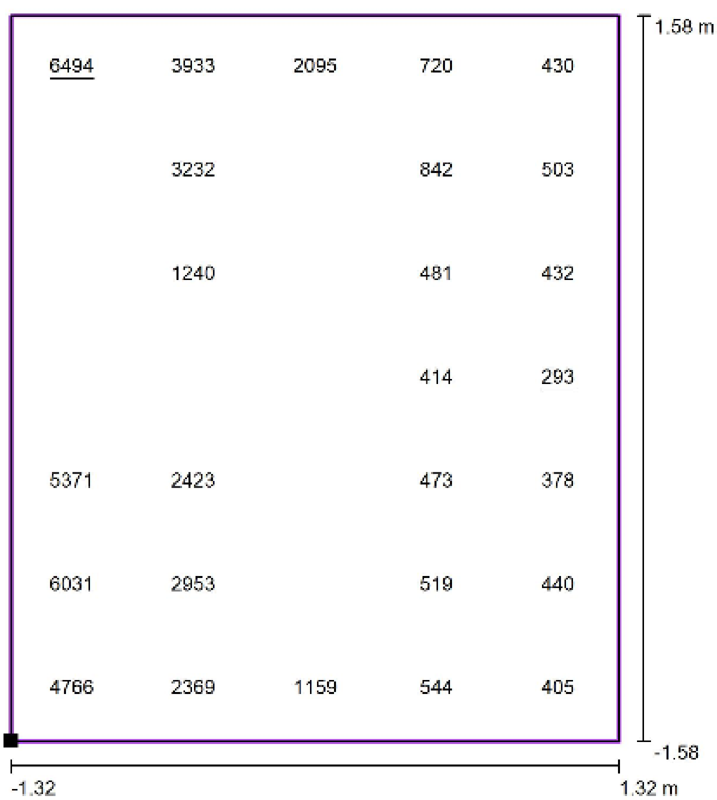


Fig. 9.11 Point wise daylight lux level (summer time)

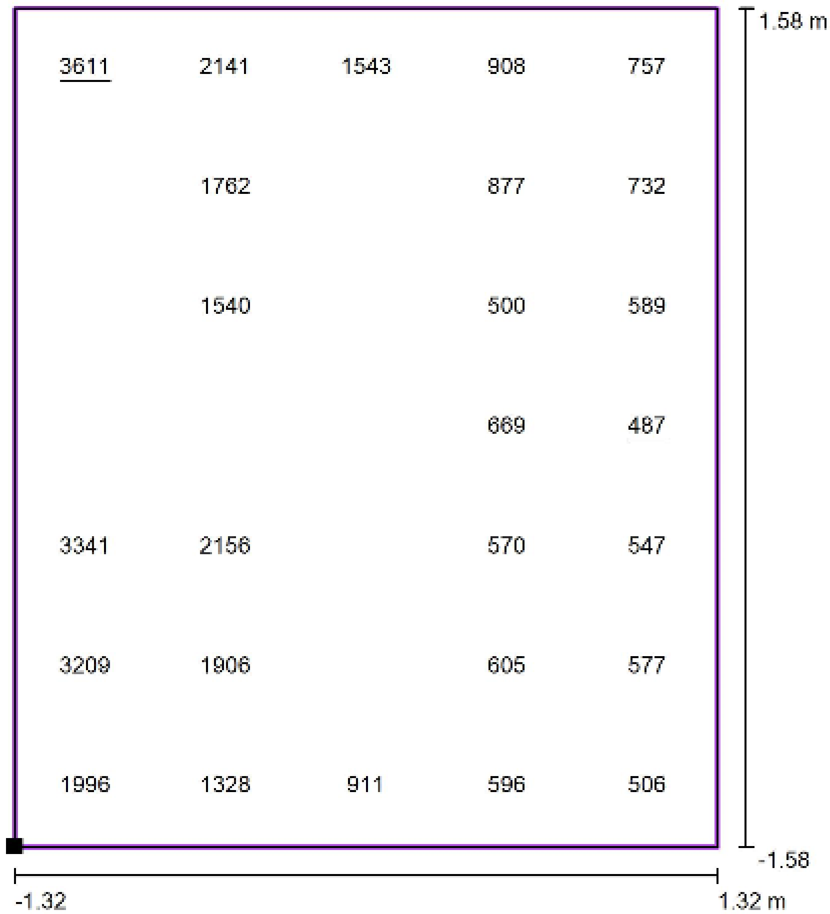


Fig. 9.11 Point wise daylight lux level (winter time)

Daylight Availability Study for CABIN 2 time 12.00pm

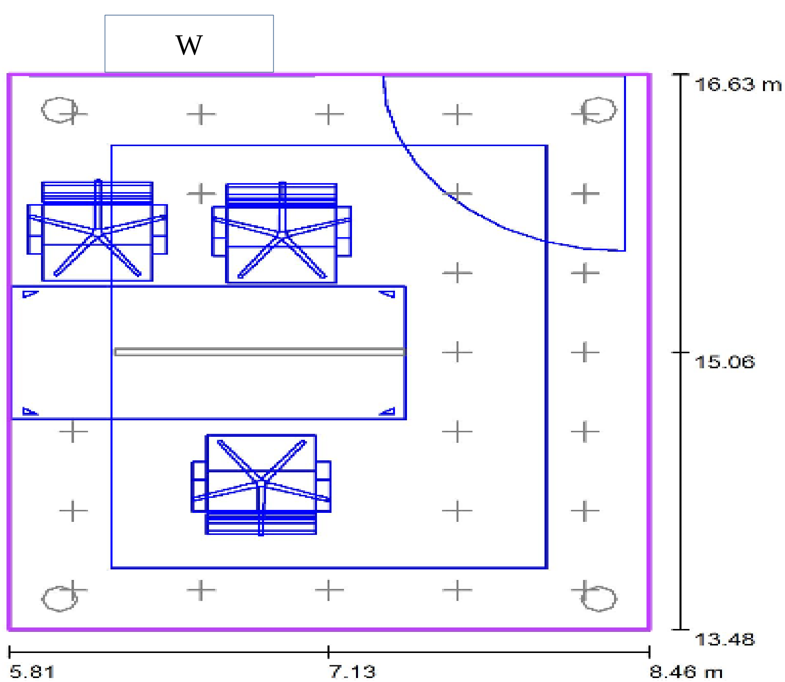


Fig. 9.12 CABIN 2 with object

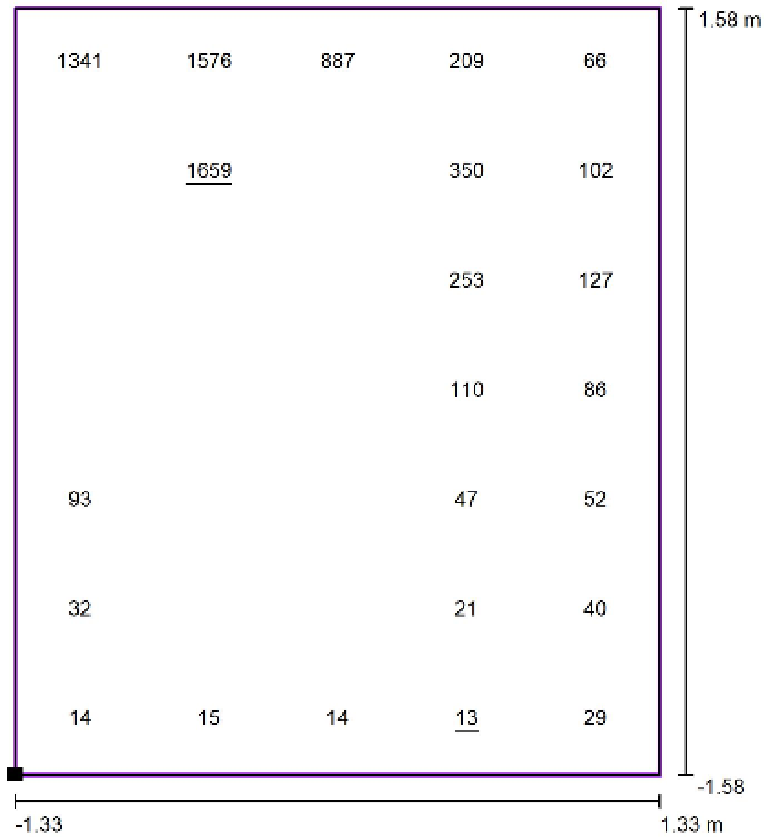


Fig. 9.13 Point wise daylight lux level (summer time)

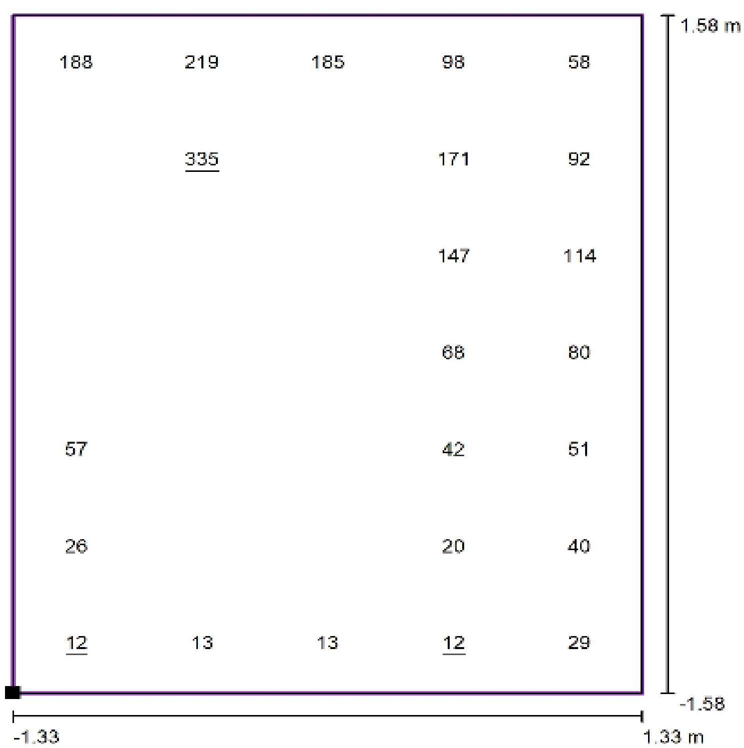


Fig. 9.14 Point wise daylight lux level (winter time)

Daylight Availability Study for CABIN 5 time 12:00pm

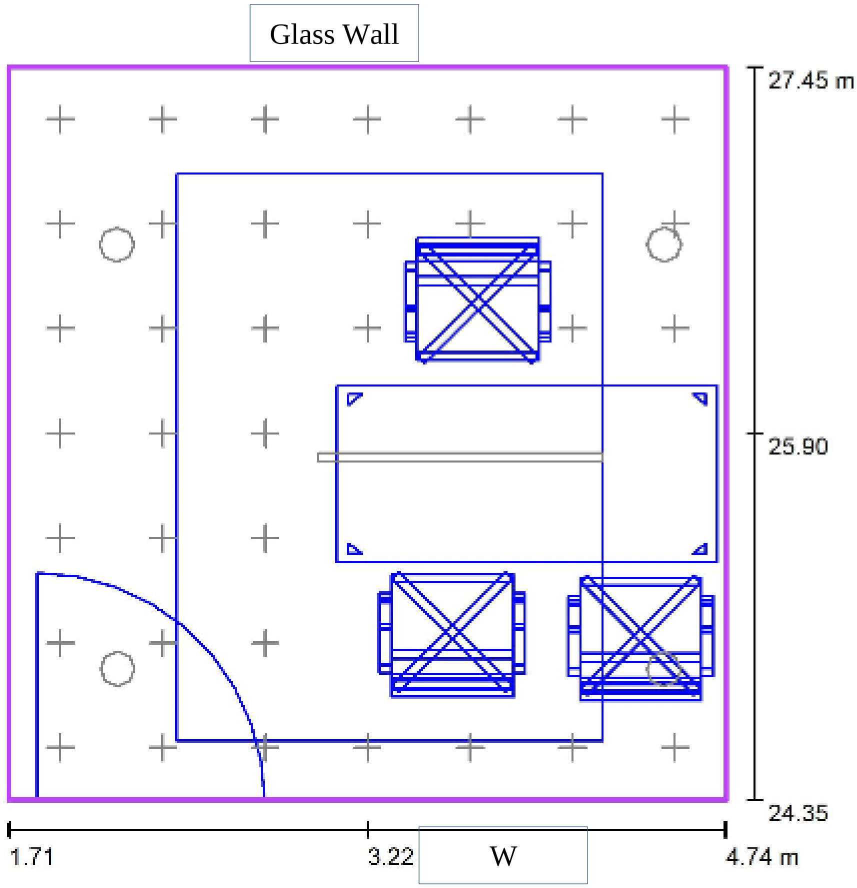


Fig. 9.15 CABIN 5 with object

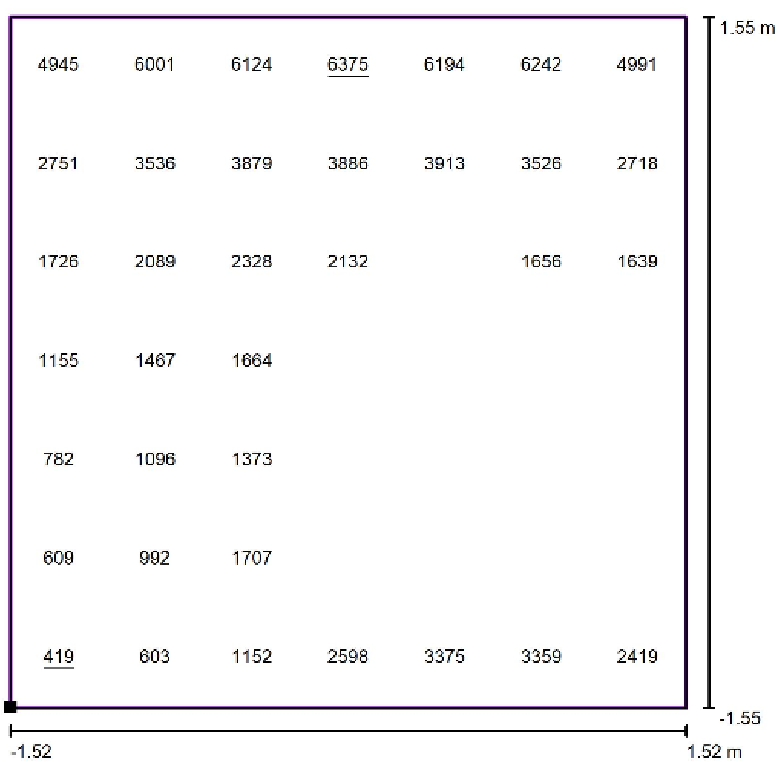


Fig. 9.15 Point wise daylight lux level (summer time)

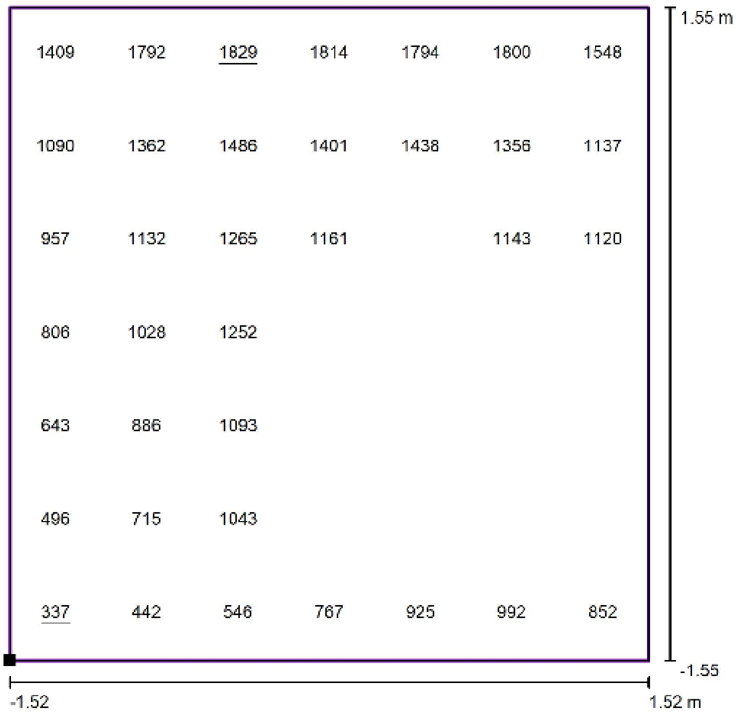


Fig. 9.16 Point wise daylight lux level (winter time)

Daylight Availability Study for WORKSPACE time 12.00pm

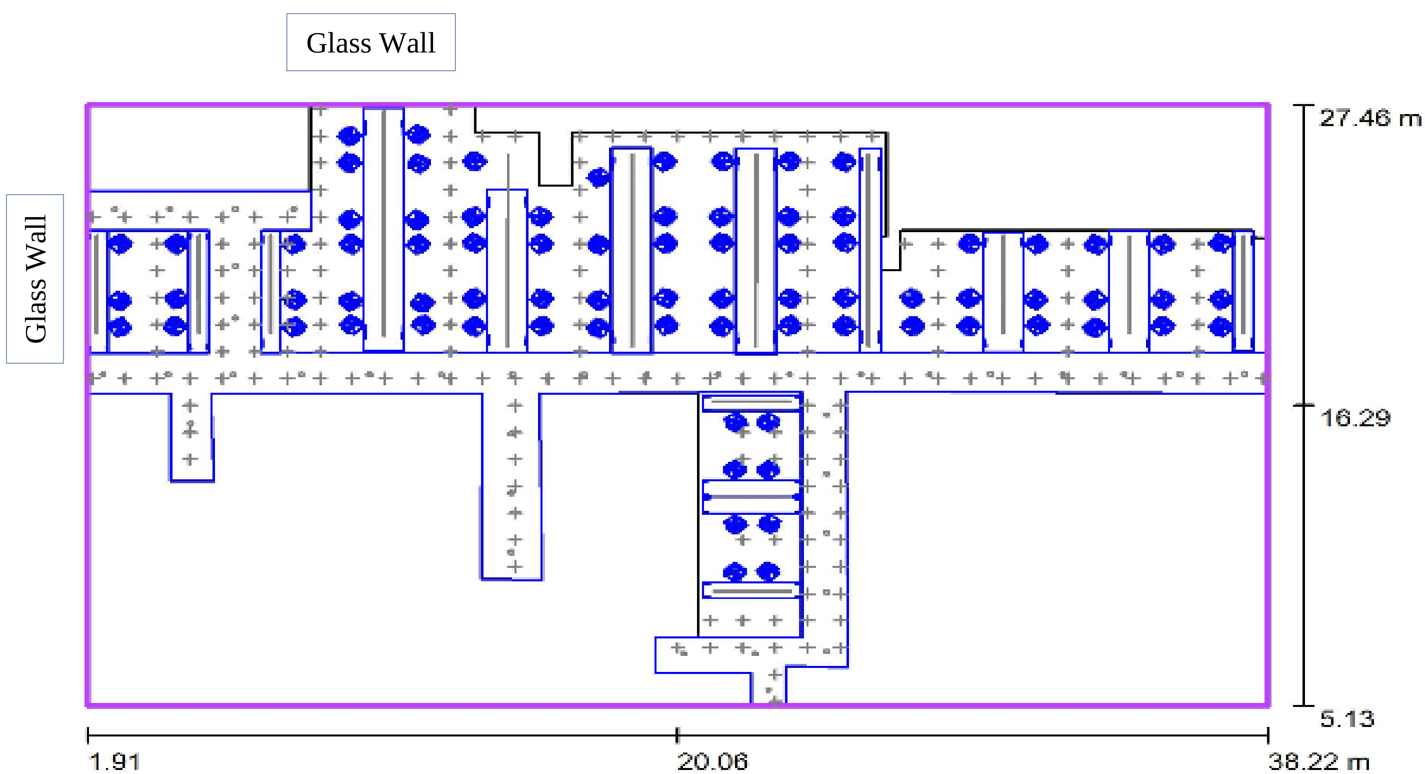


Fig. 9.17 WORKSPACE with object

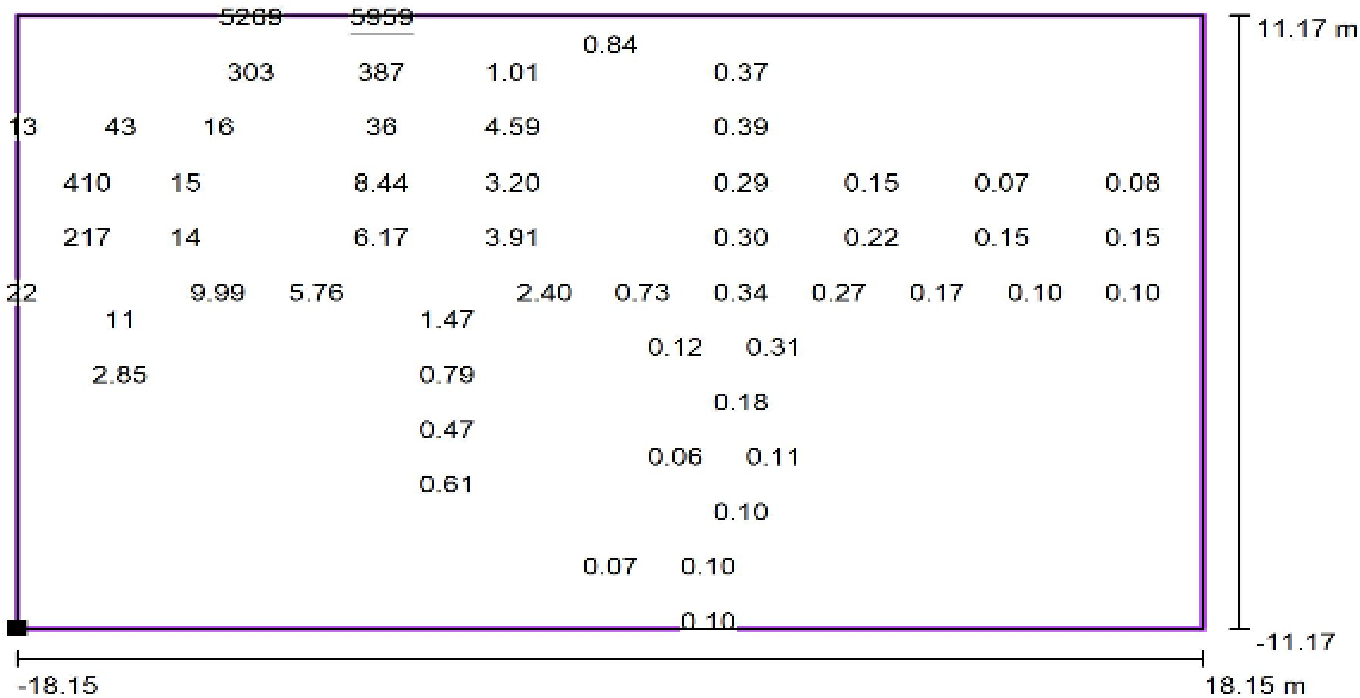


Fig. 9.17 Point wise daylight lux level (summer time)

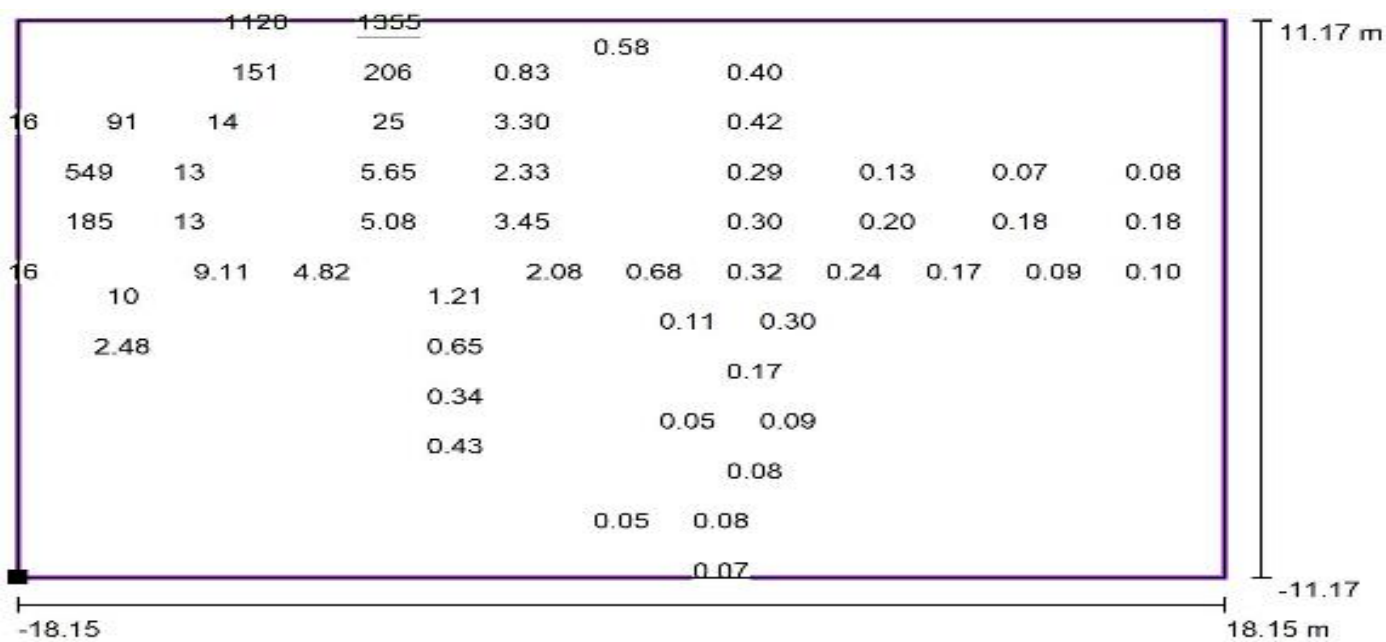


Fig. 9.18 Point wise daylight lux level (winter time)

10. DAYLIGHT SIMULATION METHOD:-

The integrated lighting solution can be achieved through different evaluation technique that allows to determining both qualitative and quantitative information regarding designing of a daylighting system. Although lighting evaluation program may not produce entirely accurate results compared to traditional analysis methods, they can convey valuable lighting performance data for a building. Daylighting simulation by computer-based evaluation tools aims to predict the lighting situation in an area or building under specific daylight condition. It also allows objective analysis of different daylighting performance variables. It helps to create a design scheme for each setting that will visualize a lighting concept in a particular space. Integrating daylight with the electric lighting system greatly enhances the visual comfort of the space and can save significant amounts of energy. In the current study daylight performance of the building has been analyzed by ***DIALux,*** open lighting design simulation software.

10.1 Design Arrangement:-

The design arrangement has been made to enhance indoor lighting quality by guiding useable daylight to the interior and reduce discomfort glare. Some essential features of DIALux software are as follows:

- It can simulate daylight for different weather patterns;
- It has the unique capability of incorporating interior and exterior objects taking into account their reflection coefficients and interference in the spread of light;
- It provides a variety of useful lighting design quantities, like luminance (L), average illuminance (E_{avg}), uniformity level, that allow an adequate description of the task.

10.2 Case Study Scenario:-

There are three case study scenarios need to incorporate for this study.

The scenarios are based on the following conditions:

- Lighting measurement in only daylight condition.
- The illuminance need to measures when only artificial lighting is present in the room
- Illuminance measurement in presence of both daylight & artificial lighting condition.

Depending on above conditions, the lighting simulation with various time of day may be considered as follows:-

- First scenario is the basic condition when the entire office room is operated in the daytime.
- The calculation has been done under simulated situation of a mixed type sky without any contribution of the artificial lighting system.
- Second scenario is the condition when the room is illuminated with the help of artificial light only.
- This condition arises when availability of daylight becomes zero.
- Third situation occurs due to the combine effect of both daylight and artificial lighting condition.
- Under this situation, illuminance has been calculated in presence of both daylight & artificial light.
- Reflectance of all rooms is 40:20:10(celling: wall: floor) except glass walls.
- Height of the room according to given celling height.
- Maintenance Factor :- 0.80.

These studies enable to determine the indoor daylight conditions in different rooms within a building model to ascertain the daylight availability level experienced within a room.

Notes:- For the glass wall various types of glasses is present but for this design I considered the solar control glass whose transmission rate is 50% . Solar control glass is a double or triple-glazed glass with a metal oxide coating on the inner face of the external glass unit. The metal oxide's special coating on glass reflects the sun's maximum UV rays as well as the unbearable heat by allowing natural light to pass through. According to IESNA Glass type is triple glaze whose properties is given below.

Glass Type	Color	VT (%)	SHGC (%)	LSG	U-Factor (Winter)
Standard Low-E	• Clear	79	70	1.13	2.74
	• Grey Tint	40	45	0.89	2.74
	• Bronze Tint	48	50	0.96	2.74
	• Blue-Green Tint	60	39	1.54	2.74
Reflective Low-E	• Reflective Grey	15	27	0.56	2.74
	• Reflective Bronze	19	30	0.63	2.74
Spectrally Selective Low-E	• Low Iron Clear	64	27	2.37	1.60
	• Green	49	28	1.75	1.60
Skylight, Low-E, Double w/Argon Fill	• Clear	53	32	1.66	2.85
	• White	38	30	1.27	2.74
Skylight, Triple	• White	45	58	0.78	1.71

The detailed descriptions of simulated design in different room are as follows.

10.3 Lighting Assessment of **CAFÉ 35 PAX:-**

The assessment comprises the direct analysis and comparison of the indoor illuminance level on table top and work plane in the specified room. The room is East facing with the dimensions of 12m x 5m x 2.6m and having west facing glass wall. The illuminance was measured upon a table top with a height of 0.760m. The basic layout plan of the luminaires as per DIALux is given below.

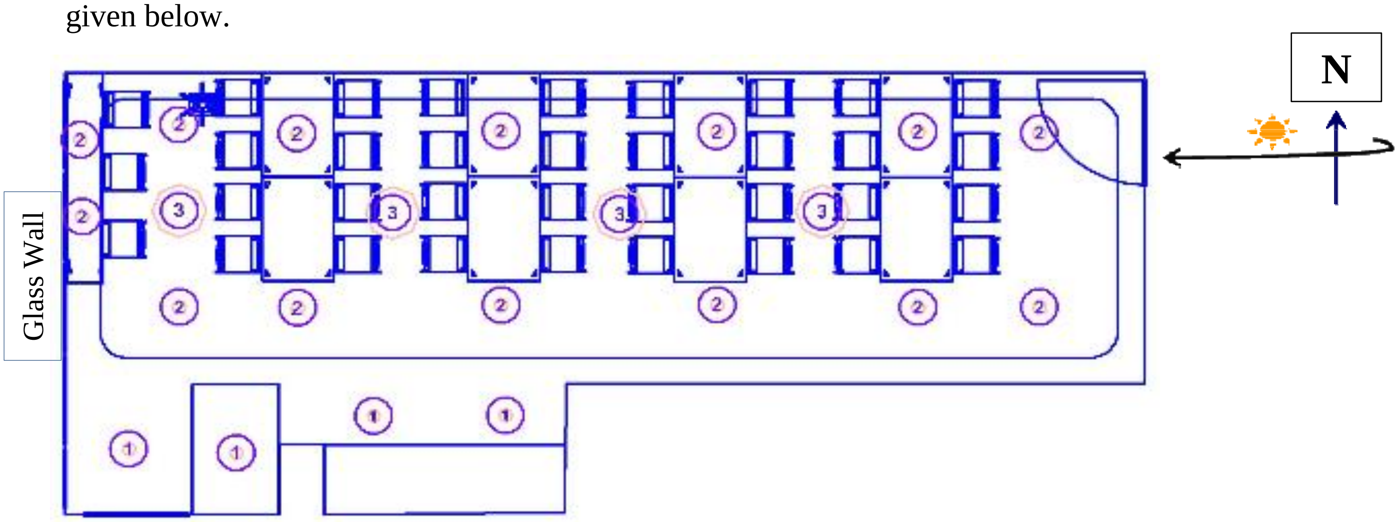
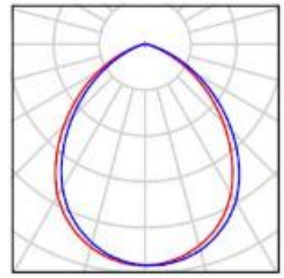


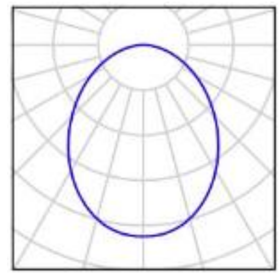
Fig:- 10.1 CAFÉ 35 PAX luminaires position and object position

LUMINAIRE SPECIFICATIONS & DATASHEET:-

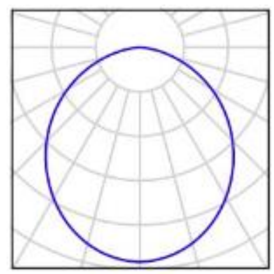
1. Luminous flux (Luminaire): 1500 lm
   Luminous flux (Lamps): 1500 lm
   Luminaire Wattage: 15.0 W
   Luminaire classification according to CIE: 100
   CIE flux code: 60 90 99 100 100
   Fitting: 1 x 49 (Correction Factor 1.000).



2. Luminous flux (Luminaire): 1800 lm
   Luminous flux (Lamps): 1800 lm
   Luminaire Wattage: 18.0 W
   Luminaire classification according to CIE: 100
   CIE flux code: 52 81 96 100 100
   Fitting: 1 x LED (Correction Factor 1.000).



3. Luminous flux (Luminaire): 2537 lm
   Luminous flux (Lamps): 2537 lm
   Luminaire Wattage: 22.3 W
   Luminaire classification according to CIE: 100
   CIE flux code: 49 81 97 100 100
   Fitting: 1 x 120LED 5000K (Correction Factor 1.000).



10.3.1 Lighting Measurements:-

The visualization of the luminous environment of a given design arrangement under different lighting conditions are evaluated below:-

10.4.1.1 Measurement under 'Only Daylight' Condition:-

The illuminance for CAFÉ 35 PAX under '*Only Daylight*' Condition has been measured and simulated. The photometric data by DIALux is being illustrated here under.

Surface	Average illuminances [lx] direct	indirect	total	Reflection factor [%]	Average luminance [cd/m²]
Workplane	408	22	429	/	/
TABLE TOP	186	34	220	/	/
TABLE TOP	42	14	56	/	/
TABLE TOP	11	7.89	18	/	/
TABLE TOP	4.25	4.63	8.89	/	/
TABLE TOP	5085	61	5146	/	/
Floor	380	23	402	10	13
Ceiling	0.00	37	37	40	4.66
Wall 1	93	35	128	20	8.13
Wall 2	0.00	142	142	20	9.05
Wall 3	231	68	300	20	19
Wall 4	166	45	211	20	13
Wall 5	75	28	104	20	6.60
Wall 6	0.00	3.00	3.00	20	0.19
Wall 7	16	11	27	20	1.70
Wall 8	79	14	94	20	5.96
Wall 9	12	4.25	16	20	1.01
Wall 10	28	4.45	33	20	2.10

Fig:- 10.2 Photometric Data

The isoline diagram plotted in DIALux with the help of these above data is shown below:-

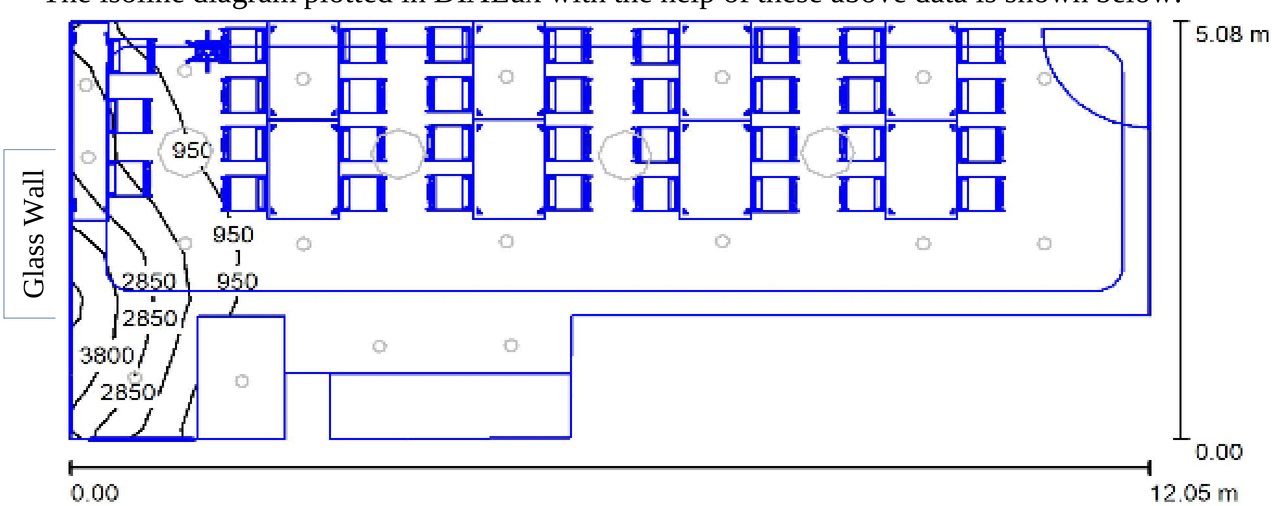


Fig:- 10.3 Isoline plot

It has been observed that with the help of daylight, the CAFÉ 35 PAX has achieved an average illuminance level of 429 lux on floor level which is more than sufficient of standard values recommended as per IS 3646(Part-I):1992. The results of the illuminance measurements of CAFÉ 35 PAX under '*Only Daylight*' condition is summarized below,

Height of Room: 2.600 m, Mounting Height: 2.500 m, Light loss factor: 0.80 Values in Lux, Scale 1:87

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	429	4.65	4571	0.011
Floor	10	402	3.48	4579	0.009
Ceiling	40	37	2.78	232	0.076
Walls (10)	20	101	3.00	1640	/

Workplane:

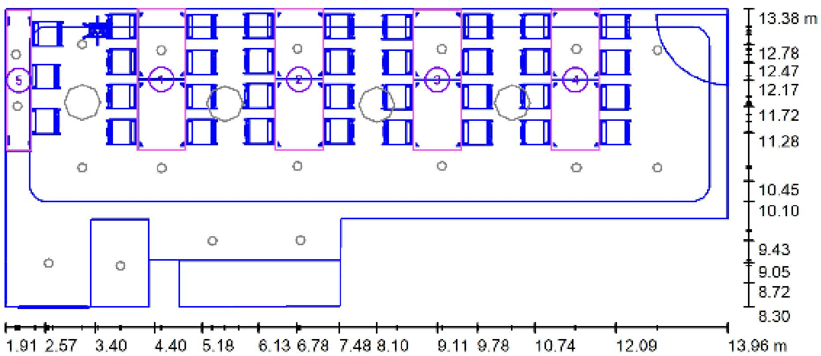
Height:	0.000 m
Grid:	19 x 9 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.206, Ceiling / Working Plane: 0.085.

Pure daylight scene, no luminaires involved.

Fig:- 10.4 Summary only for Daylight condition

Calculation surface results:-



Scale 1 : 87

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	TABLE TOP	perpendicular	4 x 2	220	161	286	0.732	0.562
2	TABLE TOP	perpendicular	4 x 2	56	50	63	0.887	0.781
3	TABLE TOP	perpendicular	2 x 4	18	15	22	0.824	0.687
4	TABLE TOP	perpendicular	2 x 4	8.89	7.30	10	0.821	0.700
5	TABLE TOP	perpendicular	4 x 1	5146	4259	5568	0.828	0.765

Fig:- 10.5 Calculation results overview only for Daylight condition

The 3-D Rendering & False colour rendering in DIALux is shown below:-

Fig 10.6 3D rendering view of CAFÉ 35 PAX under 'Only Daylight' Condition

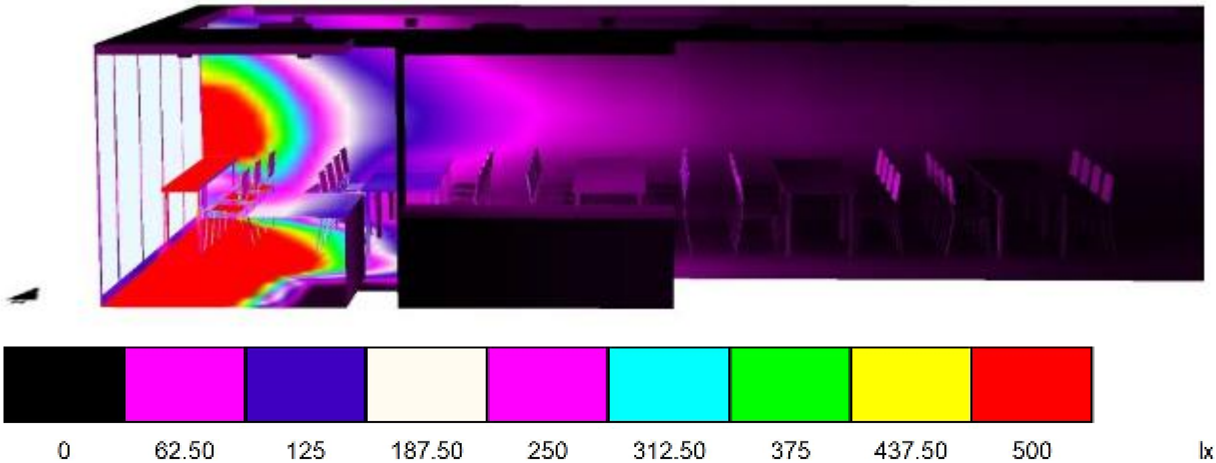


Fig 10.7 False color rendering view of CAFÉ 35 PAX under 'Only Daylight' Condition

10.4.1.1 <u>Measurement under 'Only Artificial Light' Condition:-</u>

The illuminance for CAFÉ 35 PAX under '*Only Artificial Light'* Condition has been measured and simulated. The photometric data provided by DIALux is being illustrated here under.

Surface	Average illuminances [lx]			Reflection factor [%]	Average luminance [cd/m²]
	direct	indirect	total		
Workplane	214	23	237	/	/
TABLE TOP	554	37	590	/	/
TABLE TOP	468	34	502	/	/
TABLE TOP	467	34	501	/	/
TABLE TOP	425	31	456	/	/
TABLE TOP	539	32	571	/	/
Floor	199	23	221	10	7.04
Ceiling	0.03	51	51	40	6.46
Wall 1	162	43	204	20	13
Wall 2	111	25	136	20	8.63
Wall 3	97	28	125	20	7.98
Wall 4	106	23	130	20	8.26
Wall 5	134	33	167	20	11
Wall 6	51	16	67	20	4.27
Wall 7	58	24	82	20	5.24
Wall 8	100	25	125	20	7.98
Wall 9	136	33	169	20	11
Wall 10	92	30	122	20	7.78

Fig 10.8 Photometric results

The Isoline diagram plotted in DIALux with the help of the above data is shown below:

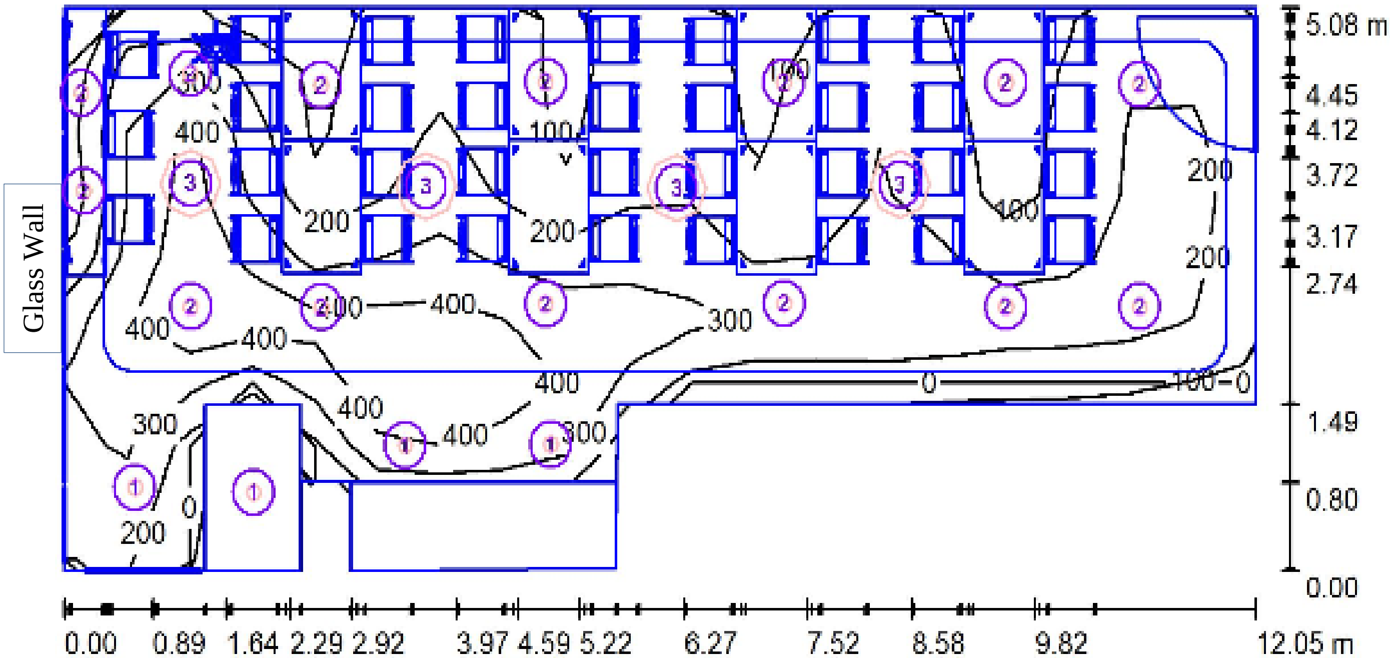


Fig 10.9 Isoline plot

It has been observed that with the help of artificial light, the CAFÉ 35 PAX has achieved an average illuminance level of 237 lux on floor level which is sufficient of standard values recommended as per IS 3646(Part-I):1992. The results of the illuminance measurements of CAFÉ 35 PAX under '*Only Artificial light*' condition is summarized below,

Height of Room: 2.600 m, Mounting Height: 2.500 m, Light loss factor: 0.80 Values in Lux, Scale 1:87

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	237	16	518	0.066
Floor	10	221	6.31	517	0.029
Ceiling	40	51	4.59	98	0.090
Walls (10)	20	157	5.74	670	/

Workplane:

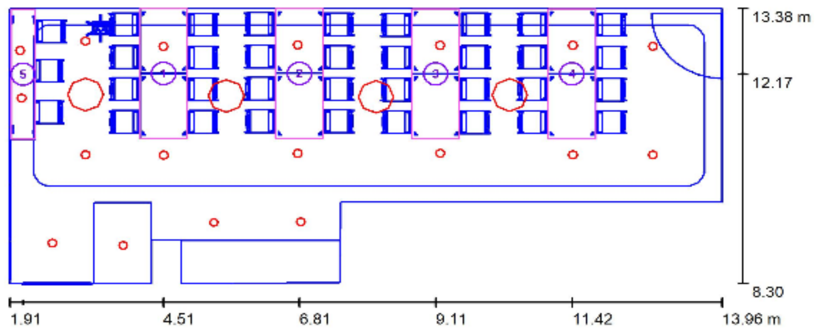
Height:	0.000 m
Grid:	19 x 9 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.679, Ceiling / Working Plane: 0.214.

Specific connected load: 7.85 W/m² = 3.23 W/m²/100 lx (Ground area: 51.10 m²)

Fig:-10.10 Summary only for Artificial Light

Calculation surface results:-



Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	TABLE TOP	perpendicular	32 x 16	590	393	670	0.666	0.587
2	TABLE TOP	perpendicular	32 x 16	502	345	582	0.687	0.592
3	TABLE TOP	perpendicular	16 x 32	501	345	552	0.690	0.625
4	TABLE TOP	perpendicular	16 x 32	456	340	511	0.745	0.665
5	TABLE TOP	perpendicular	32 x 8	571	370	695	0.649	0.533

Fig:-10.11 Calculation surface results only for Artificial Light

The 3-D Rendering & False colour rendering in DIALux is shown below:-

Fig:-10.12 3D Rendering view

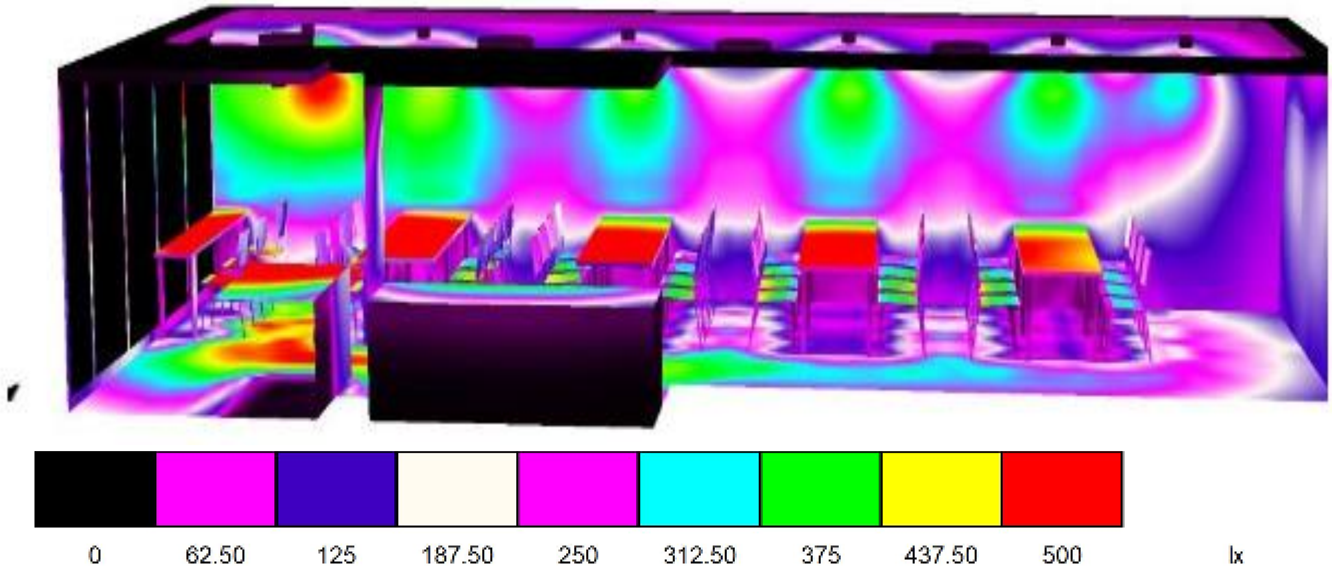


Fig:-10.13 False color Rendering view

10.4.1.2 Measurement under 'Both Daylight & Artificial Light' Condition:-

The illuminance for CAFÉ 35 PAX under *'Both Daylight & Artificial Light'* Condition has been measured and simulated. The photometric data by DIALux is being illustrated below.

Surface	Average illuminances [lx]			Reflection factor [%]	Average luminance [cd/m²]
	direct	indirect	total		
Workplane	519	36	555	/	/
TABLE TOP	435	47	482	/	/
TABLE TOP	323	30	353	/	/
TABLE TOP	281	24	305	/	/
TABLE TOP	319	22	342	/	/
TABLE TOP	5115	69	5184	/	/
Floor	482	35	516	10	16
Ceiling	0.01	63	63	40	8.06
Wall 1	180	56	235	20	15
Wall 2	12	149	161	20	10
Wall 3	238	75	314	20	20
Wall 4	166	52	217	20	14
Wall 5	158	41	199	20	13
Wall 6	42	17	58	20	3.72
Wall 7	62	27	89	20	5.68
Wall 8	161	29	190	20	12
Wall 9	110	24	134	20	8.53
Wall 10	112	30	142	20	9.02

Fig:-10.14 Photometric Data

The Isoline diagram plotted in DIALux with the help of these above data is shown below:

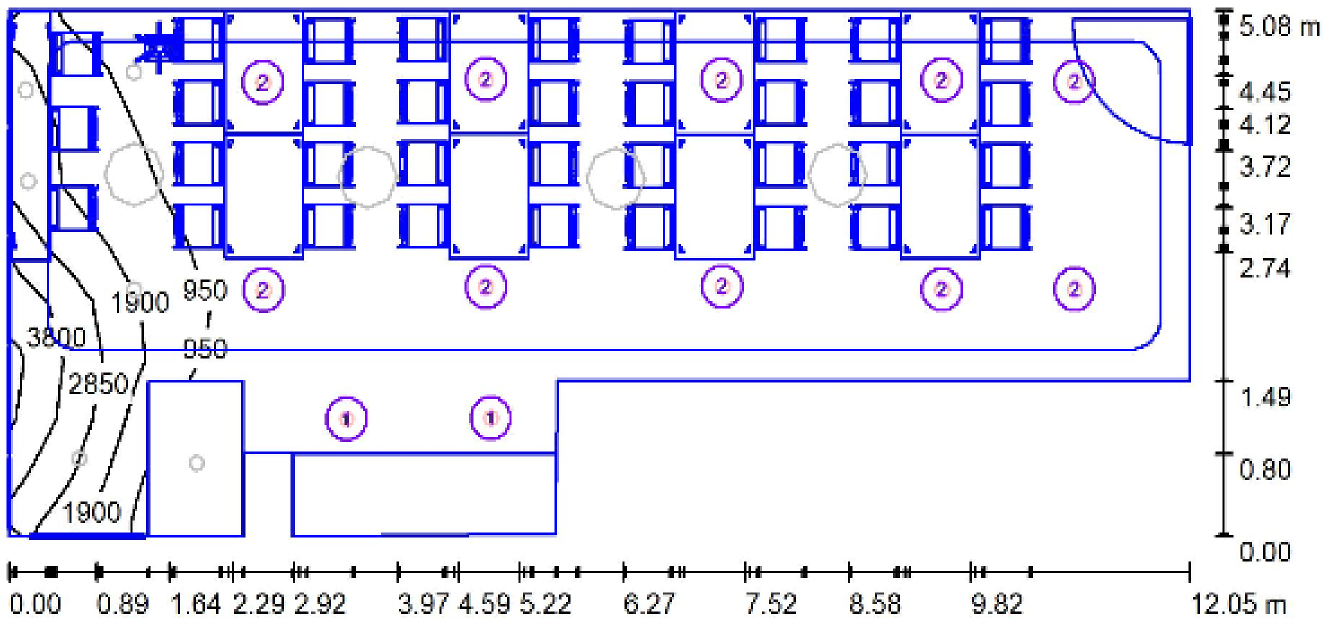
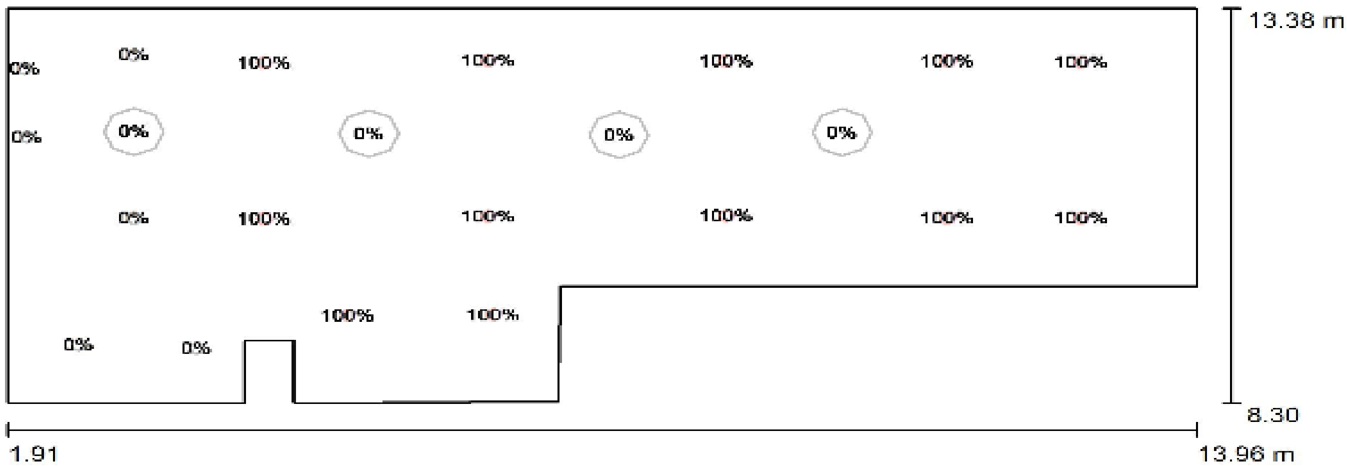


Fig:-10.15 Isoline Plotted

It has been observed that by using artificial light blended with available daylight, the CAFÉ 35 PAX has achieved an average illuminance level of 1262 lux which is very high with respect to standard values, but it can be minimized up to a value of 555 lux by means of control arrangement which is tolerable as per recommended IS 3646(Part-I):1992. As the lux level is higher in the zone nearer to the window, therefore luminaires arranged in that portion [Fig10.16] has been dimmed to 0% of its maximum value. The controlled luminaire arrangement is shown below.



Daylight parameters:
Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 360.0°
Date: 22.05.2024, Time:12:00:00 (+5 hours difference to GMT)
Reference sky type: Mixed sky

Fig:-10.16 Luminaire controlling with daylight integrating

The *DIALux* simulated results of the illuminance measurements of CAFÉ 35 PAX under '*Both Daylight & Artificial Light'* condition is summarized below,

Height of Room: 2.600 m, Mounting Height: 2.500 m, Light loss factor: 0.80 Values in Lux, Scale 1:87

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	555	24	4617	0.043
Floor	10	516	20	4629	0.039
Ceiling	40	63	14	251	0.225
Walls (10)	20	185	13	1669	/

Workplane:

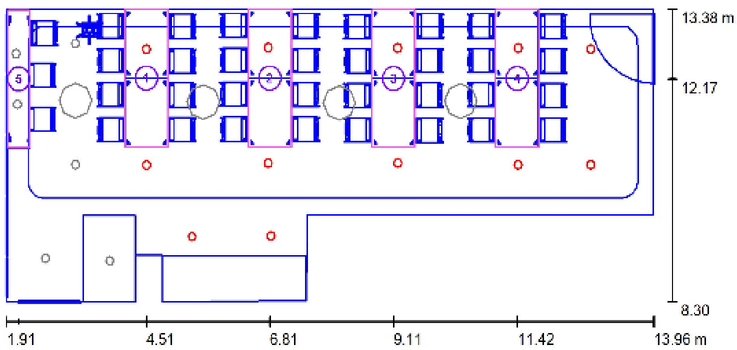
Height:	0.000 m
Grid:	19 x 9 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.326, Ceiling / Working Plane: 0.114.

Specific connected load: 4.11 W/m² = 0.71 W/m²/100 lx (Ground area: 51.10 m²)

Fig:-10.17 Summary for Artificial Light & Daylight

Calculation surface results:-



Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	TABLE TOP	perpendicular	16 x 8	482	365	591	0.757	0.618
2	TABLE TOP	perpendicular	16 x 8	353	273	427	0.772	0.638
3	TABLE TOP	perpendicular	8 x 16	305	238	340	0.779	0.699
4	TABLE TOP	perpendicular	8 x 16	342	263	389	0.770	0.678
5	TABLE TOP	perpendicular	8 x 2	5184	4291	5611	0.828	0.765

Fig:-10.18 Calculation surface results

The 3-D Rendering & False colour rendering in DIALux is shown below:-

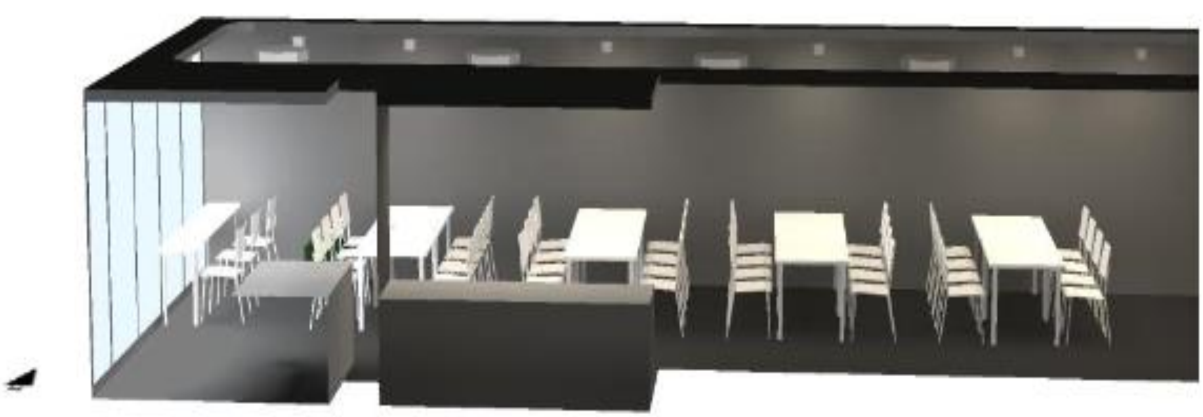


Fig:-10.19 3D Rendering

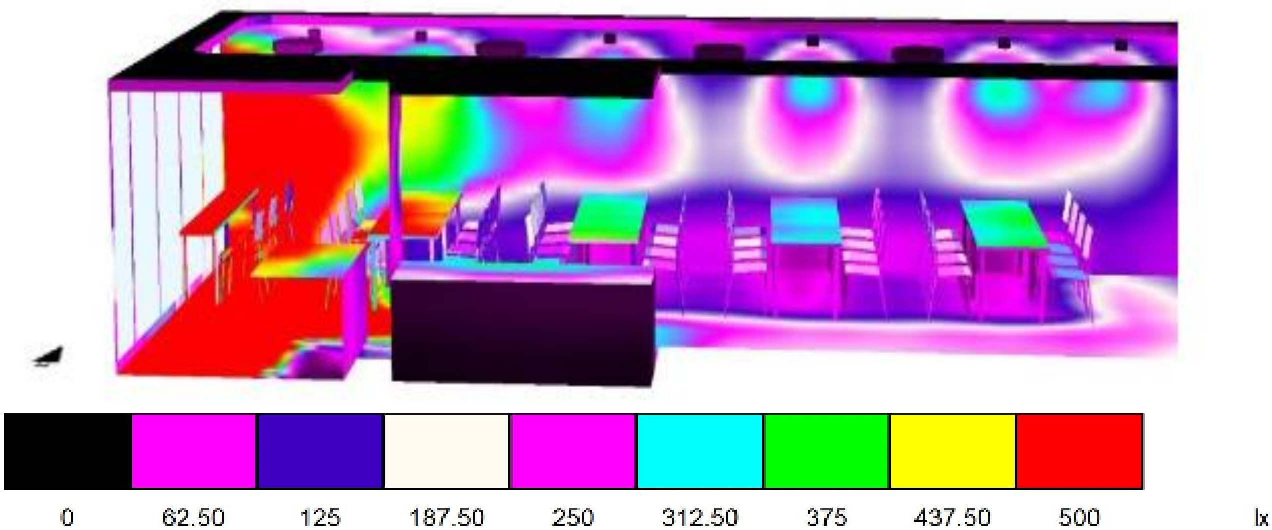
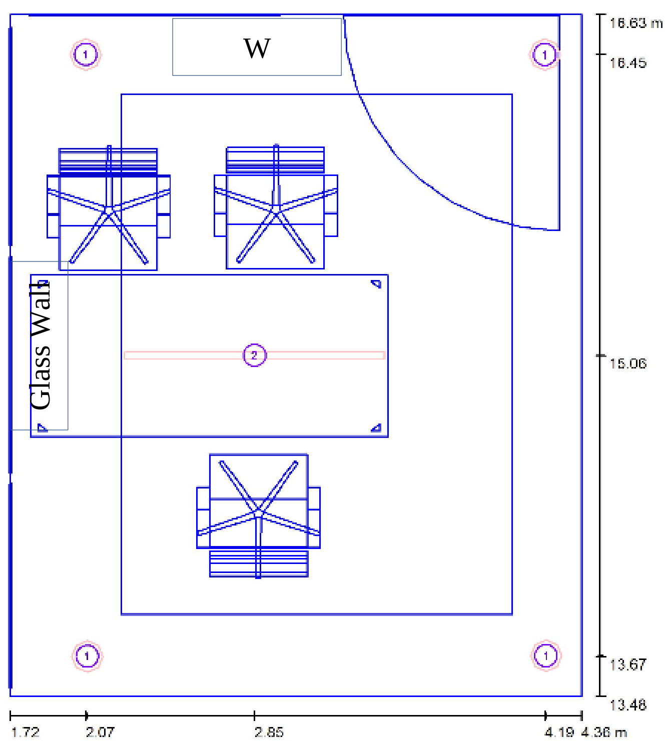


Fig:-10.20 False color Rendering

10.4 Lighting Assessment of **CABIN 01 ,02,05(typical):-**

The assessment comprises the direct analysis and comparison of the indoor illuminance level at the work plane in the specified room. The room is North facing with the dimensions of 2.6m x 3.1m x 2.7m and having two north facing glass window and west side glass wall(solar control glass) . The illuminance was measured upon a table top with a height of 0.760m. The basic layout plan of the luminaires as per DIALux is given below.



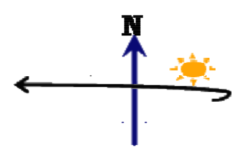


Fig:-10.21 CABIN 01

LUMINAIRE SPECIFICATIONS & DATASHEET:-

1. Luminous flux (Luminaire): 1500 lm

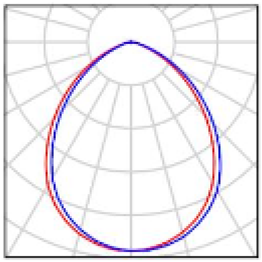
   Luminous flux (Lamps): 1500 lm

   Luminaire Wattage: 15.0 W

   Luminaire classification according to CIE: 100

   CIE flux code: 60 90 99 100 100

   Fitting: 1 x 49 (Correction Factor 1.000).



2. Luminous flux (Luminaire): 3000 lm

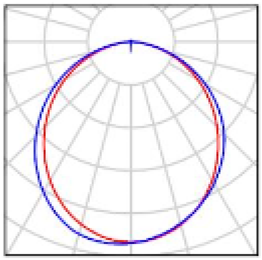
   Luminous flux (Lamps): 3000 lm

   Luminaire Wattage: 30.0 W

   Luminaire classification according to CIE: 100

   CIE flux code: 49 80 96 100 100

   Fitting: 1 x User defined (Correction Factor 1.000).



10.4.1 Lighting Measurements:-

The visualization of the luminous environment of a given design arrangement underdifferent lighting conditions are evaluated below.

10.5.1.1 Measurement under 'Only Daylight' Condition:-

The illuminance for CABIN 01 under '*Only Daylight*' Condition has been measured and simulated. The photometric data by DIALux is being illustrated hereunder.

Surface	Average illuminances [lx]			Reflection factor [%]	Average luminance [cd/m²]
	direct	indirect	total		
Workplane	1732	115	1847	/	/
TABLE TOP	2698	78	2775	/	/
Floor	1713	120	1833	10	58
Ceiling	0.00	110	110	40	14
Wall 1	470	133	603	20	38
Wall 2	406	106	512	20	33
Wall 3	420	182	602	20	38
Wall 4	63	181	243	20	15

Fig:-10.22 Photometric Data

The Isoline diagram plotted in DIALux with the help of these above data is shown below:

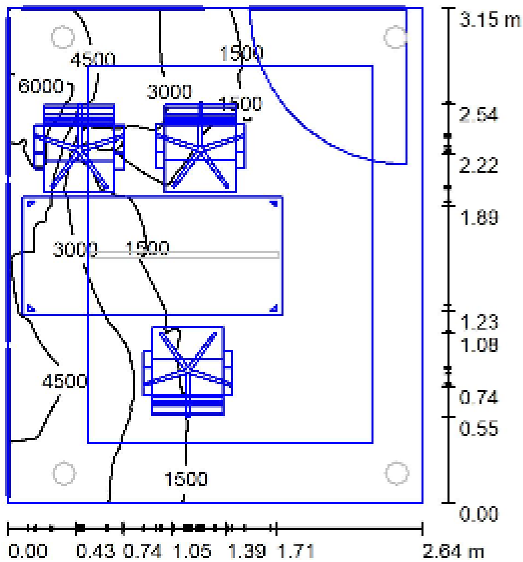


Fig:-10.23 Isoline plot

It has been observed that with the help of daylight, the CABIN 01 has achieved an average illuminance level of 1847 lux which is excessive as recommended by IS 3646(Part-I):1992. The results of the illuminance measurements of CABIN 01 under '*Only Daylight*' condition is summarized below,

Height of Room: 2.700 m, Light loss factor: 0.80 — Values in Lux, Scale 1:41

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	1847	105	7484	0.057
Floor	10	1833	339	6418	0.185
Ceiling	40	110	29	258	0.266
Walls (4)	20	480	54	1662	/

Workplane:

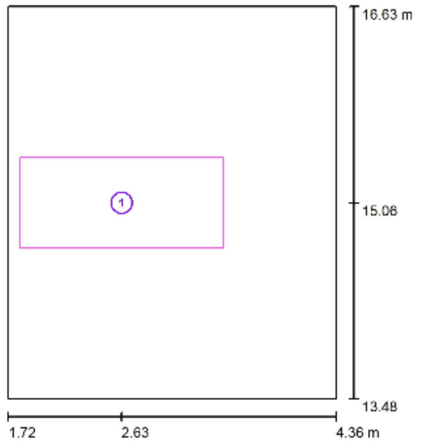
Height:	0.000 m
Grid:	128 x 128 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.297, Ceiling / Working Plane: 0.059.

Pure daylight scene, no luminaires involved.

Fig:-10.24 SUMMARY

Calculation Surface Results:-



Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	TABLE TOP	perpendicular	4 x 2	2775	894	5644	0.322	0.158

Fig:-10.25 Calculation surface result

The 3-D Rendering & False colour rendering in DIALux is shown below:-

Fig:-10.26 3D Rendering

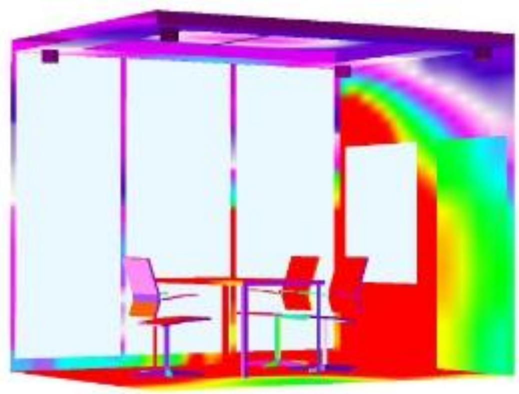
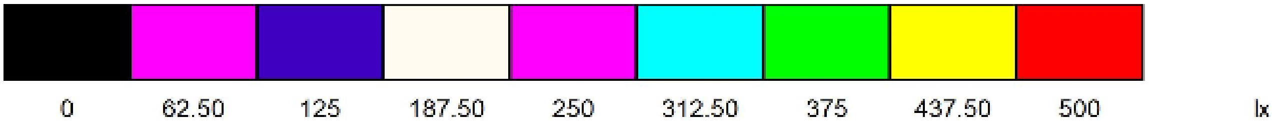


Fig:-10.27 False color Rendering



10.5.1.2 Measurement under 'Only Artificial Light' Condition:-

The illuminance for CABIN 01 under '*Only Artificial Light'* Condition has been measured andsimulated. The photometric data provided by DIALux is being illustrated here under.

Surface	Average illuminances [lx] direct	indirect	total	Reflection factor [%]	Average luminance [cd/m²]
Workplane	146	20	167	/	/
TABLE TOP	341	28	369	/	/
Floor	144	20	164	10	5.23
Ceiling	0.00	23	23	40	2.87
Wall 1	171	29	200	20	13
Wall 2	166	30	196	20	12
Wall 3	235	29	264	20	17
Wall 4	96	19	116	20	7.36

Fig:-10.28 Photometric Result

The isolux diagram plotted in DIALux with the help of these above data is shown below:-

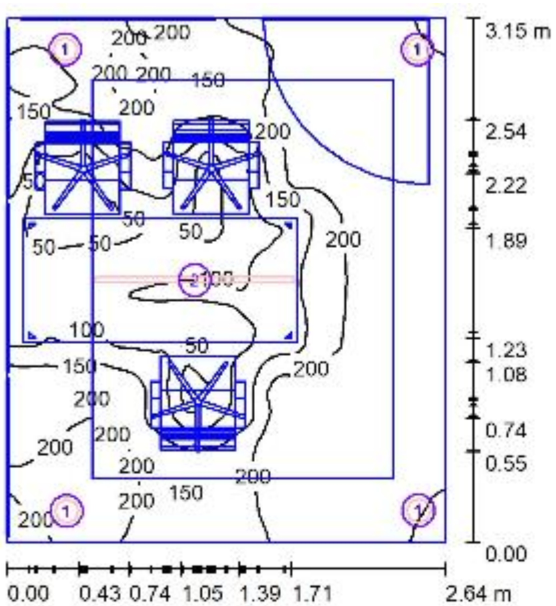


Fig:-10.29 Iso line plot

It has been observed that with the help of artificial light, the CABIN 01 has achieved an average illuminance level on table top 369 lux which is sufficient of standard values recommended as per IS 3646(Part-I):1992. The results of the illuminance measurements of CABIN 01 under '*Only Artificial light*' condition is summarized below, Height of Room: 2.700 m, Light loss factor: 0.80 Values in Lux, Scale 1:41

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	167	16	239	0.094
Floor	10	164	15	242	0.090
Ceiling	40	23	4.63	171	0.205
Walls (4)	20	190	12	3929	/

Workplane:

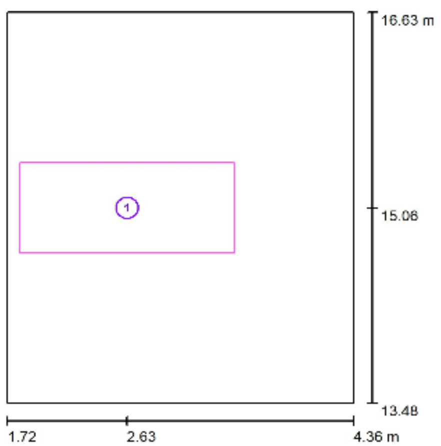
Height:	0.000 m
Grid:	128 x 128 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 1.215, Ceiling / Working Plane: 0.135.

Specific connected load: 10.82 W/m² = 6.50 W/m²/100 lx (Ground area: 8.32 m²)

Fig:-10.29 Summary

Calculation surface result:-



Scale 1 : 36

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	TABLE TOP	perpendicular	32 x 16	369	308	398	0.834	0.774

Fig:-10.30 Calculation surface results

<u>The 3-D Rendering & False colour rendering in DIALux is shown below:-</u>

Fig:-10.31 3D Rendering

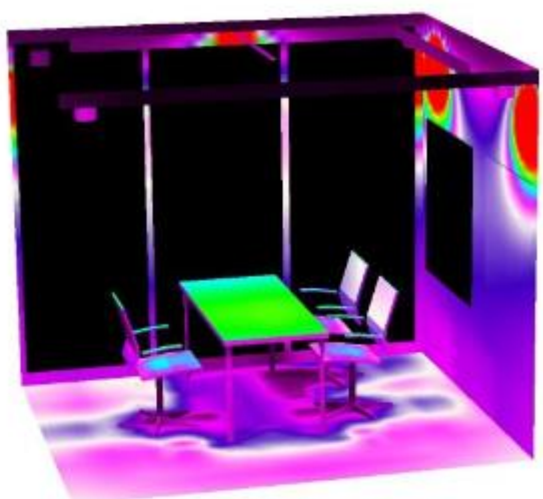
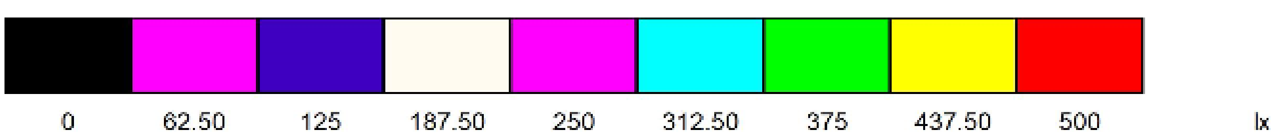


Fig:-10.32 False color Rendering



10.5.1.3 Measurement under ‘Both Daylight & Artificial Light’ Condition:

The illuminance for CABIN 01 under *‘Both Daylight & Artificial Light’* Conditionhas been measured and simulated. The photometric data by DIALux is being illustrated below.

Surface	Average illuminances [lx]			Reflection factor [%]	Average luminance [cd/m²]
	direct	indirect	total		
Workplane	1832	129	1961	/	/
TABLE TOP	2945	96	3041	/	/
Floor	1811	135	1947	10	62
Ceiling	0.00	126	126	40	16
Wall 1	574	154	728	20	46
Wall 2	557	129	687	20	44
Wall 3	545	201	746	20	47
Wall 4	123	197	320	20	20

Fig:-10.33 Photometric data

The isolux diagram plotted in DIALux with the help of these above data is shown below:

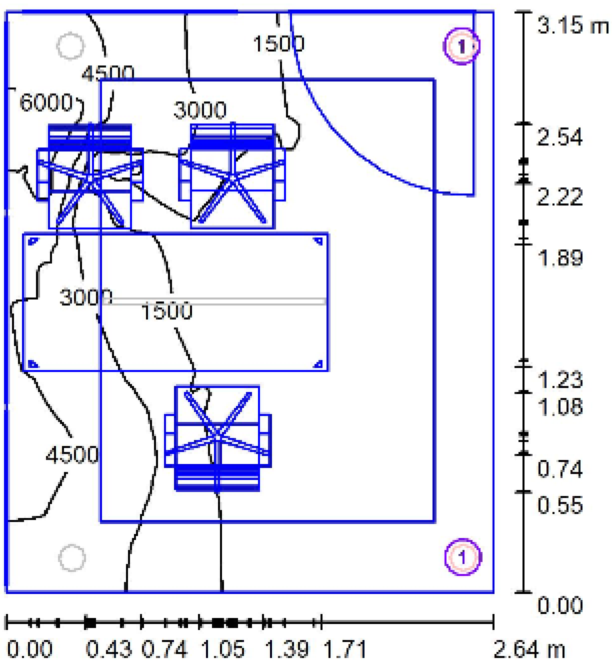
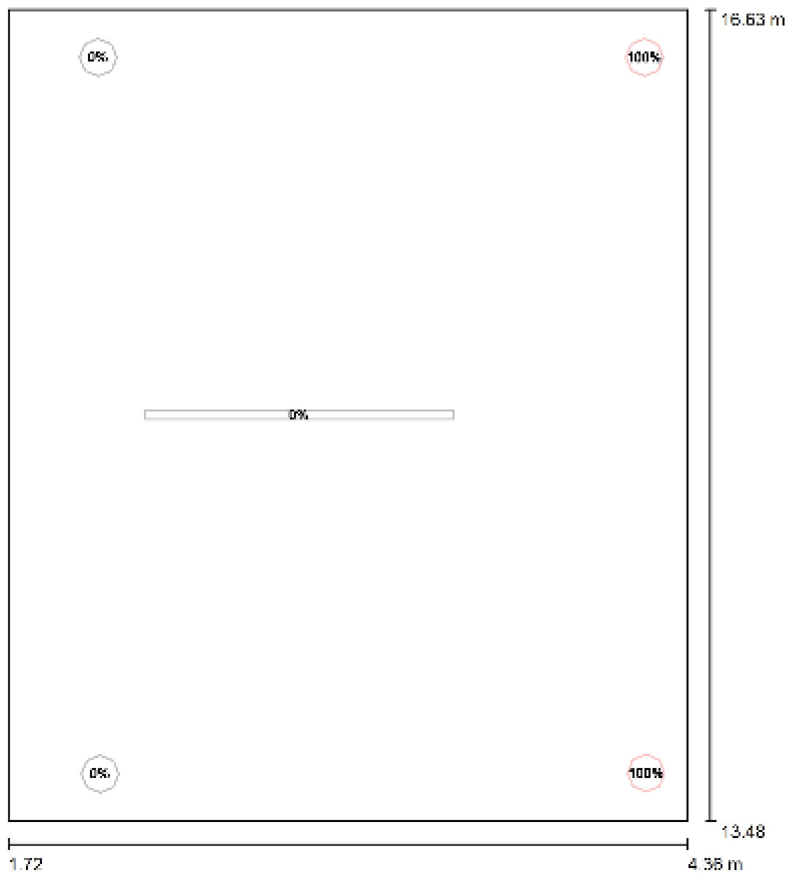


Fig:-10.34 Isoline plot

It has been observed that by using artificial light blended with available daylight, the office room has achieved an average illuminance level of 1980 lux whereas the minimum value reach up to 139 lux by means of control arrangement which can be tolerable with respect to standard values as recommended in IS 3646 (Part-I):1992. As the lux level is higher in the zone nearer to the window, therefore luminaires arranged in that portion [Fig10.35] has been dimmed to 0% of its maximum value. The controlled luminaire arrangement is shown below:



Daylight parameters:
Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 360.0°
Date: 22.05.2024, Time:12:00:00 (+5 hours difference to GMT)
Reference sky type: Mixed sky

Fig 10.35 Simulated Lighting layout of CABIN 01 for '*Both Daylight & Artificial Light'* Condition

The *DIALux* simulated results of the illuminance measurements of CABIN 01 under '*Both Daylight & Artificial Light'* condition is summarized below:

Height of Room: 2.700 m, Light loss factor: 0.80

Values in Lux, Scale 1:41

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	1908	139	7486	0.073
Floor	10	1895	433	6444	0.229
Ceiling	40	116	31	266	0.269
Walls (4)	20	551	58	4022	/

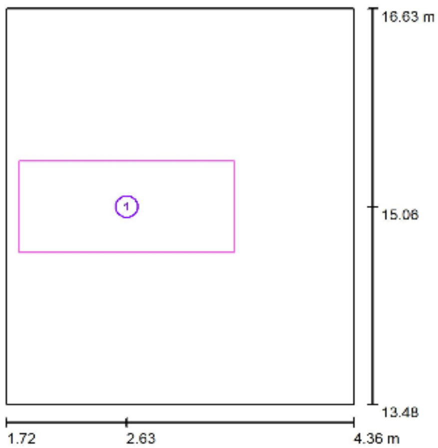
Workplane:

Height:	0.000 m
Grid:	128 x 128 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.332, Ceiling / Working Plane: 0.061.

Specific connected load: 3.61 W/m² = 0.19 W/m²/100 lx (Ground area: 8.32 m²)

Calculation surface result:-



Scale 1 : 36

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	TABLE TOP	perpendicular	8 x 4	2833	976	5676	0.345	0.172

The 3-D Rendering & False colour rendering in DIALux is shown below:-

Fig:-10.36 3D Rendering

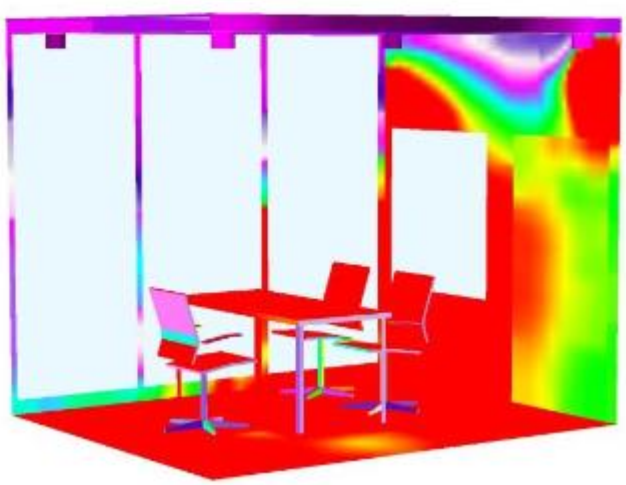
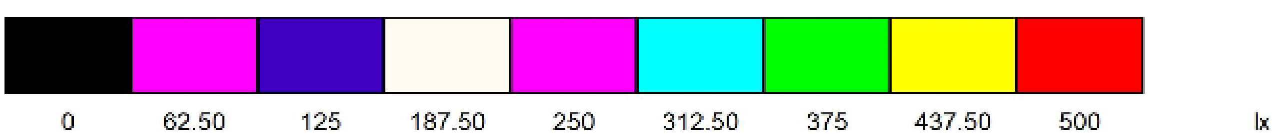
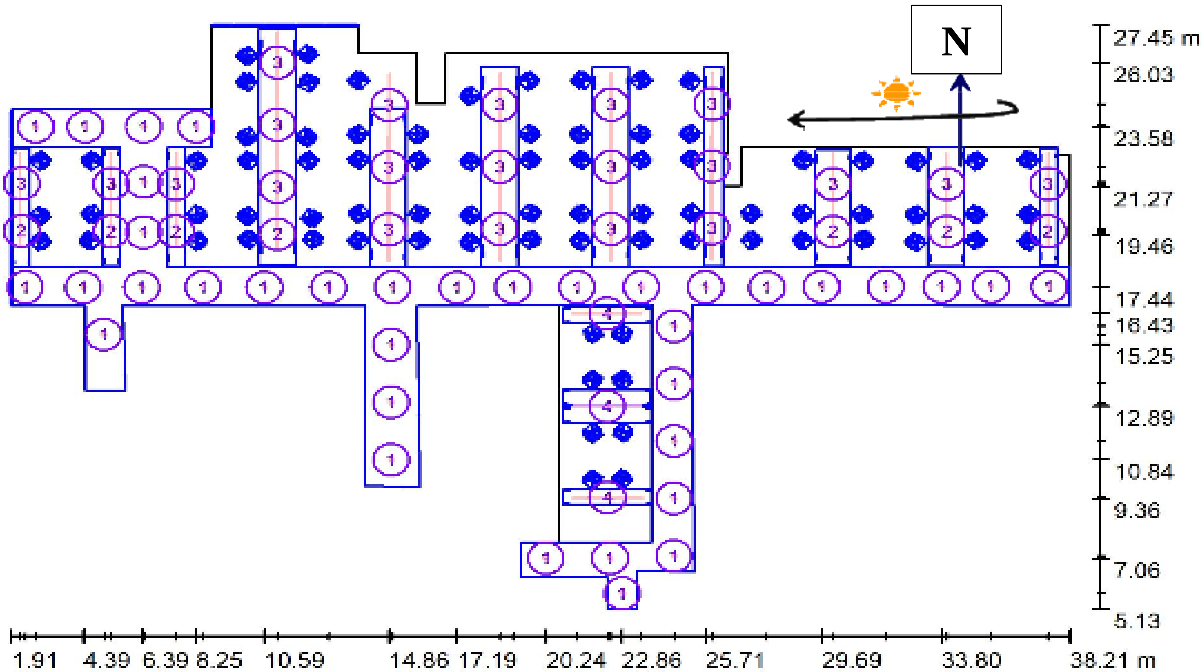


Fig:-10.37 False color Rendering



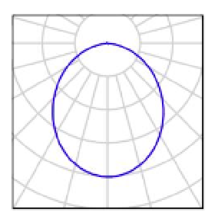
10.5 Lighting Assessment of **WORKSTATION**

The assessment comprises the direct analysis and comparison of the indoor illuminance level at the table top in the specified workspace. The workstation or workspace is north facing having west facing and north facing glass wall . The illuminance was measured upon all table top with a height of 0.760mm. The basic layout plan of the luminaires as per *DIALux*is given below.

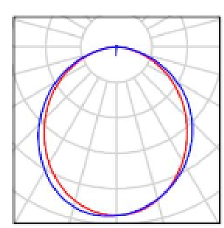


LUMINAIRE SPECIFICATIONS & DATASHEET:-

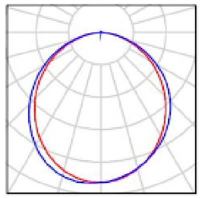
1. Luminous flux (Luminaire): 1800 lm
   Luminous flux (Lamps): 1800 lm
   Luminaire Wattage: 18.0 W
   Luminaire classification according to CIE: 100
   CIE flux code: 51 82 97 100 100
   Fitting: 2 x User defined (Correction Factor 1.000).



2. Luminous flux (Luminaire): 2000 lm
   Luminous flux (Lamps): 2000 lm
   Luminaire Wattage: 20.0 W
   Luminaire classification according to CIE: 100
   CIE flux code: 49 80 96 100 100
   Fitting: 1 x User defined (Correction Factor 1.000).



3. Luminous flux (Luminaire): 4000 lm
Luminous flux (Lamps): 4000 lm
Luminaire Wattage: 40.0 W
Luminaire classification according to CIE: 100
CIE flux code: 49 80 96 100 100
Fitting: 1 x User defined (Correction Factor 1.000).



10.5.1 Lighting Measurements

The visualization of the luminous environment of a given design arrangement under different lighting conditions are evaluated below

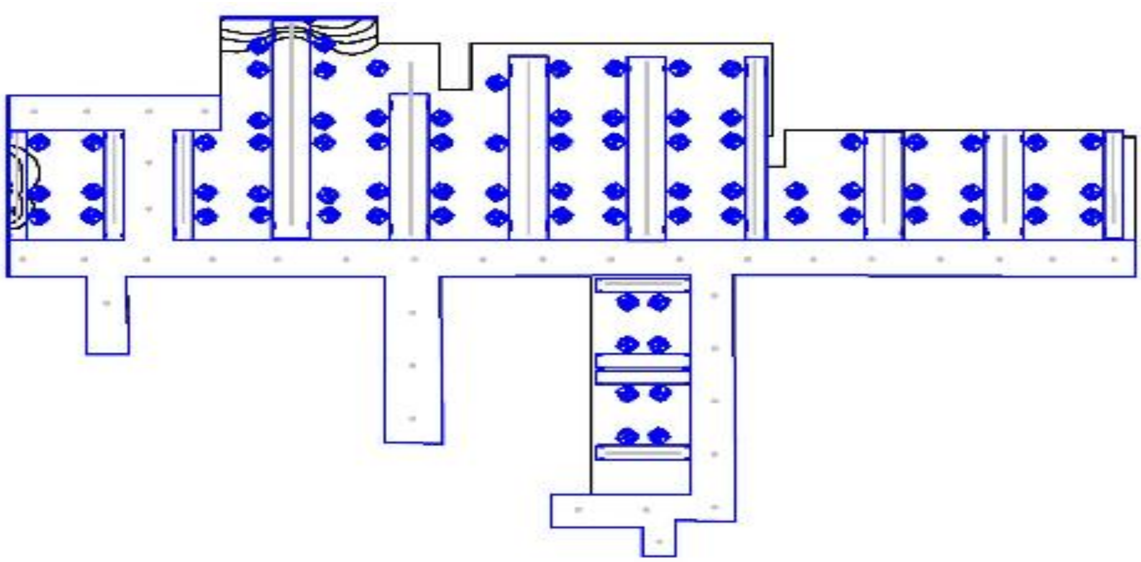
10.6.1.1 Measurement under 'Only Daylight' Condition:

The illuminance for Workspace under '*Only Daylight*' Condition has been measured and simulated. The photometric data by DIALux is being illustrated here under.

Surface	Average illuminances [lx]			Reflection factor [%]	Average luminance [cd/m²]
	direct	indirect	total		
Workplane	101	8.27	109	/	/
TABLE TOP	595	28	624	/	/
TABLE TOP	35	16	51	/	/
TABLE TOP	2581	45	2626	/	/
TABLE TOP	108	27	135	/	/
TABLE TOP	33	12	45	/	/
TABLE TOP	4.21	3.14	7.35	/	/
TABLE TOP	1.44	0.86	2.30	/	/
TABLE TOP	0.91	0.64	1.55	/	/
TABLE TOP	0.45	0.18	0.62	/	/
TABLE TOP	0.33	0.13	0.47	/	/
TABLE TOP	0.30	0.20	0.50	/	/
TABLE TOP	1.97	0.44	2.42	/	/
TABLE TOP	0.21	0.20	0.41	/	/
TABLE TOP	0.00	0.16	0.16	/	/
TABLE TOP	0.00	0.14	0.14	/	/
Floor	102	7.58	109	10	3.47
Ceiling	0.00	21	21	40	2.66
Wall 1	74	48	122	20	7.77
Wall 2	6.35	4.75	11	20	0.71
Wall 3	0.00	7.10	7.10	20	0.45
Wall 4	26	6.20	32	20	2.05
Wall 5	66	13	79	20	5.06
Wall 6	0.00	0.90	0.90	20	0.06
Wall 7	4.33	2.51	6.84	20	0.44
Wall 8	8.20	2.59	11	20	0.69

Wall 9	23	5.53	29	20	1.82
Wall 10	0.00	0.24	0.24	20	0.02
Wall 11	0.00	0.08	0.08	20	0.00
Wall 12	0.00	0.09	0.09	20	0.01
Wall 13	0.00	0.98	0.98	20	0.06
Wall 14	0.00	0.14	0.14	20	0.01
Wall 15	0.00	1.05	1.05	20	0.07
Wall 16	0.00	0.82	0.82	20	0.05
Wall 17	0.00	1.06	1.06	20	0.07
Wall 18	2.87	1.00	3.87	20	0.25
Wall 19	0.95	0.45	1.41	20	0.09
Wall 20	1.74	0.70	2.44	20	0.16
Wall 21	0.00	0.27	0.27	20	0.02
Wall 22	0.00	0.95	0.95	20	0.06
Wall 23	0.00	0.22	0.22	20	0.01
Wall 24	0.00	0.20	0.20	20	0.01
Wall 25	0.60	0.42	1.03	20	0.07
Wall 26	5.44	3.34	8.78	20	0.56
Wall 27	0.00	0.99	0.99	20	0.06
Wall 28	3.62	2.84	6.46	20	0.41
Wall 29	0.42	2.11	2.53	20	0.16
Wall 30	0.00	1.74	1.74	20	0.11
Wall 31	3.37	11	15	20	0.94
Wall 32	43	34	77	20	4.91
Wall 33	6.55	25	31	20	2.00
Wall 34	695	134	830	20	53
Wall 35	0.40	151	152	20	9.67
Wall 36	377	106	483	20	31
Wall 37	59	29	88	20	5.62
Wall 38	1.53	52	53	20	3.41

The isoline diagram for the Workspace plotted in DIALux with the help of these above data is shown below:



It has been observed that with the help of daylight, the workspace has achieved a minimum illuminance level of 109 lux which is not match with the recommend value of IS 3646(Part-I):1992. The results of the illuminance measurements of Workspace under '*Only Daylight*' condition is summarized below,

Height of Room: 2.700 m, Light loss factor: 0.80 Values in Lux, Scale 1:287

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	109	0.09	5112	0.001
Floor	10	109	0.09	5067	0.001
Ceiling	40	21	0.21	282	0.010
Walls (38)	20	40	0.08	1387	/

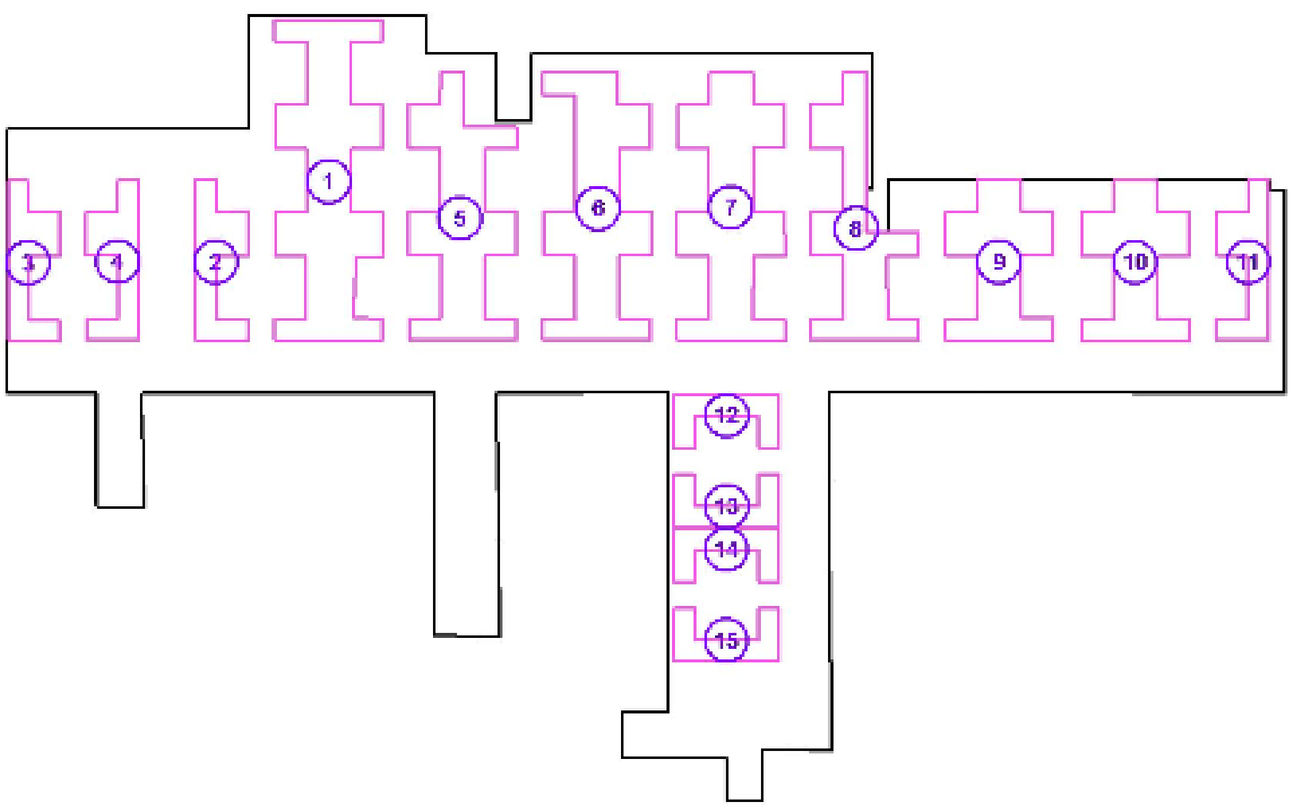
Workplane:

Height:	0.000 m
Grid:	128 x 128 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.342, Ceiling / Working Plane: 0.191.

Pure daylight scene, no luminaires involved.

Calculation surface Result:-



No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	TABLE TOP	perpendicular	16 x 8	624	24	4635	0.039	0.005
2	TABLE TOP	perpendicular	8 x 4	51	38	59	0.752	0.648
3	TABLE TOP	perpendicular	8 x 4	2626	425	5661	0.162	0.075
4	TABLE TOP	perpendicular	4 x 8	135	86	264	0.635	0.325
5	TABLE TOP	perpendicular	16 x 8	45	16	166	0.356	0.096
6	TABLE TOP	perpendicular	16 x 8	7.35	3.14	14	0.427	0.227
7	TABLE TOP	perpendicular	16 x 8	2.30	1.02	4.69	0.445	0.219
8	TABLE TOP	perpendicular	32 x 16	1.55	0.64	2.31	0.413	0.277
9	TABLE TOP	perpendicular	128 x 128	0.62	0.18	1.09	0.283	0.162
10	TABLE TOP	perpendicular	128 x 128	0.47	0.13	0.88	0.282	0.149
11	TABLE TOP	perpendicular	8 x 4	0.50	0.20	0.79	0.395	0.252
12	TABLE TOP	perpendicular	8 x 4	2.42	0.44	4.23	0.183	0.105
13	TABLE TOP	perpendicular	4 x 8	0.41	0.20	1.88	0.492	0.107
14	TABLE TOP	perpendicular	8 x 4	0.16	0.16	0.16	1.000	1.000
15	TABLE TOP	perpendicular	8 x 4	0.14	0.14	0.14	1.000	1.000

<u>The 3-D Rendering & False colour rendering in DIALux is shown below:-</u>

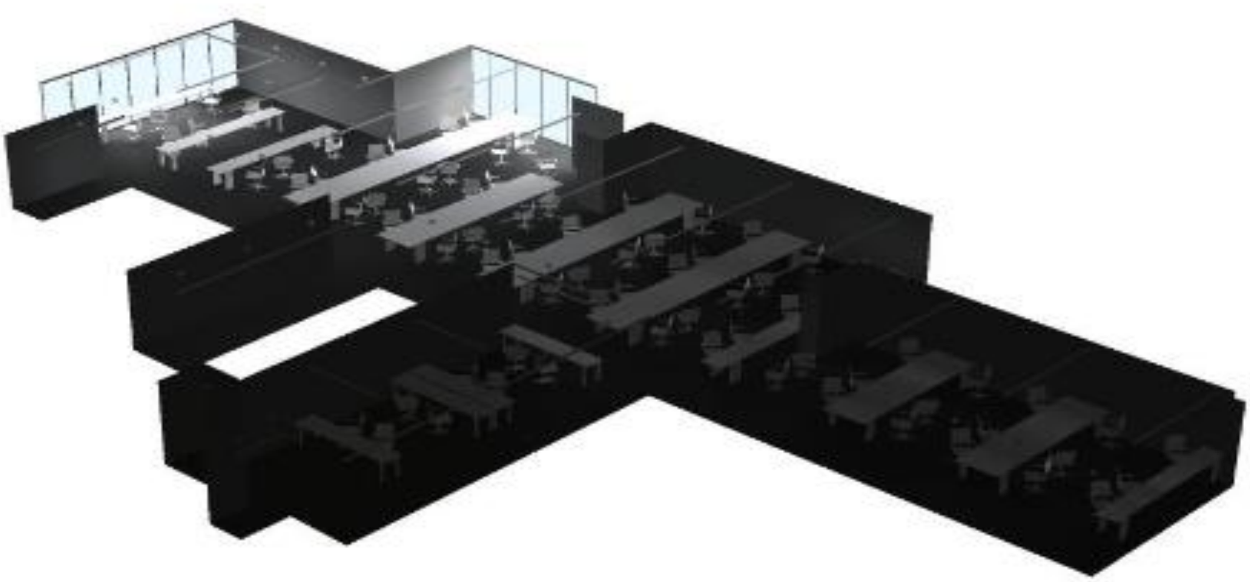


Fig:-10.38 3D Rendering

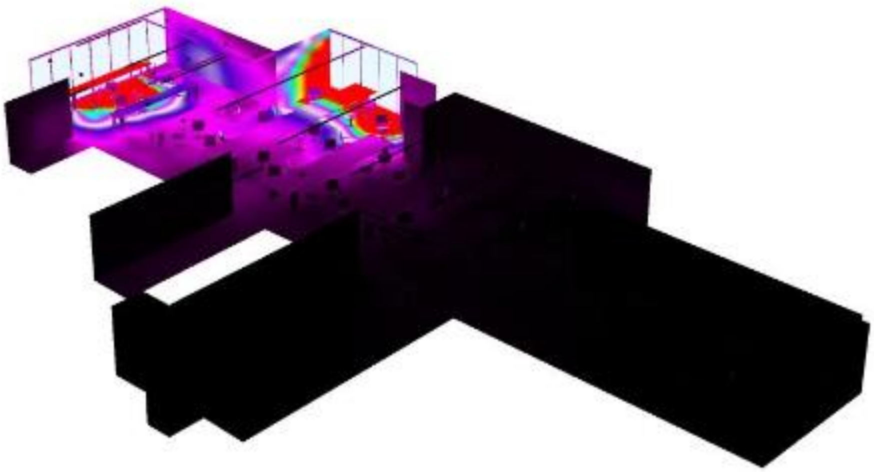
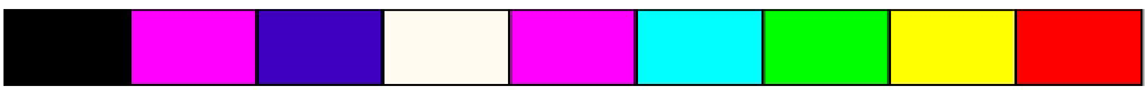


Fig:-10.38 False color rendering



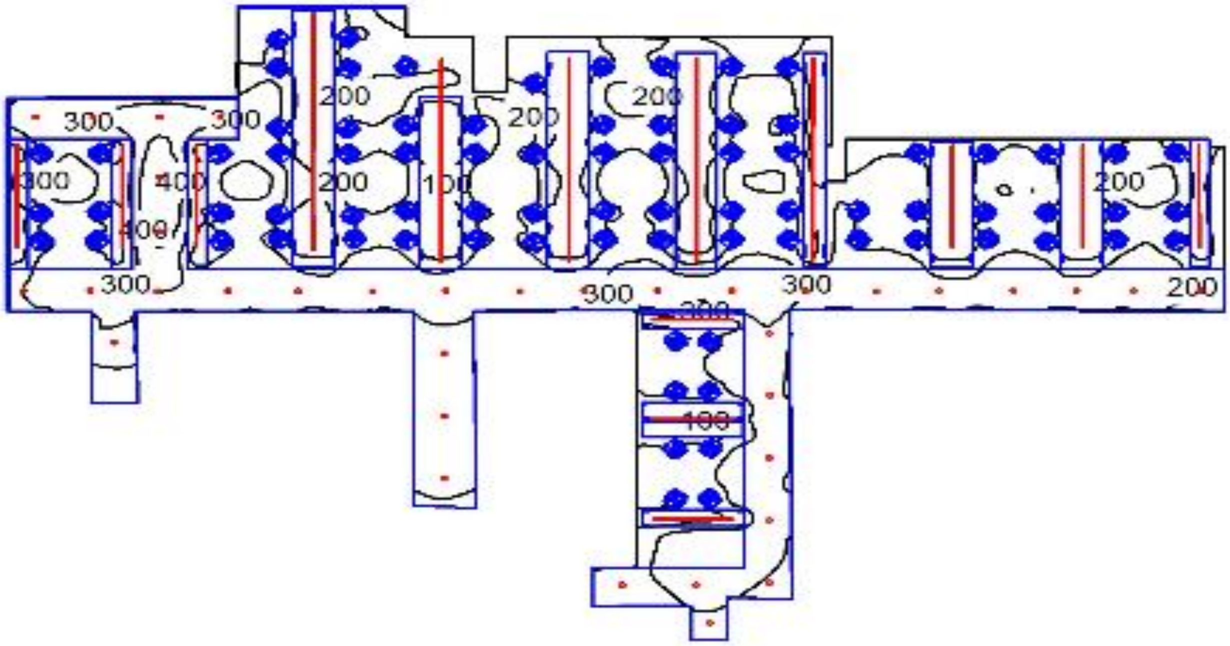
10.6.1.2 Measurement under 'Only Artificial Light' Condition:

The illuminance for Workspace under '*Only Artificial Light'* Condition has been measured and simulated. The photometric data provided by DIALux is being illustrated here under.

Surface	Average illuminances [lx] direct	indirect	total	Reflection factor [%]	Average luminance [cd/m²]
Workplane	165	19	184	/	/
TABLE TOP	337	24	360	/	/
TABLE TOP	455	25	480	/	/
TABLE TOP	337	21	359	/	/
TABLE TOP	461	24	485	/	/
TABLE TOP	349	26	375	/	/
TABLE TOP	341	27	367	/	/
TABLE TOP	355	28	382	/	/
TABLE TOP	339	26	366	/	/
TABLE TOP	275	20	296	/	/
TABLE TOP	288	22	310	/	/
TABLE TOP	290	27	317	/	/
TABLE TOP	383	22	405	/	/
TABLE TOP	275	19	295	/	/
TABLE TOP	267	18	285	/	/
TABLE TOP	293	19	313	/	/
Floor	164	19	183	10	5.82
Ceiling	0.31	44	44	40	5.66
Wall 1	136	23	159	20	10
Wall 2	67	13	80	20	5.09
Wall 3	27	9.52	37	20	2.34
Wall 4	65	12	77	20	4.90
Wall 5	141	28	169	20	11
Wall 6	77	13	90	20	5.72
Wall 7	66	12	78	20	4.95
Wall 8	74	12	86	20	5.46
Wall 9	139	30	169	20	11
Wall 10	93	31	124	20	7.89

Wall 11	99	17	116	20	7.37
Wall 12	84	17	101	20	6.45
Wall 13	98	19	116	20	7.40
Wall 14	123	21	144	20	9.16
Wall 15	140	20	160	20	10
Wall 16	134	21	155	20	9.88
Wall 17	120	20	140	20	8.91
Wall 18	131	22	153	20	9.75
Wall 19	132	24	156	20	9.91
Wall 20	136	29	165	20	11
Wall 21	114	33	147	20	9.37
Wall 22	122	34	157	20	9.97
Wall 23	84	29	114	20	7.23
Wall 24	29	20	49	20	3.13
Wall 25	108	35	143	20	9.09
Wall 26	214	51	265	20	17
Wall 27	119	49	168	20	11
Wall 28	158	39	197	20	13
Wall 29	80	34	114	20	7.23
Wall 30	58	32	90	20	5.70
Wall 31	79	39	117	20	7.47
Wall 32	103	28	131	20	8.35
Wall 33	89	30	119	20	7.55
Wall 34	34	19	53	20	3.37
Wall 35	46	22	69	20	4.38
Wall 36	61	26	87	20	5.55
Wall 37	171	28	199	20	13
Wall 38	110	20	130	20	8.27

The isolux diagram plotted in DIALux with the help of these above data is shown below:



It has been observed that with the help of artificial light, the workspace have achieved an average illuminance level of on the table top 361 lux which is same as the standard values as perIS 3646(Part-I):1992. The results of the illuminance measurements of Workspace under '*Only Artificial light*' condition is summarized below,

Height of Room: 2.700 m, Light loss factor: 0.80 — Values in Lux, Scale 1:287

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	184	17	498	0.093
Floor	10	183	17	499	0.091
Ceiling	40	44	0.79	138	0.018
Walls (38)	20	130	8.41	812	/

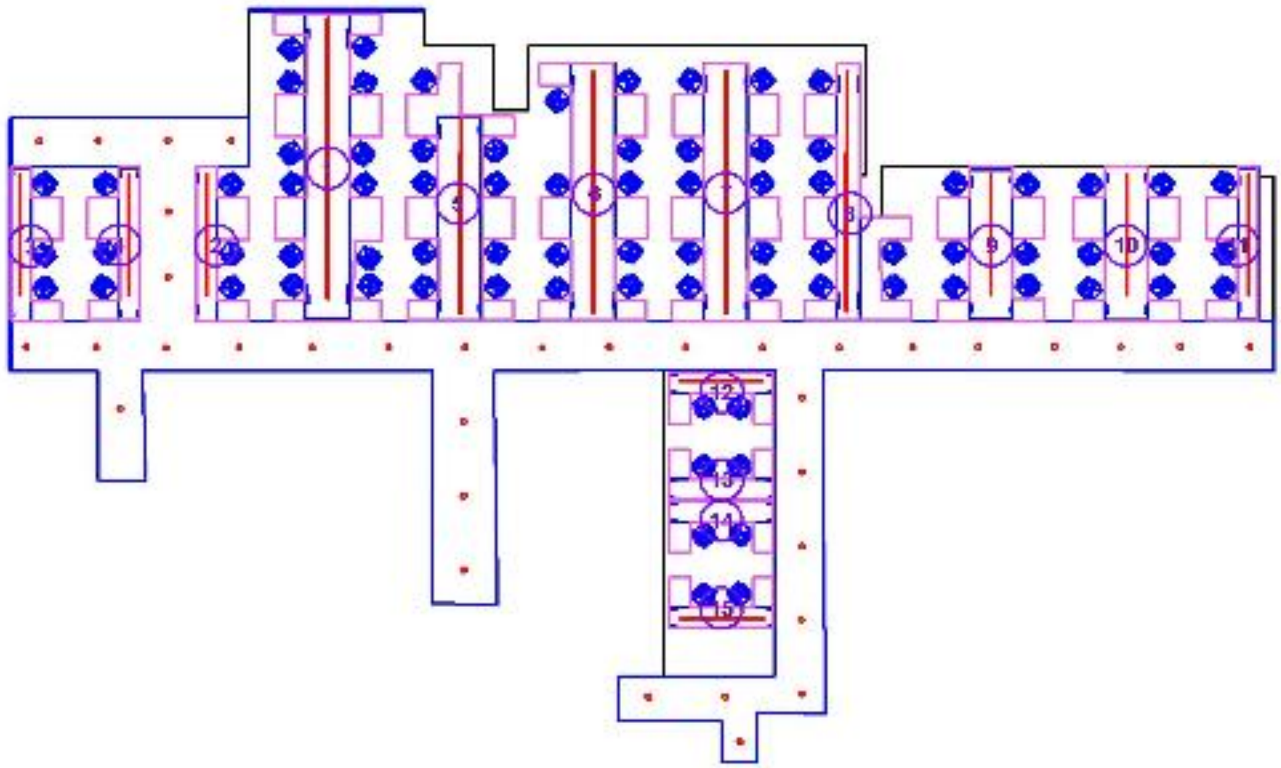
Workplane:

Height:	0.000 m
Grid:	128 x 128 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.737, Ceiling / Working Plane: 0.242.

Specific connected load: 4.82 W/m² = 2.62 W/m²/100 lx (Ground area: 362.81 m²)

Calculation surface result:-



No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	TABLE TOP	perpendicular	64 x 32	360	113	482	0.313	0.234
2	TABLE TOP	perpendicular	32 x 16	480	300	627	0.625	0.478
3	TABLE TOP	perpendicular	32 x 16	359	261	432	0.729	0.605
4	TABLE TOP	perpendicular	16 x 32	485	313	639	0.646	0.490
5	TABLE TOP	perpendicular	64 x 32	375	214	475	0.571	0.451
6	TABLE TOP	perpendicular	64 x 32	367	114	478	0.311	0.239
7	TABLE TOP	perpendicular	64 x 32	382	219	486	0.572	0.450
8	TABLE TOP	perpendicular	64 x 32	366	149	467	0.408	0.319
9	TABLE TOP	perpendicular	128 x 128	296	172	399	0.583	0.432
10	TABLE TOP	perpendicular	128 x 128	310	198	407	0.639	0.486
11	TABLE TOP	perpendicular	32 x 16	317	230	391	0.725	0.587
12	TABLE TOP	perpendicular	32 x 16	405	189	537	0.467	0.352
13	TABLE TOP	perpendicular	16 x 32	295	153	391	0.519	0.391
14	TABLE TOP	perpendicular	32 x 16	285	142	378	0.499	0.376
15	TABLE TOP	perpendicular	32 x 16	313	157	404	0.501	0.388

The 3-D Rendering & False colour rendering in DIALux is shown below:-

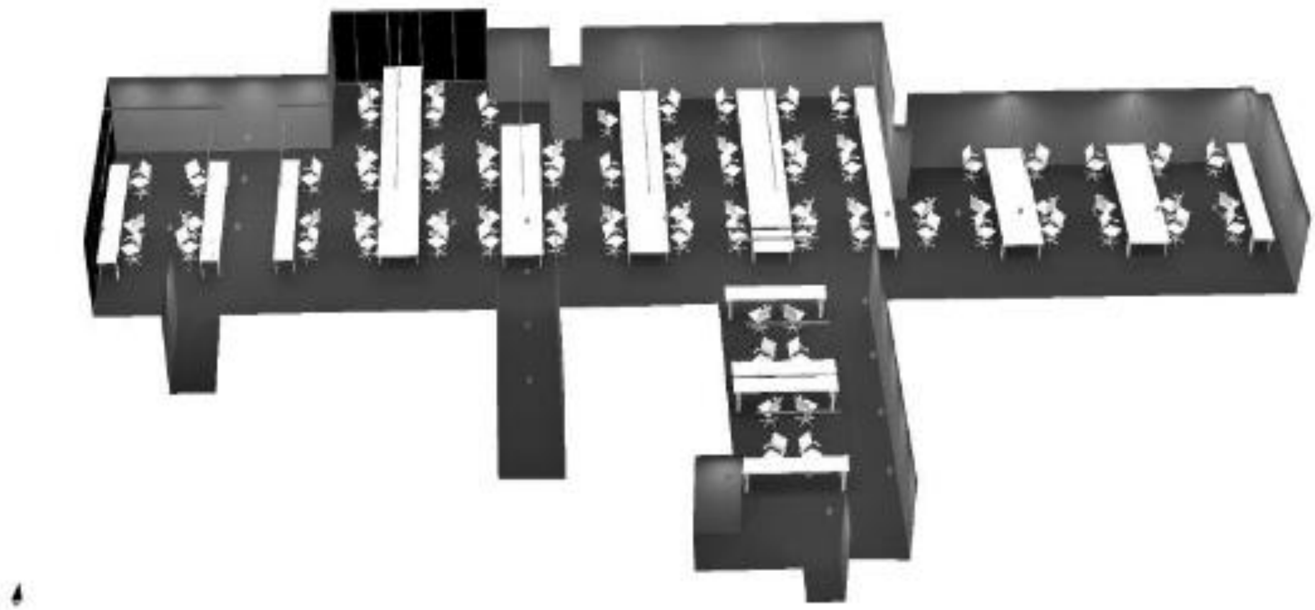


Fig:-10.39 3D Rendering

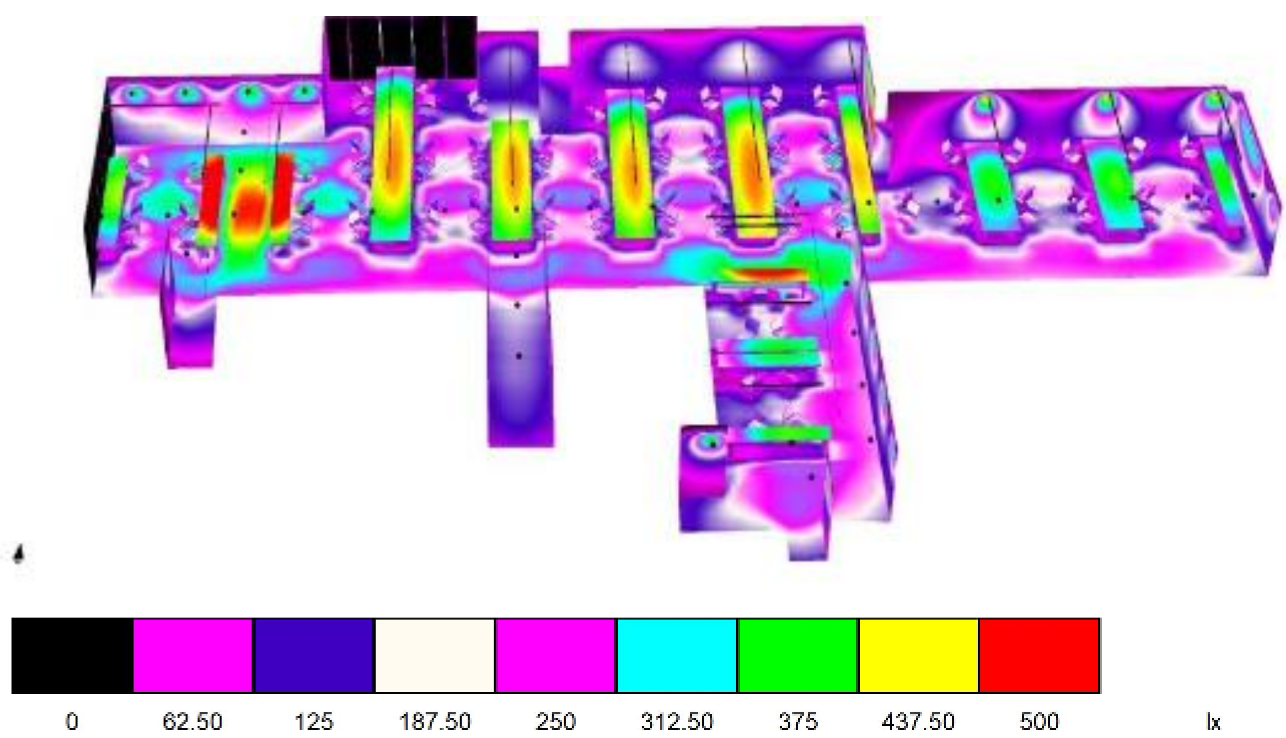


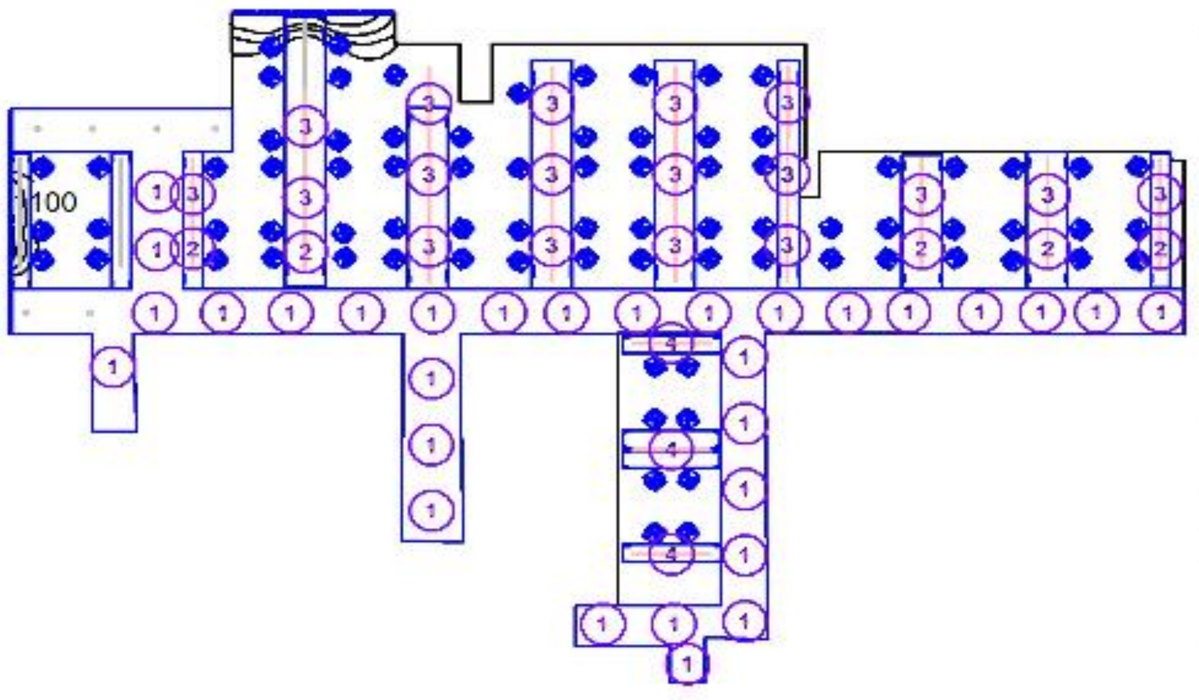
Fig:-10.40 False color Rendering

10.6.1.3 Measurement under 'Both Daylight & Artificial Light' Condition:

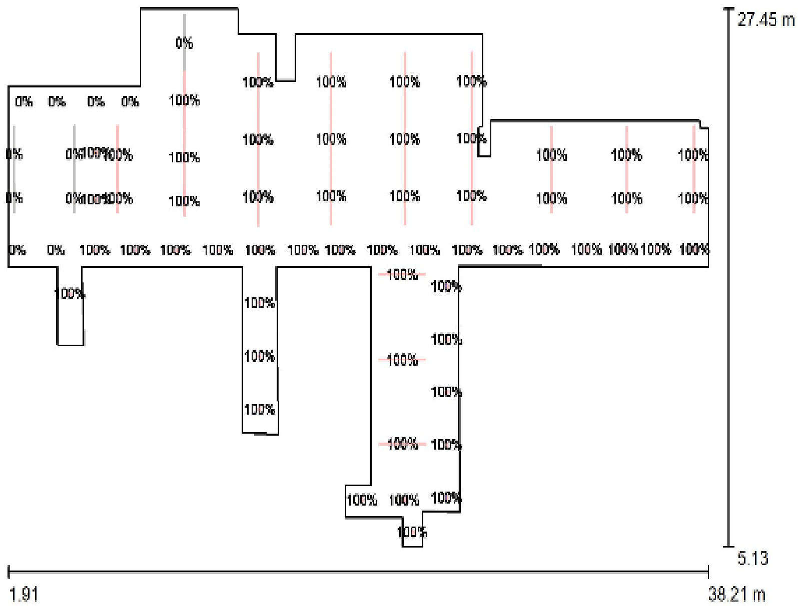
The illuminance for workspace under *'Both Daylight & Artificial Light'* condition has been measured and simulated. The photometric data by DIALux is being illustratedbelow.

Surface	Average illuminances [lx]			Reflection factor [%]	Average luminance [cd/m²]
	direct	indirect	total		
Workplane	242	23	265	/	/
TABLE TOP	841	47	887	/	/
TABLE TOP	411	33	444	/	/
TABLE TOP	2596	50	2645	/	/
TABLE TOP	250	39	288	/	/
TABLE TOP	376	35	411	/	/
TABLE TOP	342	28	371	/	/
TABLE TOP	357	26	383	/	/
TABLE TOP	338	23	361	/	/
TABLE TOP	276	20	296	/	/
TABLE TOP	288	21	310	/	/
TABLE TOP	291	24	314	/	/
TABLE TOP	386	18	404	/	/
TABLE TOP	276	15	292	/	/
TABLE TOP	268	15	284	/	/
TABLE TOP	294	16	310	/	/
Floor	237	22	260	10	8.26
Ceiling	0.30	60	61	40	7.73
Wall 1	83	56	139	20	8.87
Wall 2	67	12	79	20	5.06
Wall 3	22	14	36	20	2.27
Wall 4	76	14	90	20	5.70
Wall 5	187	32	219	20	14
Wall 6	73	11	84	20	5.34
Wall 7	71	11	83	20	5.25
Wall 8	79	12	91	20	5.82
Wall 9	150	30	181	20	11
Wall 11	98	11	110	20	6.98
Wall 12	87	12	99	20	6.31
Wall 13	93	15	108	20	6.86
Wall 14	119	16	135	20	8.61
Wall 15	135	18	153	20	9.76
Wall 16	128	19	147	20	9.37
Wall 17	114	17	131	20	8.32
Wall 18	125	22	148	20	9.41
Wall 19	124	21	145	20	9.23
Wall 20	140	29	168	20	11
Wall 21	120	33	153	20	9.72
Wall 22	123	40	163	20	10
Wall 23	86	30	116	20	7.38
Wall 24	34	24	58	20	3.70
Wall 25	109	37	146	20	9.29
Wall 26	223	54	277	20	18
Wall 27	132	46	178	20	11
Wall 28	161	39	200	20	13
Wall 29	78	35	113	20	7.18
Wall 30	60	33	92	20	5.89
Wall 31	89	44	134	20	8.52
Wall 32	139	59	197	20	13
Wall 33	93	51	144	20	9.18
Wall 34	706	147	853	20	54
Wall 35	25	163	188	20	12
Wall 36	405	123	528	20	34
Wall 37	90	41	131	20	8.35
Wall 38	15	60	75	20	4.80

The isolux diagram of Workspace plotted in DIALux with the help of these above data is shown below:



It has been observed that by using artificial light combined with available daylight, the workspace can maintain an average illuminance level of 519 lux on table top by means of control arrangement which can be permissible with respect to standard values as recommended in IS 3646 (Part-I):1992. As the lux level is higher in the zone nearer to the window, therefore luminaires arranged in that portion [Fig10.40] has been dimmed to 0% of its maximum value. The controlled luminaire arrangement is shown below.



Daylight parameters:
Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 360.0°
Date: 22.05.2024, Time: 12:00:00 (+5 hours difference to GMT)
Reference sky type: Mixed sky

Fig 10.40 Simulated Lighting layout of work space for '*Both Daylight & Artificial Light'* Condition

The *DIALux* simulated results of the illuminance measurements of workspace under '*Both Daylight & Artificial Light'* condition is summarized below,

Height of Room: 2.700 m, Light loss factor: 0.80 | Values in Lux, Scale 1:287

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	265	24	5137	0.092
Floor	10	260	45	5115	0.173
Ceiling	40	61	1.91	295	0.031
Walls (38)	20	146	15	1410	/

Workplane:

Height:	0.000 m
Grid:	128 x 128 Points
Boundary Zone:	0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.566, Ceiling / Working Plane: 0.229.

Specific connected load: 4.08 W/m² = 1.54 W/m²/100 lx (Ground area: 362.81 m²)

<u>The 3-D Rendering & False colour rendering in DIALux is shown below:-</u>

Fig 10.41 3D Rendering

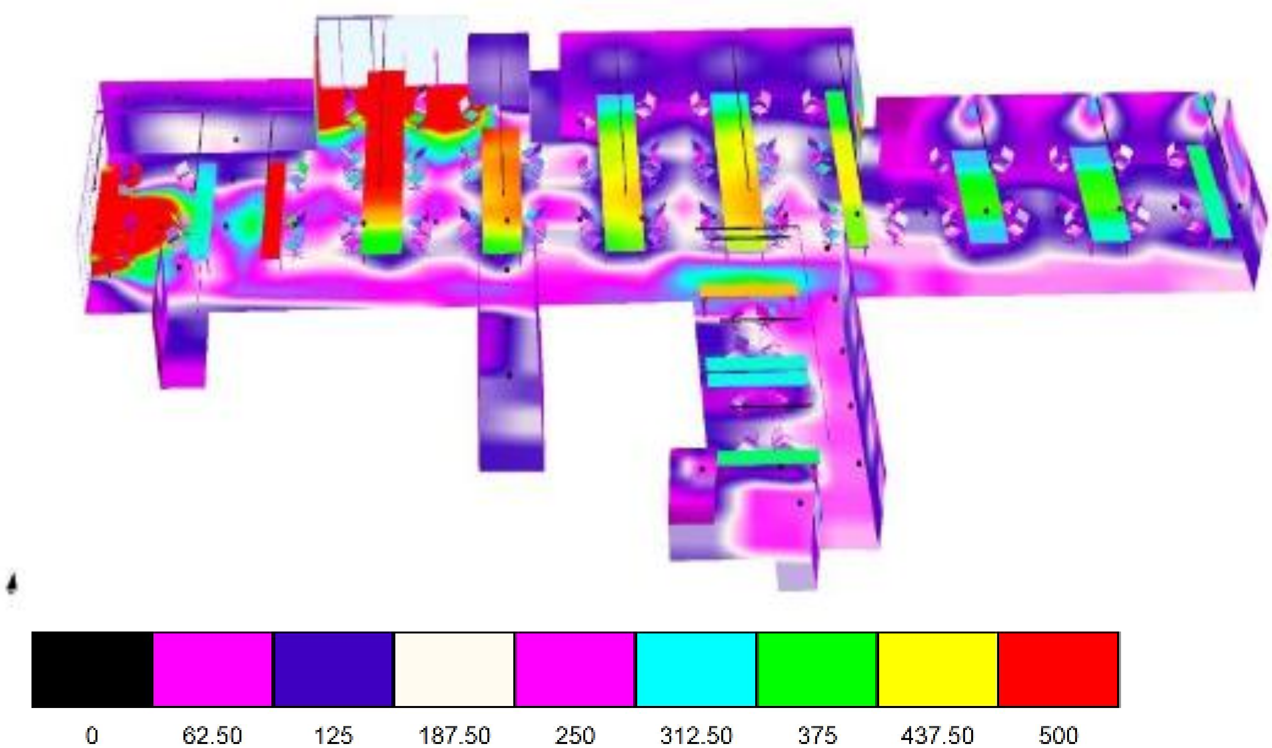


Fig 10.42 False color Rendering

11. RESULTS AND DISCUSSION

This chapter analyses the performance of each model and identify the best lighting solution in terms of illuminance level and illuminance distribution. Before that analysis a qualitative overview of the results is needed for easier introduction to the quantitative analysis in comparison of daylight performance for different systems having correlation between indoor illuminance and external weather conditions by using statistical tools and energy simulation results.

11.1 Qualitative overview

The present study has focused on assessment to provide the maximum use of daylight for maintaining proper illumination level within the specified rooms. It has been noticed that being a office building the occupants can use lighting energy for 9 hrs. i.e., between 09.00AM to 06.00PM. During this period the room is illuminated with sufficient amount of daylight between 10.00 AM to 2.00 PM throughout the year. During 02.00PM to 06.00PM, the required lighting level need to be supplemented through artificial light combined with the available daylight. Specifically, during the months of October to February use of artificial lighting is needed during the afternoon hours after 2.00PM and lighting need to be done with the artificial light only after 4.00PM because there is not sufficient illuminance level in the interior for office activities.

11.2 Lighting Availability Analysis

The lighting assessment has been done by considering monthly 30 days working. The complete lighting scenario is given below.

SUMMARY SHEET OF LIGHTING AVAILABILITY

Location	Lighting Contribution	Available Daylight Hour											
		Daily contribution of Available light in Hrs. [Quarterly assessment]				Monthly contribution of Available light in Hrs. [Quarterly assessment]				Yearly Contribution of lighting Availability in Hrs. [Seasonal reflection]			
		Jan - Mar	Apr - Jun	Jul - Sept	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sept	Oct - Dec	Mar	May	Aug	Dec
CAFÉ 35 PAX	Only Daylight	4	5	4	4	120	150	120	120	360	450	360	360
	Only Artificial light	3	2	3	4	90	60	90	120	270	180	270	360
	Both Daylight & Artificial light	2	2	2	1	60	60	60	30	180	180	180	90
CABIN 1	Only Daylight	4	5	4	4	120	150	120	120	360	450	360	360
	Only Artificial light	3	2	3	4	90	60	90	120	270	180	270	360
	Both Daylight & Artificial light	2	2	2	1	60	60	60	30	180	180	180	90
CABIN 2	Only Daylight	4	5	4	4	120	150	120	120	360	450	360	360
	Only Artificial light	3	2	3	4	90	60	90	120	270	180	270	360
	Both Daylight & Artificial light	2	2	2	1	60	60	60	30	180	180	180	90
CABIN 5	Only Daylight	4	5	4	4	120	150	120	120	360	450	360	360
	Only Artificial light	3	2	3	4	90	60	90	120	270	180	270	360
	Both Daylight & Artificial light	2	2	2	1	60	60	60	30	180	180	180	90
WORK SPACE	Only Daylight	4	5	4	4	120	150	120	120	360	450	360	360
	Only Artificial light	3	2	3	4	90	60	90	120	270	180	270	360
	Both Daylight & Artificial light	2	2	2	1	60	60	60	30	180	180	180	90

Fig 11.1 Lighting Availability scenario in the case study of Office Building

11.3 Energy simulation

The study compares the energy consumption between the entire three reference scenario (Only Daylight Condition, Only artificial light condition, both daylight & artificial light condition). The results indicate that the additional energy saving has been done by contributing appropriate daylight energy. From the DIALux simulation it is analyzed that when both daylight and artificial light are taken into consideration in all the rooms, then, to maintain proper lighting level only some of luminaires need to be operated.

The detail of the energy assessment is discussed with the help of following datasheet

SUMMARY SHEET OF LIGHTING ENERGY ASSESSMENT [CASE STUDY ANALYSIS]

Location	Total No of Luminaires	No of luminaire in 'Only Artificial light' condition	No of luminaire in'Both Daylight & Artificial light' condition	Yearly Consumption of Light energy in kwh[For Artificial condition]	Yearly Consumpti onof Light energy in kwh[For Artificial &Daylight condition]	Yearly Energy Savings in kwh	Percentage of Energy Savings
CAFÉ 35 PAX	22	22	12	432	132.3	299.7	69.347
CABIN 01	5	5	2	108	18.9	89.1	84.85
CABIN 02	5	5	2	108	18.9	89.1	84.85
CABIN 05	5	5	2	108	18.9	89.1	84.85
WORKSPACE	67	67	56	1887.84	932.4	955.44	50.61
TOTAL SAVINGS						1522.44	57.58

Fig 11.2 Lighting Energy Assessments of Case study building using Daylight integration

From the individual room analysis it has been derived that, proper geometrical orientation of a room can cause better illuminance level with the integration of daylight performance. Energy simulation of the studied case is based on allowing daylight into the located area and energy consumption by electric lighting and artificial lighting. The study assesses the additional energy saving potential provided by the integration of appropriate daylight level based on its daylight contribution to the existing office building areas. The room lighting connected with 0%-5% dimming controls, as per requirement, allows daylight distribution to compensate for the illuminance output from electric lighting. Therefore it can be estimated that the overall energy consumption could be reduce by 57.58% of total lighting energy consumption which is very much satisfactory for a office building.

LIGHTING POWER DENSITY Table:-

Room name	Condition	LPD value	Remarks
Café 35 pax	Artificial light only	7.85	Meet with ECBE standard
	Daylight & Artificial light	4.11	Meet with ECBE standard
Cabin 01,02,05	Artificial light only	10.82	Does not meet with ECBE standard
	Daylight & Artificial light	7.61	Meet with ECBE standard
Work space	Artificial light only	4.82	Meet with ECBE standard
	Daylight & Artificial light	4.08	Meet with ECBE standard

From the above table according to ECBC standard LPD match with the standard value during daylight & artificial light condition which means with proper daylight arrangement with artificial light arrangement we can create a Green Bulding.

12. CONCLUSIONS

The present study has focused on the assessment for utilization of daylight in the subject office building. Initial study has been carried out to find the daylight availability at various seasons in different places in the subject building. For energy efficient lighting design point of view, adoption of daylight integration is likely to be a good option. Simulated results illustrated that there will be an energy saving potential by proper utilization of the daylight throughout the year. Daylighting will provide tremendous operating cost reductions, energy savings and save environmental pollution if properly integrated with an artificial lighting system. From the results obtained by software simulation, it has been observed that daylight distribution has the potential to reduce overall energy consumption by 57.58%.

However, there are also some drawbacks of daylight integrating system in a other building. An unwanted glare caused by excessive daylight penetration may occurs during morning and afternoon time especially for east and west facing room(s). For best result, the experiment need to requires simultaneously logging of indoor and outdoor measurement data under different sky conditions over a prolonged period in order to assemble a reasonable collection of data. To optimize the energy saving potential, a proper controlled light dimming system and control algorithm is needed.

Despite the limitations mentioned above, to cope with the skyrocketing cost of energy and environmental concerns, architects and lighting specialists need to utilize daylight as a primary source of illumination in mainstream application. In addition, the implementation of such daylighting technology can also be the driver for the adoption of green building practices.

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