Studies on Daylight Integrated Lighting Design of a Classroom

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

Master of Technology in

Illumination Technology and Design

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled "**Studies on Daylight Integrated Lighting Design of a Classroom"** submitted by **KAUSTABH DALAL, Examination Roll No.: M6ILT22015** under my supervision and guidance for partial fulfillment of the requirement of Master of Technology (Illumination Technology and Design) in School of Illumination Science, Engineering & Design, during the academic session 2021 - 2022.

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CERTIFICATE OF APPROVAL

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

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his **Master of Technology** (Illumination Technology and Design) studies during academic session 2019-2022.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by this rules and conduct, I have fully cited and referred all material and results that are not original to this work.

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List Of Content:

Abstract:

In educational buildings a significant component of the energy used is spent in illuminating the interior of the building. As the energy cost rises, increasing effort has gone into minimizing the energy consumption of lighting installations. This effort could follow three basic directions: new more efficient equipment (lamps, control gear, etc.), utilization of improved lighting design practices (localized task lighting systems), improvements in lighting control systems to avoid energy waste for unoccupied and daylight hours. By controlling the lighting in such a way that the lighting level is always accurately matched to the actual need allows to save on the energy costs and to improve the human comfort and efficiency. Establishing an integrated lighting control concept is a very important part of the lighting design process. The paper describes optimization of illumination of a classroom by integrating both Daylight and Artificial Light with successive reduction in Energy Consumption of the classroom.

Chapter-1

Introduction

The study of lighting in school buildings has been a subject of interest for many years, and rightly so. Good daylight has shown to be closely associated with improvement in student performance and promotion of better health. It also contributes significantly to the aesthetics and physical character of the learning space.

Throughout history day lighting has been considered as a crucial factor in the design of schools, more, perhaps, than in the design of any other building types.

1.1: Literature Survey:

1. The gap between energy demand and supply is considerable issue of present times. It is a peak time to reduce the educational building energy consumption right from the design state so that a proper reduction in the educational building electric loads can be achieved. This would result in reducing the energy demand or supply shortage. Lighting is one of the important energy consuming sector to be considered in a educational building. Hence, an appropriate lighting scheme design is to be applied for a building by integrating naturally available daylight. If designed building is based on maximum utilization of daylight and use of energy efficient luminaires, cost of using energy is greatly reduced.

In this paper, a typical classroom of Manipal Institute of Technology, Manipal is analyzed for lighting analysis. A standard artificial lighting is designed using RELUX software. The availability of daylight in the interior of the room is also analyzed. The results of daylight analysis showed that one fourth of the room receives adequate illumination with only daylight, thus reducing the need for artificial lighting. The extent of daylight penetration and uniformity level are also studied in this paper. For all the cases and time, an overall uniformity greater than 0.3 could be achieved, indicating a good light distribution in the classroom. The results of the lighting analysis comply with the lighting standard considered in this study, i.e. Indian Standard SP41. By integrating daylight with artificial lighting, two luminaires can be made functionally OFF. This would result in 100 W reduction in the lighting load. This also result in an energy savings of 210 kWh per annum. Corresponding energy cost savings also can be achieved. Since there is a reduction in lighting load, there will be reduction in heat generation also, which would reduce the load on the HVAC system. Hence the energy savings per annum will be a good amount. This study shows that a proper daylight integration results in ample amount of energy savings just for a single classroom. Hence a considerable reduction in energy consumptions can be obtained by implementing the same to all other rooms. This will finally result in the reduction of energy demand and supply shortage, reduction in the amount of coal to produce the electrical energy and hence reduction in the carbon footprints. This measure of load reduction is a path for sustainable development.[1]

2. Natural lighting and its impact on the performance of students have gotten the attention of researchers for many years. Before the artificial lighting become the dominant, all the classrooms ware lighted by the natural light, of course. Recently, more interest has revived the importance of

the windows to provide daylight and looking to outside, especially whenever a good exterior landscapes be available.

The primary goal of this study is to examine some classrooms in the educational buildings at King Abdul Aziz University to determine whether daylight can affect student performance. Collect information about the natural lighting conditions in the classroom is the first step to test the impact on student performance. Also other aspects of the internal environment of the classroom affect student performance and interact with the light of day. To achieve the objective of the study, information about the selected classrooms, including, along with natural lighting, HVAC, ventilation, windows and roof coverings, and opinion, and the quality of indoor air, has to be considered.

Daylight in classrooms has an essential effect on the learning environment. The careful introduction of daylight into educational buildings reduces operating costs, improves students' vision and perception, and contributes to students' health, comfort, and productivity. In general, classrooms should get as much daylight as possible, although designers must control the illumination of areas within the students' fields of vision. Effective use of daylight in classrooms can help educational buildings realize significant energy savings, increase students' attendance, demonstrate environmental responsibility, and provide a better environment in which students can learn.[2]

1.2: Problem Identification:

In Indian Classroom there is some uncomfortable lighting condition affects students improper visibility. This condition are not properly use of daylight, lack of uniformity, low visibility from back side desk, improper orientation of class room desk, very uneven illuminance level on desk, not dimmable FTL luminaire etc. In various survey the following points of lighting condition of Indian schools comes out:

- Improper Use of Daylight: As India located in tropical region it has enormous daylight, But due to lack of proper architectural design daylight does not enters many of class room properly and secondly due to high dust particles accumulated on the window glass, there is reduction of daylight in the classroom. This causes visibility in the classroom.
- Use of FTL as Artificial Luminaire: In India maximum of classroom are illuminated by old T8 or T12 FTL luminaire. This FTL luminaire are not dimmable, so it causes uneven illuminance in the classroom. Not dimmable properties some time creates glare, specially on blackboard or darkness on desk.
- High Energy Consuming FTL: FTL luminaires consume more energy than LED batten and over this they are not dimmable so there is loss of unused energy.
- Degradation of luminous flux over time: In FTL luminaire there is degradation of luminous flux over time, so there is reduction of illuminance level on desk.
- Low Visibility from backside desk: In classroom there is low visibility from backside desk, due to all desk are placed on same plane, so backside student's visibility get obstructed from the desk in front of them.
- Improper Orientation of Desk: In classroom all desk are arranged back to back, so there is no blackboard orientation. There is some obstruction related problem arise from back side of the class.

- Dark Colored Desk: All desks are painted dark colored, so it creates very high contrast to eye causes fatigue.

1.3: Objective:

The objective of this study is to maintain optimization in between students better visibility and energy saving, by maintaining existing classroom condition.

1.4: Methodology:

To counter above problems this study tries to find solution by following way:

- By cleaning the window glass daylight transmittance factor is increased.
- Energy Efficient & Dimmable LED Batten are used.
- Design lighting such a way that try maintain all lighting parameter like average illuminance, uniformity & glare to their recommended specification, without altering the luminaire position co-ordinate points.
- Appling steps to the desk one after another for better visibility.
- Orient all the desk towards blackboard for better concentration of the students.
- Paint light color to desk to eliminate contrast problem.

1.5: Thesis Outline:

This thesis is divided into 10 chapters.

The **first chapter** deals with introduction to the work, motivation to take up this project, literature review, Problem definition and details about the project.

Chapter 2 gives introduction of Indoor Lighting Design, Objective of Good Lighting, Criteria for Lighting Design, Fundamentals of Indoor Lighting Design, Details of Indoor Lamps & Different Areas of School Building.

Chapter 3 deals with the details of Classroom Design Consideration like Codes & Standards for Classroom Lighting, Types of Ceiling, Types of Luminaire, Type of Sensors, Digital Timers, Photo Sensors, Comparison of Photo Sensor, Lighting Design Methodology, Choice of Luminaire and Software Used for the Lighting Design.

Chapter 4 enumerates the details of the classroom considered like dimension of the room, details of the classroom floor, walls & ceiling. Beyond this gives the details of the classroom objects like table & chair for students and teachers. Lastly deals with considered work plane for lighting parameter measurement.

Chapter 5 gives the details of existing lighting condition, including luminaires used and lighting parameter measurement for four time of the day and comparison of these measurements.

Chapter 6 analysis lighting parameters with only daylight by four times a day.

Chapter 7 analysis the lighting parameters with only by artificial LED luminaire.

Chapter 8 gives proposed optimized lighting design using both daylight and artificial light.

Chapter 9 analyze all the above design by comparison and charts.

Chapter 10 conclude the thesis and gives future scope.

Chapter-2

Indoor Lighting Design

2.1 Introduction:

Lighting design is both aesthetic process. It is the process of sensibly integrating light into the fabric of architecture. Regardless of the area to be lighted— a bank, a church, an office, a gallery, a restaurant, a store, a classroom—and regardless of the luminaire available for use, the process is always the same.

Because lighting design is a process, it can be learned. This study traces the steps in the lighting design process much as a professional performs them in practice. Design, of course, is not always a straight process. At times some of these steps are used simultaneously. But, as a whole, the order of the material corresponds to professional practice.

This study does not describe the lighting design process; it describes a lighting design process. It is a process built on the conviction that the lighting condition of a space has enormous emotional impact on people.

A common mistake when providing light for buildings is to select the lighting equipment first. Selecting luminaires is the last most step in the process. What is important is not what makes the light, but which objects and surfaces receive it. The key to successful lighting design is to decide what light is needed first, and then work backward to determine the solution.[3]

2.2 Objective of Good Lighting:

2.2.1 Visibility:

In physical terms an object is visible when light reflects from it and it is perceive that light through eyes. However, just because something reflects light does not make it clearly visible. Visibility has a lot to do with modeling and intensity contrast. For example, in presence of high intensity light level on the stage, it may be difficult to see people clearly if there is no modeling or contrast. So, visibility is how "clearly" the user can see something. Good visibility is comfortable on the eyes and is enhanced by all the qualities of light.[4][5]

2.2.2 Selective Focus:

Selective focus means that objects and people are highlighted or darkened to control the user attention (or focus). The user is free to look all around the office. It is the lighting designer's job to guide the audience's focus to important moments.[4][5]

2.2.3 Modeling:

This aspect of lighting allows the designer to help emphasize the three-dimensionality of an object or person. Some objects may be appeared as "flat" and uninteresting. This is usually due to a lack of angled light creating shadows on objects. The contrast of light and shadows creates visual interest and allows us to see things more clearly, especially the human face. This is also true for three-dimensional objects and textures used on stage. Correct angles of lighting should be used to create the appearance of texture to the audience.[4][5]

2.2.4 Mood:

Creating the mood occurs when the designer brings life to the lighting atmospheres that evoke emotional moods in office. Mood creation can use all the qualities of light, but the most effective are color, angle, and movement. Color changes will affect the users perception.[4][5]

2.2.5 Appearance and Comfort:

The way in which the area is lighted can affect the users comfort and appearance of the area.[4][5]

2.2.6 Color Management:

The use of lighting can add to or subtract from the overall colors of a room or from only those surfaces the light is meant to enhance. Darker colors make a room feel smaller and cramped, while light-colored walls do the opposite. The illusion of space is defined by light reflected off of the surfaces of the walls. Some types of lighting help with this illusion by further illuminating the walls. In addition, directional lighting, such as a track light, can soften the wall colors. There is also recessed can lighting, which has a soft, downward glow that illuminates the floors, not walls. This is opposed to lights hung from the center of the room, which provide ambient illumination, or wall lighting. In both cases, this can affect how light or dark a colored section can appear.[6]

2.2.7 Functionality:

One major role of lighting in the interior setting is functionality. Lighting needs to serve a purpose, or it simply wastes electricity. Chandeliers are not only used in large, open foyers, entryways and rooms because of their centrally themed placement but also because they provide excellent illumination for the room. Wall lights add length and size, visually, to an entryway hall, as well as light the way. Consider the style of lighting, it is ensured to get the best directional or luminescent type for the setting. Look into task-specific lighting for desks and other work areas where functionality is more important than overall room illumination.[6]

Apart from this there are some objectives of indoor lighting design as follows:

- Look good!
- Provide the proper amount of light in every room.
- Be built and constructed within budget, code, and other constraints.
- Be environmentally responsible.
- Respond to the Architecture and Interior Design
- Be able to control the lights

2.3 Criteria for Lighting Design:

2.3.1 Average Illuminance:

Illuminance is the quantity of light, or luminous flux, falling on per unit area of a surface. It is designated by the symbol E. The unit is Lux(lx) and is the SI derived unit of Illuminance. One Lux is equal to one lumen per square meter (lm/m^2)[8]. Lighting level produced by a lighting installation on any surface is usually measured in terms of illuminance produced on the specified, plane. In most cases, this plane is the major plane of the tasks in the interior and is commonly called the working plane. The surface may be horizontal, vertical or inclined. The illuminance provided by an installation affects both the performance of the tasks and the appearance of the space.[7]

Average illuminance (E) given by the Lumen Method is given by :

$E = (\phi \times n \times N \times UF \times MF) / A$,

Where,

- ϕ = Initial bare lamp luminous flux (lumens)
- n = Number of lamps per luminaire
- N = Number of luminaires
- UF = Utilisation factor
- MF = Maintenance factor
- A = Area of the surface (m^2)

2.3.2 Illuminance ranges:

The circumstances may be significantly different for different interiors used for the same application or for different conditions for the same kind of activity. Therefore, a range of illuminance is recommended for each type of interior or activity intended, instead of a single value of illuminance. Each range consists of three successive steps of the recommended scale of illuminance. For working interiors, the middle of each range represents the recommended service illuminance that would be used unless one or more of the factors mentioned below apply. The higher value of the range should be used when:

The lower value of the range may be used where reflectance or contrasts are unusually high, Speed and accuracy is not important; and the task is executed only occasionally.

- Unusually low reflectance or contrasts are present in the task,
- Errors are costly to rectify,
- Visual work is critical,
- Accuracy or higher productivity is of great importance and
- The visual capacity of the worker makes it necessary.

The lower value of the range may be used where reflectance or contrasts are unusually high, Speed and accuracy is not important; and the task is executed only occasionally.[7]

2.3.3 Luminance Distribution:

On major room surfaces the distribution of luminance should be regarded as complementary to the design on the illuminance in the interior. It should consider the following aspects: - Luminance of the task and its immediate surroundings; Luminance of ceiling, walls, and floor; - Avoidance of glare by limiting the luminance of luminaires and windows. Luminance Distribution in the Task Area The luminance of the immediate surroundings of the task should, if possible, be lower than the task luminance, preferably not less than l/3 of this, value. This implies that the ratio of the reflectance of the immediate background of a task to that of the task itself should preferably be in the range 0.3 to 0.5.[7]

2.3.4 Restriction of Glare:

General Glare may be caused by lamps, luminaires, and windows (direct glare) or by the reflection of bright sources from surface with high reflectance (reflected glare). In interior lighting, discomfort glare from lamps and luminaires is likely to be more of a problem than disability glare.

Restriction of direct glare: Direct glare is deemed to be adequately restricted, if the mean luminance of the luminaires in the critical glare range 45° < Y < 85°, where Y is the ratio of horizontal distance from the viewer and luminaire to the vertical distance between observer's eye and the foremost luminaire. The stepped scales of the glare rating G are based on the following interpretation of observer's impressions: 0 = No glare, 2 = Perceptible, 4 = Uncomfortable and 6 = Intolerable glare.[7]

2.3.5 Shadows and Modeling:

The appearance of interiors is improved when their structural features, the objects and people within them are lighted. The shapes are revealed clearly and pleasingly and shadows are formed without confusion. This occurs when the light flows noticeably more in one direction than in any other. The term modeling is used to describe the way in which the shapes of three-dimensional objects are revealed by lighting. Requirements for revealing shape and texture for some specific types of task may be special and experiments may be necessary in these cases to establish the best solution.[7]

2.3.6 Color Appearance and Color Rendering Index of Lamps:

This can be provided by additional luminaires placed at a small distance from the visual task, which illuminate only a limited area. In industrial cases, this is often referred to as supplementary lighting. The color of light emitted by a 'near white' source can be indicated by its correlated color temperature (CCT). Each lamp type has a specific correlated color temperature, but for practical use the correlated color temperatures have been grouped into three classes. The choice of appropriate apparent color of light source in a room is largely determined by the function of the room. This may involve such psychological aspects of the color as the impression given of warmth, relaxation, clarity, etc., and more mundane considerations such as 'the need to have a color appearance compatible with daylight and yet to provide a white color at night. Unlike the CCT, the CRI refers to how a light source renders the colors of other objects and surfaces. The CRI can reach a maximum value of 100, which means the light source in question has the same color-rendering capability as natural daylight. Color rendering is increasingly distorted as the CRI becomes lower, and there is no lower limit: negative CRI values indicate extremely poor light sources that completely distort color perception. The color rendering groups of the various lamps to be used for lighting of interiors are described in Fig 2.1 below. The CIE 1931 x, y chromaticity space, also showing the chromaticity of black-body light sources of various temperatures (Planckian locus), and lines of constant correlated color temperature is indicated in Fig 2.2.[7]

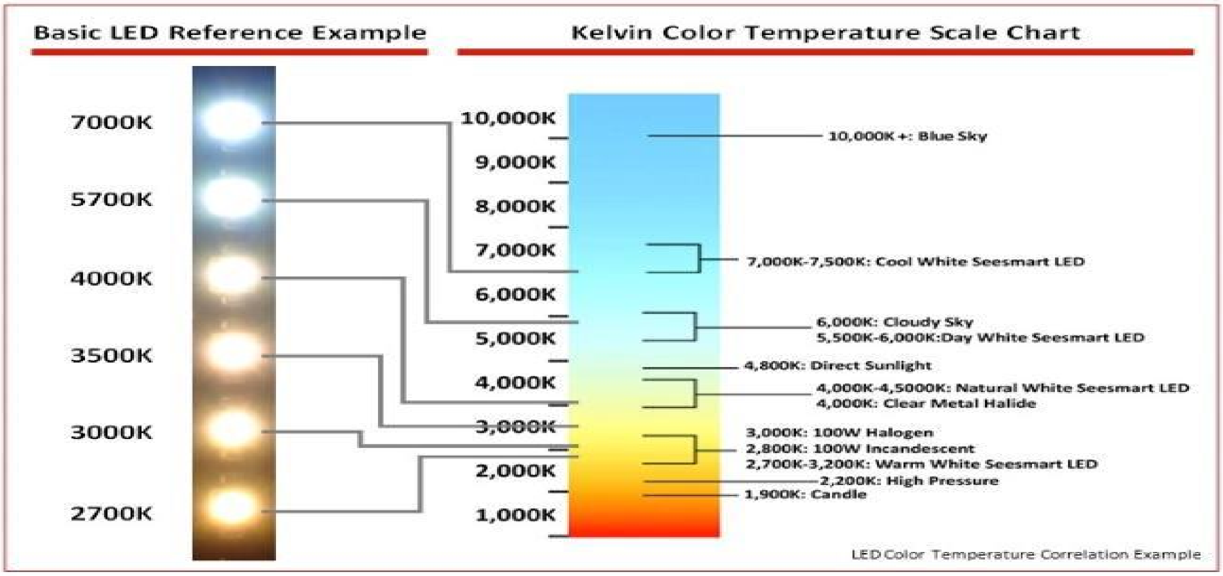


Fig 2.1: Co-related Color Temperature for LED

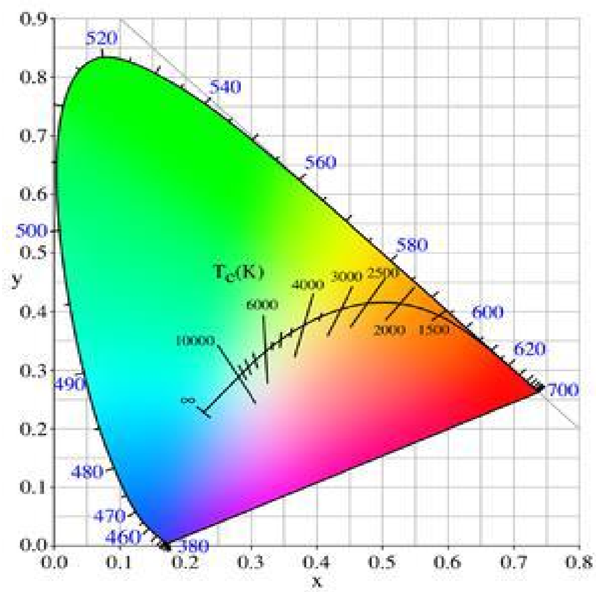


Fig 2.2: CIE 1931 x, y Chromaticity Space

Table 2.1: Correlated Color Temperature & Color Rendering Index

Type of Lamp	CCT (K)	CRI
General Lighting Service lamp	2500-2700	100
Tungsten Halogen Lamp	2700-3200	100
Florescent Tube Light	3000-6500	60-90
Compact Fluorescent Lamp	2700-6500	>80
High Pressure Mercury Vapor Lamp	3200-3900	40-50
Quartz tube Metal Halide Lamp	3000-5000	60-90
Ceramic tube Metal Halide Lamp	3000-4400	78-93
SOX (Low Pressure sodium vapor lamp)	2100	19
SON (High Pressure sodium vapor lamp)	1900-2500	40
Induction Lamp	2500-4000	80
Light Emitting Diode	2700-6500	>70

2.4 Fundamentals of Indoor Lighting Design:

The following design ideas should generally be considered when designing a lighting solution for indoor applications:[8]

- Whether the luminaires will be installed in a safe or hazardous area.
- The necessary illumination level for the tasks to be performed in the area.
- The working plane level at which the required illuminance level is to be achieved.
- Types of lamp and luminaire to be utilized and their lumen output.
- Available mounting height.
- Uniformity of illumination to be bring out.
- The color rendering requirement for the task to be performed in the area.
- Total electrical energy used
- Cut back of Light Pollution.

2.4.1 Closed v/s Open Areas:

The amount of protection necessary for the luminaires against factors such as weather, corrosion and water or dust ingress depends on whether the luminaires is installed in indoors or outdoors. It is not justified to use indoor luminaires where there are no side walls but only a roof at the installation. Nevertheless, the reflectance factors of the luminaires can play a key role in improving illuminance (Lux) levels.[8]

2.4.2 Working Plane Height:

The working plane in a reading area or assembly shop is generally at desk level (750 to 900 mm from floor level) whereas, on a corridor or in a sports field, it may be at floor level.[8]

2.4.3 Mounting Height:

The mounting height of the lamps dictates the illuminance on the working plane. Indoor lighting is contrived by the cavity above the mounting height, (the ceiling cavity) and below the working plane, as well as by the walls surrounding the work area as shown in Fig 2.3.[8]

Fig 2.3: Working plane and Mounting Heights

2.4.4 Reflectance Factors:

Reflectance can be categorized into three types – Light, Medium and Dark. The average value of these factors for ceiling, walls and floor can be obtained from the following Table 2.2[8]

Table 2.2: The average value of the reflectance for ceiling, wall and floor

Surface reflectance	Light	Med	Dark
Ceiling cavity	0.70	0.50	0.30
Walls	0.50	0.30	0.10
Floor cavity	0.30	0.20	0.10

2.4.5 Coefficient of Utilization:

This is the ratio of the luminous flux which gains by the working plane to the total flux emitted by the mounted lamps, taking into account the floor and ceiling cavities, as well as reflectance. In a closed room, CoU (Coefficient of Utilization) is depends on the room's internal dimensions (length, width and luminaire mounting height) and is governed by the formula:

$$\textbf{Room Index} = \frac{\textbf{Length} \times \textbf{Width}}{\textbf{Mounting Height} \times (\textbf{Length} + \textbf{Width})}$$

CoU factors are provided by luminaire manufacturers for each type of luminaire with different room specification and reflectance factors and are used in the lighting calculations to determine the number of luminaires required.[8]

2.4.6 Maintenance / Depreciation Factor:

Luminaire depreciation factor relates to the depreciation in the amount of light output of the luminaire as it ages and as a result of dirt accumulation, degradation of materials etc. The lamp output also degrades gradually with age because of factors such as filament evaporation. This is mentioned to as the lamp depreciation factor. The maintenance factor (MF) can also be supposed to cater for reduced light output by the luminaires or lamps. A MF of 0.7 – 0.8 is commonly assumed in the design calculations where data on the maintenance plan or the luminaire or lamp type to be used is not available.[8]

2.5 Lamps:

The list of sources of artificial light, that emit light and sources that generates wavelengths from about 390 to 700 nanometers, i.e. visible light. These are appended below:

2.5.1 Incandescent lamp:

It is an electric lamp with a wire filament warmed up until it glows. The filament is circumscribed in a bulb to protect the filament from oxidation. Current is provided to the filament by terminals or wires embedded in the glass. A bulb socket provides mechanical holding up and electrical connections. They require no external regulating instrument, have low manufacturing costs, and work equally well on either alternating current or direct current. As a result, the incandescent bulb as shown in Fig 2.4 was extensively used previously in household and commercial lighting such as table lamps, car headlamps, and flashlights, and for decorative and advertising lighting. Incandescent bulbs are much in-efficient than other types of electric lighting, converting less than 5% of the energy they use into visible light. The remaining energy is lost as heat [9].

Fig 2.4: Incandescent lamp

2.5.2 Halogen lamp:

Halogen Lamp also familiar as a tungsten halogen lamp as shown in Fig 2.5 is an incandescent lamp consisting of a tungsten filament sealed into a compact transparent envelope that is filled with a mixture of an inert gas and a small amount of a halogen such as iodine or bromine. The combination of the halogen gas and the tungsten filament generates a halogen cycle chemical reaction which re-deposits evaporated tungsten to the filament, increasing its life and maintaining the clarity of the envelope. This allows the filament to work at a higher temperature than a standard incandescent lamp of similar power and operating life; this also produces light with higher luminous efficacy and color temperature [9].

Fig 2.5: Halogen Lamp

2.5.3 Fluorescent Tube Lamp (FTL):

Fluorescent lamps are familiar as gaseous discharge lamps which produce light by discharging an electric arc through a tube filled with low pressure argon gas and mercury atoms. Few of the electrons in the arc collide with electrons in mercury atoms. Outcome of this, mercury electrons get knocked out of orbit and jump to a higher energy level and immediately return to the normal orbit by giving up the absorbed energy. The initial emission is in ultraviolet range and hence are invisible to the human eye. The ultraviolet light in turn interacts with special blends of phosphors coating in the interior surface of the fluorescent lamp tube that efficiently converts the invisible light into desired white light.[9]

Fig 2.6: T5, T8 and T12 Fluorescent Tube Lamp

2.5.3.1 Classification:

Fluorescent Tube Lamps are available in different structure as shown in the Fig 2.6. The letter "T" indicates tubular shape and is followed by a number that expresses the diameter in eights of an inch.

2.5.3.1.1 T12 Fluorescent Tubes:

The earliest fluorescent lamps have the largest diameter of 12/8 inches. They are quite inefficient related to T5 and T8 lamps and lasts up-to 8,000 hours Fig 2.6.[9]

2.5.3.1.2 T8 Fluorescent Tubes:

These second-generation fluorescent lamps have equivalently smaller diameter of 1 inch. They are one of the most popular conventional lamps and are also energy efficient compared to T12 lamps, lasting up to 15,000 hours, and even longer in some cases. They are commonly available in 4 Feet lengths of 36W giving an output of around 2500 lumens Fig 2.6.[9]

2.5.3.1.3 T5 Fluorescent Tubes:

These third-generation lamps having the smallest diameter of 5/8 inch are the most energy efficient and typically last up to 20,000 hours. This is the first linear lamp type to be of serviced to only by electronic ballasts. They have attractively high efficacy of around 90 to 100 lumens per watt. The CRI of the T5 lamps can be drawn up from 70 to the mid 90s. Generally, 28W 4 Feet tubes are available produce about 2500 Lumens Fig 2.6.[9]

2.5.4 Compact Fluorescent Lamp (CFL):

A CFL can be seen as an modernised version of a fluorescent lamp that usually have premium phosphors and the ballasts may be attached directly to the lamp, or may be remotely connected. The principle of operation in a CFL bulb remains alike as in other fluorescent lighting: electrons that are bound to mercury atoms are excited to states where they emit ultraviolet light as they return to a lower energy level; this emitted ultraviolet light is transformed into visible light as it strikes the fluorescent coating on the bulb. They last from 8,000 to 12,000 hours and are available in many wattages of 9W, 10W, 11W, 13W, 18W, 20W, 26W, 36W, 40W and 55W. [9]

2.5.4.1 Non-Integrated CFL:

Non-integrated CFLs have the ballast installed out of lamp, generally in the luminaire and usually only the fluorescent tube is changed at its end of life. These ballasts are last much longer than the integrated ones. Types of non-integrated lamps are as follows:

2.5.4.1.1 Bi-pin tube :

It can be casted of with both magnetic and electronic ballasts but are not dimmable Fig 2.7.[9]

2.5.4.1.2 Quad-pin tube:

It is mainly paired with electronic ballasts and can be dimmable Fig 2.8. [9]

Fig 2.7: Bi-pin tube CFL Lamp

Fig 2.8: Quad-pin tube CFL Lamp

2.5.4.2 Integrated/Retrofit CFL :

Integrated lamps incorporate the tube and ballast in a single unit. This helps in easy replacement of incandescent lamps with CFLs Fig 2.9.[9]

Fig 2.9: Integrated CFL lamp showing the position of Ballast inside

2.5.5 Ballasts:

There are two types of ballasts for operate with the fluorescent lamp: electromagnetic and electronic.

2.5.5.1 Electromagnetic Ballast:

The mass electromagnetic ballasts are current limiting transformers as shown in Fig 2.10. In this ballast, coils of varnished copper magnet wire are wound on a core of transformer grade steel. Power requirement for these ballasts is approximately 15 to 25 percent of the rated lamp power which is dissipated as heat. They are main cause for both the generation and limitation of harmonic current.[9]

Fig 2.10: Electromagnetic Ballast

2.5.5.2 Electronic Ballast:

Electronic ballasts as shown in Fig 2.11 employ an oscillator circuit to produce frequencies in the 20 to 40 kHz range. Fluorescent lamps favours operation at higher frequency. The internal power losses are much lower compared to an electromagnetic ballast.[9]

Fig. 2.11: Electronic Ballast

2.5.6 LED Light Source:

Light-Emitting Diodes (LED) light sources use diodes that emit light when connected in a circuit. The outcome is a form of electro luminescence where LEDs release a large number of photons. LEDs made of p and n regions with a junction between them just like a regular diode. When sufficient voltage is given to the semi-conductor chip, electrons can move easily across the junction where they are immediately attracted to the positive forces in the p region. When an electron moves sufficiently near to a positive charge in the p region, the two charges “re-combine”. When an electron combines with a positive ion, the electric potential energy gets changed to electromagnetic energy and this results in emission of a photon of light. This photon has a frequency determined by the property of the semiconductor material (usually a combination of the chemical elements gallium, arsenic, and phosphorus). LEDs that emit dissimilar colors are made of different semiconductor materials.[9]

2.5.6.1 Advantages of LEDS:

- They have higher efficacy, over 100 lumens per watt.
- Energy loss through heat is lower in LEDs as contrast to the conventional sources.
- They have a very longer life, around 50000 hours.
- LEDs are eco-friendly as they do not have any Lead or Mercury.
- LEDs can be controlled very simply. Dimming is possible for 0.1 % to 100% without variations the lamp Co-related Color Temperature (CCT) and Color Rendering Index (CRI).
- LED chips are small in size and hence luminaires of any shape and size can be made.
- LEDs emit light in a specified direction, thus reducing the need for reflectors.
- LEDs reach full brightness immediately with no re-striking delay.

2.5.6.2 White LEDS:

A LED unable to emit white light naturally. However, use of some technologies makes an LED to emit white light. There are two main ways of producing White LEDs (WLEDs), which are:

2.5.6.2.1 Wavelength Conversion:

In this method of wavelength conversion, an LED which generates blue color radiation is used to excite a yellow color phosphor (Yttrium Aluminium Garnet) as shown in Fig 2.12 and Fig 2.13. This results in the emission of yellow and blue light and this results mixture of blue and yellow light gives the appearance of white light. The efficacy of this type of LED is higher than RGB but has comparatively cool color temperature.[9]

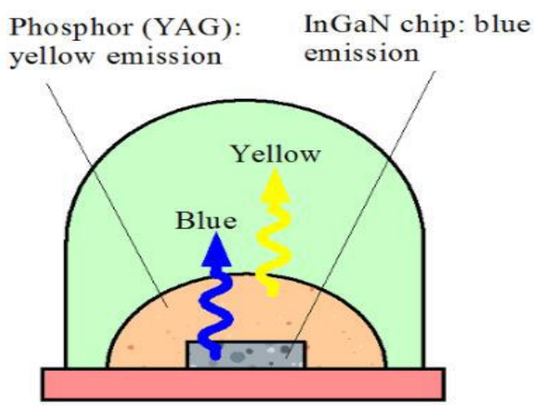


Fig 2.12: White LED using Wavelength Conversion.

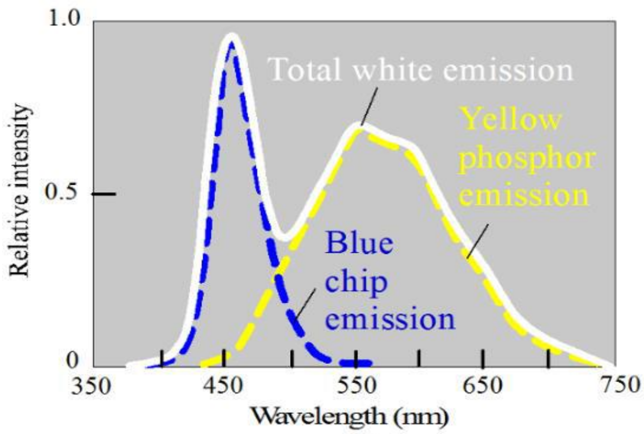


Fig 2.13: SPD of phosphor coated Blue LED

2.5.6.2.2 Color Mixing:

LEDs emitting the primary colors red, blue and green are merged inside a lamp and the intensity of every LED is tuned proportionately to obtain white light as shown in Fig 2.14 and Fig 2.15. This method has many uses because of the flexibility of mixing different colors and thus color temperature of the white light can be tuned easily.[9]

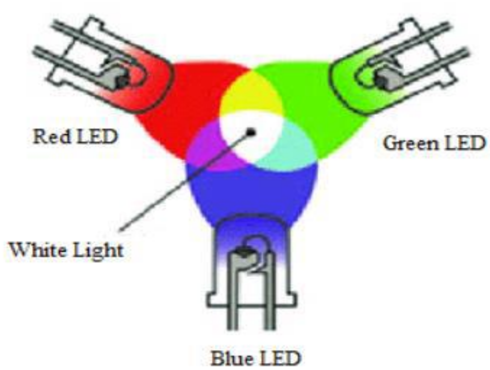


Fig 2.14: Mixing of RGB to Produce White Light.

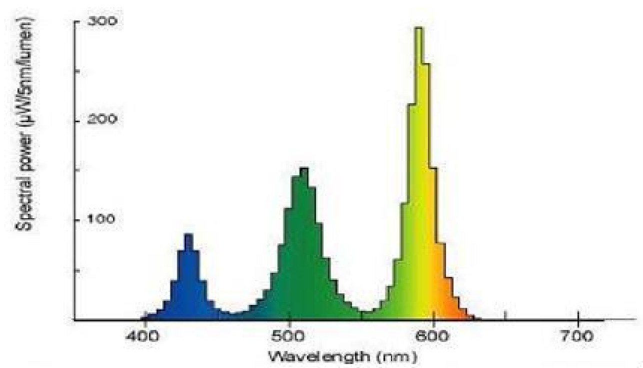


Fig 2.15: Spectral Power Distribution (SPD) of white light of an RGB LED

2.5.6.2.3 LED Driver:

LEDs require drivers for two purposes:

- LEDs are made to run on low voltage (12-24V), direct current. However, most places supply higher voltage (120-277V), alternating current electricity. An LED driver changes higher voltage, alternating current to low voltage, direct current.
- LED drivers, shown in Fig. 2.12, also give protection LEDs from voltage or current fluctuations. A change in voltage could cause a change in the current being given to the LEDs. LED light output is co-related to its current supply and LEDs are rated to operate within a certain current range (measured in amps). Therefore, too much or too little current can cause light output to change or degrade faster due to higher temperatures within the LED.

2.5.6.2.3.1 Constant Current Type:

The characteristic of constant current drive is that the output current is same. The output voltage is varied in one range Fig 2.16.[9]

Fig 2.16: Constant Current Driver

2.5.6.2.3.2 Constant Voltage Type:

Power LEDs that need a fixed output voltage with a maximum output current. In these LEDs, the current is already controlled, either by simple resistors or an internal constant-current driver, within the LED module. These LEDs need one stable voltage, usually 12V DC or 24V DC Fig 2.17.[9]

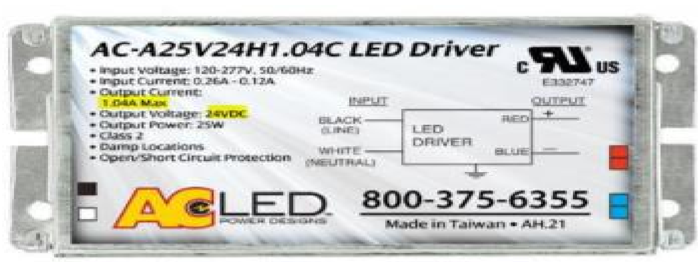


Fig 2.17: Constant Voltage Driver

2.5.6.3 Benefits of LED Lighting for Educational Classroom:

LED lighting products are known for performance, energy efficiency, and long-term savings. The benefits of LED lighting in educational classroom however are not limited to that. It has been proven that installing high quality LED lights create healthy work environment and increases employee productivity.

A recent study by NASA revealed that LED lighting suppresses melatonin, which leads to better management of circadian rhythms in the human body. LED Lights have the capability of imitating sunlight. Which has a positive impact on human behavioral and biological processes. Students are happier and more productive when exposed to natural-looking light. This directly decreases the risk of sleep disorders such as insomnia and sleep deprivation. While this is major health benefit generated by LED lights, there are many others that are pushing its demand in educational establishments.

The benefits of LED lighting in offices or business places are very exciting and noteworthy. Since innovation is happening at a rapid pace and new LED technologies are emerging very frequently, the most popular benefits of using adequate LED lighting in educational classroom are appended [10] below:

2.5.6.3.1 LED lighting improves classroom productivity:

Proper lighting is crucial for classroom productivity and often influences students perception, mood, and performance. Studies have proven that harsh and inadequate lighting decreases everyday productivity. By opting LED lights which mimic natural light and have higher CRI, business owners all over the world are improving productivity among pupil and create the perfect classroom environment. This is probably the biggest benefit of using LED lighting in classroom.[10]

2.5.6.3.2 LED lighting regulates circadian rhythm:

Circadian rhythms are part of our biological process that influences physiological process. Lighting is a big influencer of circadian rhythms, but traditional lighting products were not designed keeping them in mind. Thankfully, modern LED lighting products are.

In educational classroom, circadian lighting as shown in Fig 2.18 plays an important role in pupil productivity and health. Modern LED lights are designed with circadian rhyme in mind whereas old incandescent bulbs weren't. A study found that Office workers exposed to circadian lighting performed 10 to 25%better than their counterparts.[10]

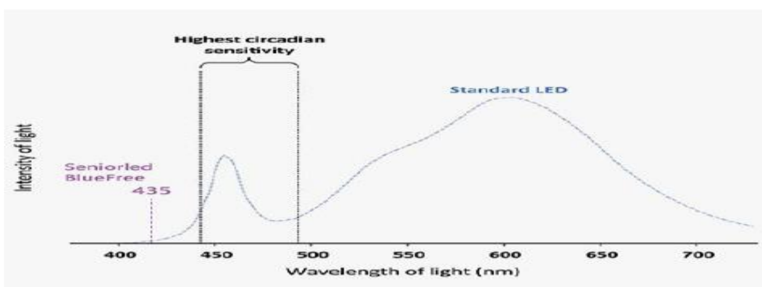


Fig 2.18: Circadian Lighting

2.5.6.3.3 LED lights are energy efficient:

With power costs rising all over the world, power saving LED lights are a boon for corporate offices and commercial spaces. In comparison to incandescent or old traditional lights, LED saves about 70% of energy [10], resulting in substantial savings in the long run. In offices or workplaces where lighting is required around the clock, LED lights have even bigger benefits.

Power efficiency is the major reasons why businesses and commercial centers are making provision of using LED lighting in new projects and undertaking LED upgrade in old ones.. LEDs provide quality lighting with 75% less energy usage than conventional lighting systems.

2.5.6.3.4 LED products have longer lifespan:

Quality LEDs have an expected lifespan of 50,000 hours or longer. While a typical incandescent bulb lasts only about 1,000 hours, a compact fluorescent lamp lasts for about 8,000 to 10,000 hours [10]. Low lifespan after to the replacement and maintenance cost for commercial establishments.

With a longer operational life, LED lighting products eliminate the need of frequent replacement in offices and workplaces, thus achieving a low maintenance lighting system.

2.5.6.3.5 LED lighting produces lesser heat:

Unlike incandescent bulbs, LED lights have low operating temperature and hence do not generate a lot of heat like their counterparts. The heat generated from lighting units come together to influence temperature in the office space.

Traditional lighting due their heat generating nature often pushes the air conditioners to work harder which makes them consume more energy. LED lighting products check such wastage and reduce the power bills as well.[10]

2.5.6.3.6 LED lighting means no bugs:

It is widely known fact that bugs and insects can be avoided if LED lighting is deployed in classroom. This is because LED lighting products emit very little heat from their lighting source which reduces their appeal to moths and bugs. Old incandescent lights on the other hand are bug magnets because of the heat and UV rays they dispense. This is the reason why schools go for modern LED lighting rather than old traditional lighting products.[10]

2.5.6.3.7 LED lighting is eco-friendly:

The carbon emission of LED light is 514 lbs of CO_2 per year which is much lower in comparison to carbon emissions of incandescent bulbs. Higher the carbon emission, greater the harm lighting unit is doing to the environment.

The demand of LED lights is increasing steadily amongst environment conscious businesses because of their low emission carbon footprint. This amazing feature of LED lighting should score the highest in the benefits of LED lighting in offices.[10]

2.5.6.3.8 LED lighting create no noise:

Unlike incandescent bulbs, LED lights do not produce any noise even after being used for years. Most incandescent lights have the common complaint of buzzing sound during the power shift or fluctuation. In office setting, the buzzing and harsh sound breaks employee concentration and disrupts workflow.

Installing LED lights in office thus will bring the benefit of fewer disruptions and also provide adequate lighting in the workplace.[10]

2.5.6.3.9 LEDs are sturdier:

LEDs are strong lighting devices that use semiconductor material rather than a filament or neon gas. A LED light is a tiny microchip element enclosed in plastic material. This is what makes the LED lighting products stronger than the traditional incandescent lighting bulbs or tubes. The fact that LED lighting products sourced from top quality LED manufacturers can easily bear multiple falls is one of the biggest benefits of LED lighting.[10]

2.5.6.3.10 LED lighting is smart lighting:

Smart lighting (Fig 2.19) continues to gain popularity due to its amazing features like scheduling, dimming and wireless control. The ability to remotely control the lighting and influence the atmosphere of offices with a single click is the major benefit of smart lighting. Smart lighting also eases the burden of school administration staff and simplifies management for them.[10]

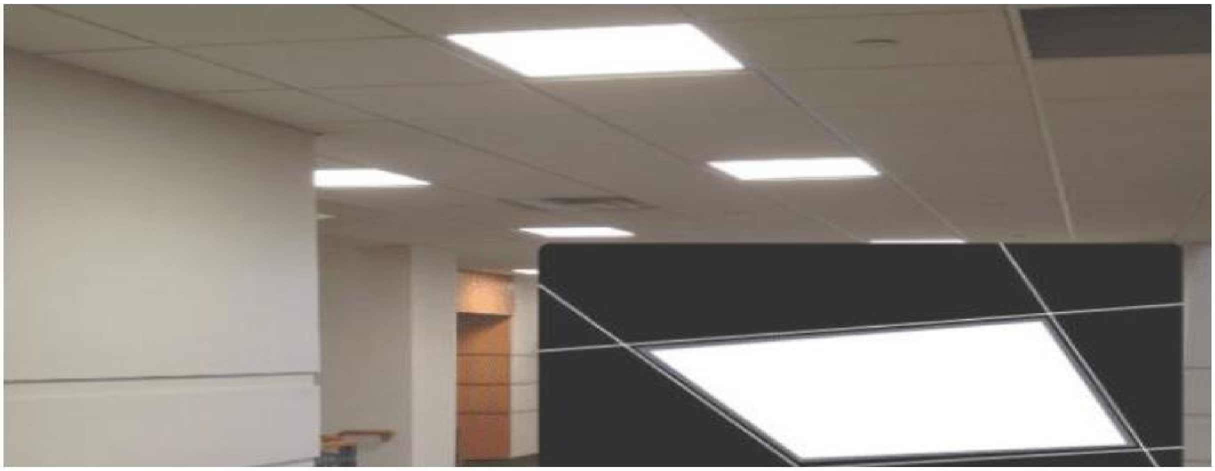


Fig 2.19: Smart Lighting Design

2.5.6.3.11 LED lighting products are safe for environment:

pupils safety is one of the top priorities in educational spaces, and there is nothing more secure than modern LED lighting. LED light has no mercury and gives away very less heat. The ultraviolet rays produced by LED light are negligible as compared to incandescent light bulbs.

Such health benefits are popularizing the usage of LED lighting in shopping centres, IT companies, commercial areas, supermarkets, hospitals, schools, colleges, government offices, etc.[10]

2.5.6.3.12 Operational in extreme weather conditions:

For LED lighting products are ideal for operating efficiently in cold and low temperature settings. Unlike other fluorescent lamps, they do not product dim lighting in extremely cold temperatures and deliver a superior lighting experience. Another benefit of LED lighting is that they do not require warm up time and provide instant light on switching ON. That is why LED lighting products are gaining more acceptance and popularity in colder regions.[10]

2.5.6.3.13 LEDs work on low voltage:

Unlike traditional incandescent lights, LEDs work on low voltage. This feature allows offices & workplaces with LED lighting to work even in low or dim power supply conditions. While incandescent bulbs could get damaged during low power supply, LED lighting does not get fused while working on low voltage supply.

The benefits of LED lighting in offices or business places are very exciting and noteworthy. Since innovation is happening at a rapid pace and new LED technologies are emerging very frequently, the demand of LED lights is increasing at higher pace.[10]

2.5.6.3.14 Benefit of Indirect Lighting:

Indirect lighting occurs when fixtures project light upwards towards the ceiling or the walls. It bounces off to illuminate the whole area with even light. Direct light causes headaches and eye strain. Indirect light eliminates glare which affects worker productivity. It also creates a calm and comfortable working environment for employees. Indirect lighting can be achieved by mounting LED office lights on walls or the ceiling. The best is LED flat panel lights.[10]

2.5.6.3.15 Faster warm up and switching times:

There are various options of choosing different colors or styles of bulb to fit with specific fixtures and preferences. No infrared (IR) radiation, no ultraviolet (UV) rays Can withstand impact and vibrations, inherently digital for ease of control.[10]

2.5.6.3.16 Wide Options of Color Temperature:

Choosing the right color temperature for office impacts the mood and behaviour of workers. LED office lights come in a wide range of color temperatures. The appropriate color temperatures for an office setting are neutral to cool white, between 3500K and 5000K. Temperatures below 3500K are too yellow and will result in low pupil productivity.[10]

2.5.6.3.17 Excellent Color Rendering Index (CRI):

The color rendering index shows how a light source causes objects to appear compared to natural light. It is a scale from 0-100. A CRI of 85 and above is considered good. LED office lights have a high CRI of 80 and above. In offices, it is imperative to see objects as they would naturally appear. Fluorescent lights make the environment look dull.[10]

2.5.6.3.18 Lighting Control:

When selecting office lighting, lighting controls can be integrated. Workers spend most of the day at their desks or designated workstations. This means there are areas within the office that do not require constant lighting. For example, in break rooms, stores, and restrooms, the amount of light can be controlled with motion sensors. In personal offices, dimmer switches can control the lighting levels.

Some LED drivers have dimming abilities and can dim LED office lights from 100% output to 0%. This does not affect the lifespan or efficiency of the lamps, as is the case with fluorescent lamps. Photo sensors detect the natural light and signal to the fixtures to reduce or increase the light.[10]

2.6 Different Areas of School Building:

The school plant includes the material conditions such as the school building, furniture, playgrounds, hostels, classrooms, school libraries, apparatus and equipment’s etc. These are the components of the school plant which are helpful in realizing the aims and objectives of education. Proper functioning of the school plant depends upon the quality and adequacy of the components of the school.[11]

The major components of a schools are as follows:

2.6.1 Class-rooms:

Class-rooms are the major component of the schools. There should have a classroom for each section of students and there should be as many classrooms as there are sections in different classes in secondary schools. The classrooms should provide sitting arrangement to accommodate 40 to 50 students with adequate space for students and teachers to sit, stand and move freely for using maps, charts, pictures etc. The classroom should be ideal and a workable one according to the present need. The size of a classroom depends upon the number of students in the class.

The class-room should have a pleasant look. The rooms should be tastefully decorated and the walls should be painted with some light color. Each classroom should have essential equipment of desk and chairs for the pupils, wall black-board, a chair and a table for the teacher and a map stand. Besides, a dais for teacher's use, an almirah for books, attendance register, chalks, duster should be there in each class-room. Bulletin board, water basin, dust-bin, door-mat, table cloth etc. may be among non-essential equipment to decorate the classroom.

Here should be adequate lighting arrangement in each classroom. The rooms should have sufficient number of sources in the form of doors, ventilators and windows for admitting light from outside. The light should come in only from the left so that no shadow is cast by the pen or the pencil when the child is working at his desk. For this purpose, the seating arrangement should also be cared for. For altering intensity of light according to need, suitable curtains and screens should be provided for the windows and doors.

Proper ventilation of the classrooms is just as important as adequate lighting. The classroom should have sufficient number of doors, windows and ventilators to admit light and air from outside. The size and number of the windows should be decided on the basis of the size of the room. Ceiling fans should be fitted in the classroom which helps in solving the problems of over-perspiration, draught and suffocation in summer and rainy seasons. Fig 2.20

Fig 2.20: A Typical Classroom

2.6.2 Subject Rooms:

Besides the class-rooms, the school plant should have accommodation for teaching of some specific subjects like Science, Mathematics, Geography, Drawing, Crafts, Music, Home Science etc. In the modern school system, where the new teaching devices like project teaching, individualized instruction, laboratory work, discussion and debate, audio-visual instruction etc. are followed, it is not desirable to provide a general classroom which is meant for teaching subjects for general nature.

The subject-rooms helps economizing time, energy, when the equipment, apparatus and other teaching aids are not moved from one end of school to another. So the schools which provide for the teaching of different practical subjects must have different special rooms for the purpose. Fig 2.21

Fig 2.21: A Typical Subject room

2.6.3 Library Room:

Library should find a dominating position in the centre of the academic life of the school. It is the most important facility in the school and it improves academic life of a school. Today it is considered to the most powerful media to promote self-education, to acquire information and to provide research facilities.

Every school building should have a separate wing for library and reading room. Where resources permit, reading room should be separated from the library hall. The library room should be "attractive, colorful and inviting." It should be well decorated, so as to present a homely look. It should be centrally located so that it may be easily accessible to pupils.

The library room should be provided with adequate natural light and ventilation with satisfactory window shades and provision for needed artificial light. The furniture, book shelves, tables, chairs, reading desks should be carefully designed with an eye to artistic effect as well as functional efficiency. It should be well-equipped with nicely selected books and literature, which should be easily approachable and accessible to one and all. It should be kept neat and clean.

The library should create a conductive reading atmosphere to encourage students to read general books. It should provide useful social experiences. Therefore, the school should have a library with a full-time librarian to stimulate learning. So library should be an intellectual hub in school with a qualified librarian. Fig 2.22

Fig 2.22: A Typical Library

2.6.4 Headmaster's Room:

In a secondary school, there should be a room for the headmaster. Site for this room should be carefully chosen. It should be situated at some prominent place where the headmaster's presence may be felt strongly. It should be easily accessible to visitors, teachers and pupils. So the room should be a spacious one, so that whenever need of calling a meeting arises, the whole staff may be seated there.

This room should be constructed with attached bathroom, lavatory and retiring room etc. It should be near the school office and staff room, so that a proper-co-ordination may be kept among these components. So the headmaster's room should be attractive one to impress the outsiders, the parents those who are coming to his office frequently. Fig 2.23

Fig 2.23: A Head Master Room

2.6.5 The School Office:

The school office is the controlling place for the working of the effective organization of the total school program. So it should be centrally located to serve as a good coordinating centre for the school. It should be as near to the Headmaster's office as far as possible. There school office should be provided with necessary equipment such as type-writer, duplicators, rubber stamps, almirah etc. This room should have adequate arrangement of the drinking water and attached bath-room and lavatory. The store-rooms of the school also be quite adjacent to the school office. Fig 2.24

Fig 2.24: A Typical School Office

2.6.6 The Staff-room:

There should be a common room for the teachers in a secondary school. This staff room is meant for the teachers to meet each other, to work together or individually. In this room teachers can rest in their vacant periods. This may be a waiting place for teachers in between working periods. It should be spacious enough to accommodate the whole teaching staff of the school. It should be situated at such a place where there is least disturbance of the classes and also should not have much distance from the headmaster's office.

The staff-room should have cup-boards in the wall, where the teachers may keep their class notes, examination papers and other things safe. Besides being equipped with cup-boards, there should be study tables and chairs and some comfortable easy chairs in the staff room. There should be adequate arrangement of drinking water. It should have attached bath-room-cum lavatory. Adequate care should be taken for its proper flooring and decoration. Fig 2.25

Fig 2.25: A Typical School Staff Office

2.6.7 School Laboratories:

Every secondary school must possess well-equipped and well-planned laboratories for teaching science subjects. The size of this room should be more spacious to accommodate all the laboratory equipment's. It should also have one or two attached rooms used as stores. The service connections for gas, electricity and water are to be provided in the wall of this room.

This arrangement will facilitate to use movable tables in one position for classwork and in another for laboratory. Built in cup-boards for storing the chemicals in a laboratory should be provided. There should be adequate provision for the individual shelf for the students for keeping their apparatus and belongings. Proper care should be taken for the adequate lighting and attention. Fig 2.26

Fig 2.26: A Typical School Laboratories

2.6.8 The School Hall:

Every school should have a big hall where assembly of the whole school may be possible. Here all the pupils assemble for general meetings, dramatics, lectures, exhibition and many other school activities for all the students whenever required by the headmaster. It should be located on the ground floor ensuring easy access to the pupils, teachers and the public.

It must be situated in an isolated wing of the school building to ensure safety from crowds and for reduced sound interference. The school hall can be used as multipurpose room as an auditorium, as gymnasium, refreshment room, the audio-visual room.

The hall should be properly furnished and well-decorated. It should have a suitable stage, a dais, mike and fans (including exhaust fans). There should be a permanent arrangement of seats and furniture. There should be adequate arrangements for lights and ventilation. The walls of the hall should be properly white-washed or painted and it should possess photo or pictures of great men, charts, paintings and sceneries etc. Sometimes, it can be used as a place for community centre. Fig 2.27

Fig 2.27: A Typical School Hall

2.6.9 The School Play-grounds:

Play ground is said to be the cradle of democracy. Games and sports are the essential parts of the total education. So every school should essentially have a due provision for the playgrounds. Play grounds are needed for all types of physical activities, sports and games, regular physical exercises etc.

Therefore, enough area should be occupied for the playgrounds in order to provide maximum number of games to the students. Due care should be taken for the maintenance of these grounds. A boundary wall should be constructed around them and there should also be provision for shady trees, grassy lawns in the play grounds. Fig 2.28

Fig 2.28: A Typical School Playground

2.6.10 The School Hostel:

The school hostel is an important component of the school plant. It is an important institution, where pupils develop their personality by learning punctuality, discipline, citizenship, regularity in works and leadership habits. The hostel should be in the school compound at a sufficient distance from the school. If possible, it should be behind the school building with playing fields and garden between.

The design of the hostel building will depend on the site available, on local circumstances, and on the amount of money available. The best type of building is the single-storey one. It should be built in the form of a quadrangle with a court-yard in the middle, hi this type of hostel building, there should be a superintendent's quarter at the gateway on one side with an office and a reading and study room on the other side.

This will form the front of the quadrangle with the main gateway in the middle. The other three sides will then be divided into dormitories. There should be an almirah for each pupil. Each pupil should have a chair and a table. Care should be taken to see that lighting arrangements are good, especially in study and reading rooms. There should be plenty of windows and skylights for proper ventilation.

The school hostel must be housed in a proper building with good sanitary arrangements. The kitchen and dining room may be placed at the back, outside the quadrangle. There should be provision for septic tank latrines at the back of the quadrangle. Care should be taken to see that arrangements for supply of waters are satisfactory both for washing of dishes and latrines. For this purpose, proper drainage should be constructed in such a manner that water is carried away. Fig 2.29

Fig 2.29: A Typical School Hostel

Chapter-3

Classroom Design Consideration

3.1 Codes & Standards for Classroom Lighting:

3.1.1 IS 3646 (Part 1): 1992 (Code of Practice for Interior Illumination):

The primary object of this code is to indicate the factors which should be considered to achieve good lighting. This code (Part 1) covers the principles and practice governing good lighting in buildings and relates to the lighting of working areas in industrial, commercial and public buildings, hospitals and schools keeping two objects in mind, namely, to make the task easy to see and to create a good visual environment.[7]

Because circumstances may be significantly different for different interiors used for the same application or for different conditions for the same kind of activity, a range of illuminance is recommended for each type of interior or activity intended of a single value of illuminance. Each range consists of three successive steps of the recommended scale of illuminance. For working interiors, the middle value of each range represents the recommended service illuminance that would be used unless one or more of the factors mentioned below apply.

The higher value of the range should be used when:

- Unusually low reflectance or contrasts are present in the task;
- Errors are costly to rectify,
- Visual work is critical,
- Accuracy or higher productivity is of great importance and
- the visual capacity of the worker makes it necessary

The lower value of the range may be used where reflectance or contrasts are unusually high, speed and accuracy are not important and the task is executed only occasionally.

Table 3.1 gives the recommended illuminance ranges for different tasks and activities. The values are related to the visual requirements of the task, to user's satisfaction, to practical experience and to the need for cost effective use of energy. The values in the table are service values, which are obtained as an average during the maintenance cycle. They apply to the average illuminance at the reference surface/working plane.

Table 3.1: Recommended Illuminance

IS 3646 (Part 1) : 1992

Table 1 (*continued*)

Type of Interior or Activity	Range of Service Illuminance in Lux	Quality Class of Direct Glare Limitation	Remarks
20.7.2 Light sensitive exhibits, for example, oil and temper paints, undyed leather, bone, ivory, wood, etc	150	—	This is a maximum illuminance to be provided on the principal plane of the exhibit
20.7.3 Extremely light sensitive exhibits, for example, textiles, water colours, prints and drawings, skins, botanical specimens, etc	50	—	This is the maximum illuminance to be provided on the principal plane of the object
20.7.4 Conservation studies and workshops	300-500-750	1	
20.8 Sports Facilities			
Multi-purpose sports halls	300-750	—	This lighting system should be sufficiently flexible to provide lighting suitable for the variety of sports and activities that take place in sports halls. Higher illuminance of 1 000-2 000 lux would be required for television coverage
21 EDUCATION			
21.1 Assembly Halls			
21.1.1 General	200-300-500	3	
22.1.2 Platform and stage	—	—	Special lighting to provide emphasis and to facilitate the use of the platform/stage is desirable
21.2 Teaching Spaces General	200-300-500	1	
21.3 Lecture Theatres			
21.3.1 General	200-300-500	1	
21.3.2 Demonstration benches	300-500-750	1	Localized lighting may be appropriate
21.4 Seminar Rooms	300-500-750	1	
21.5 Art Rooms	300-500-750	1	
21.6 Needlework Rooms	300-500-750	1	
21.7 Laboratories	300-500-750	1	
21.8 Libraries	200-300-500	1	
21.9 Music Rooms	200-300-500	1	
21.10 Sports Halls	200-300-500	1	
21.11 Workshops	200-300-500	1	
22 TRANSPORT			
22.1 Airports			
22.1.1 Ticket counters, checking desks, and information desks	300-500-750	2	Localized lighting may be appropriate
22.1.2 Departure lounges, other waiting areas	150-200-300	2	
22.1.3 Baggage reclaim	150-200-300	2	
22.1.4 Baggage handling	50-100-150	2	
22.1.5 Customs and immigration halls	300-500-750	2	
22.1.6 Concourse	150-200-300	2	
22.2 Railway Stations			
22.2.1 Ticket office	300-500-750	2	Localized lighting over the counter may be appropriate
22.2.2 Information office	300-500-750	2	Localized lighting over the counter may be appropriate

20

3.1.2 Energy Conservation Building Code 2017:

The **Energy Conservation Building Code** (**ECBC**), was launched by Ministry of Power, Government of India in May 2007, as a first step towards promoting energy efficiency in the building sector. The ECBC was developed by an Expert Committee, set up by India's Bureau of Energy Efficiency, with support and guidance from United States Agency for International Development (USAID). [12]

3.1.2.1 Building Area Method:

Determination of interior lighting power allowance (watts) by the building area method (Table 3.2) shall be in accordance with the determination of the allowed lighting power density for each appropriate building area type from Table.

- Calculation of the gross lighted carpet area for each building area type.
- The interior lighting power allowance is the sum of the products of the gross lighted floor area of each building area times the allowed lighting power density for that building area type.

Table 3.2: Interior Lighting Power-Building Area Method

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

3.1.2.2 Space Function Method:

Determination of interior lighting power allowance (watts) by the space function method (Table 3.3) shall be in accordance with the following:

- Determination of the appropriate building type and the allowed lighting power density from Table. In cases where both a common space type and building specific space type are listed, building specific space type LPD shall apply.
- For each space, enclosed by partitions 80% or greater than ceiling height, determination of the gross carpet area by measuring to the face of the partition wall. The area of

balconies or other projections is also to be included. Retail spaces do not have to comply with the 80% partition height requirements.

- The interior lighting power allowance is the sum of the lighting power allowances for all spaces. The lighting power allowance for a space is the product of the gross lighted carpet area of the space times the allowed lighting power density for that space.

Table 3.3: Interior Lighting Power-Space Function Method

Space Function	LPD (W/m^2)	Space Function	LPD (W/m^2)
Office-enclosed	11.8	• For Reading Area	12.9
Office-open plan	11.8	Hospital	
Conference/Meeting/Multipurpose	14.0	• For Emergency	29.1
Classroom/Lecture/Training	15.1	• For Recovery	8.6
Lobby*	14.0	• For Nurse Station	10.8
• For Hotel	11.8	• For Exam Treatment	16.1
• For Performing Arts Theater	35.5	• For Pharmacy	12.9
• For Motion Picture Theater	11.8	• For Patient Room	7.5
Audience/Seating Area*	9.7	• For Operating Room	23.7
• For Gymnasium	4.3	• For Nursery	6.5
• For Convention Center	7.5	• For Medical Supply	15.1
• For Religious Buildings	18.3	• For Physical Therapy	9.7
• For Sports Arena	4.3	• For Radiology	4.3
• For Performing Arts Theater	28.0	• For Laundry – Washing	6.5
• For Motion Picture Theater	12.9	Automotive – Service Repair	7.5
• For Transportation	5.4	Manufacturing Facility	
Atrium-first three floors	6.5	• For Low Bay (<8m ceiling)	12.9
Atrium-each additional floor	2.2	• For High Bay (>8m ceiling)	18.3
Lounge/Recreation*	12.9	• For Detailed Manufacturing	22.6
• For Hospital	8.6	• For Equipment Room	12.9
Dining Area*	9.7	• For Control Room	5.4
• For Hotel	14.0	Hotel/Motel Guest Rooms	11.8
• For Motel	12.9	Dormitory – Living Quarters	11.8
• For Bar Lounge/Leisure Dining	15.1	Museum	
• For Family Dining	22.6	• For General Exhibition	10.8
• Food Preparation	12.9	• For Restoration	18.3
Laboratory	15.1	Bank Office – Banking Activity Area	16.1
Restrooms	9.7	Retail	
Dressing/Locker/Fitting Room	6.5	• For Sales Area	18.3
Corridor/Transition*	5.4	• For Mall Concourse	18.3
• For Hospital	10.8	Sports Arena	
• For Manufacturing Facility	5.4	• For Ring Sports Area	29.1
Stairs-active	6.5	• For Court Sports Area	24.8
Active Storage*	8.6	• For Indoor Field Area	15.1
• For Hospital	9.7	Warehouse	
Inactive Storage*	3.2	• For Fine Material Storage	15.1
• For Museum	8.6	• For Medium/Bulky Material Storage	9.7
Electrical/Mechanical Facility	16.1	Parking Garage – Garage Area	2.2
Workshop	20.5	Transportation	
Convention Center – Exhibit Space	14.0	• For Airport – Concourse	6.5
Library		• For Air/Train/Bus – Baggage Area	10.8
• For Card File & Cataloging	11.8	• For Ticket Counter Terminal	16.1
• For Stacks	18.3		

3.1.3 National Lighting Code 2010:

This code covers the principles and practices governing good lighting of schools. It recommends the levels of illumination [13] to be achieved by general principles of lighting.

The provision made for lighting will depend on the type of classroom, for example, general classroom, study room, library, etc. and the subdivision of the floor space. Where the layout of partitioning is unknown or subject to alteration, provision should be made for a flexible installation that will allow luminaires to be placed in proper relation to any arrangement of partitioning. This flexibility may be achieved by either:

- providing fixed outlets on a modular system enough in number to ensure that luminaires can be located satisfactorily irrespective of how the interior is partitioned; or
- by using continuous lines of trouncing or lighting track along which luminaires can be located as required.

The following table gives recommended Illumination level & Glare index of different premises of schools according to NLC 2010.

Table 3.4: Illumination Value & Glare Index as per NLC 2010 for Educational Premises

Areas	*Illumination (lux)*	*Glare Index*
a) Classrooms	300	16
b) Lecture rooms (including) Demonstration areas)	300	16
c) Reading rooms	150 to 300	19
d) Laboratories	300	16
e) Corridors	70	—
f) Libraries	300	16
g) Auditorium		
i) Hall	70	—
ii) Foyer	70	—
iii) Stage area	300	16
h) Gymnasiums	150	—
j) Cafeterias	100	—
k) Staff Rooms	150	—

3.1.4 BSEN 12464-1:2021:

This document specifies lighting requirements for humans in indoor work places, which meet the needs for visual comfort and performance of people having normal, or corrected to normal ophthalmic (visual) capacity. All usual visual tasks are considered, including Display Screen Equipment (DSE).

This document specifies requirements for lighting solutions for most indoor work places and their associated areas in terms of quantity and quality of illumination. In addition, recommendations are given for good lighting practice including visual and non-visual (non-image forming) lighting needs. This document does not specify lighting requirements with respect to the safety and health of people at work and has not been prepared in the field of application of Article 169 of Treaty on the Functioning of the European Union although the lighting requirements, as specified in this document, usually fulfil safety needs.[14]

Table 3.5: UGR limits for Educational Premises

UGR limits for interior areas, tasks and activities		
BSEN12464 table	Type of area, task or activity (no. of sub-divisions)	Maximum UGR
5.35	Educational premises – Nursery school, play school (3)	19-22
5.36	Educational premises – Educational buildings (26)	16-25

3.1.5 IESNA Lighting Handbook-10th Edition:

The Illuminating Engineering Society produces The Lighting Handbook to guide and give authoritative recommendation to those who design, specify, install, and maintain lighting system, and as an impartial source of information to public. Like previous edition, the Lighting Handbook contains a mix of science, technology, and design; mirroring the nature of light itself.

From IESNA Lighting Handbook vertical & horizontal recommended illumination level for different age group and for different areas of schools can be obtained.[15]

Table 3.6: Vertical & Horizontal Illuminance as per IESNA for classroom

		Recommended Maintained Illuminance Targets (lux)[b, c, d]									
		Horizontal (E_h) Targets					Vertical (E_v) Targets				
			Visual Ages of Observers (years) where at least half are					Visual Ages of Observers (years) where at least half are			
Applications and Tasks[a]	Notes	Category	<25	25-65	>65	Gauge	Category	<25	25-65	>65	Gauge
• General Classrooms											
• Learning/teaching	Interactive experience										
• AV (dedicated AV viewing)	E_h @2' 6"; E_v @4' AFF	K	25	50	100	Avg	I	15	30	60	Avg
• Chalkboard							Q	200	400	800	Avg
• Dedicated VDT screens	CSA/ISO Type I and II negative polarity screens.[i] E_h @2' 6"; E_v @4' AFF	N	75	150	300	Avg	K	25	50	100	Avg
• Hardcopy and writing	Variety of paper tasks.[i] E_h @2' 6"; E_v @4' AFF	Q	200	400	800	Avg	N	75	150	300	Avg
• Handwritten Work	Based on fair-to-good penmanship/hand print on white or canary paper										
• Pencil											
• Graphite/HB	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg
• Red	E_h @2' 6" AFF; E_v @4' AFF[k]	R	250	500	1000	Avg	M	50	100	200	Avg
• Ballpoint/Rollerpoint/Felt-tip											
• Black	E_h @2' 6" AFF; E_v @4' AFF[k]	P	150	300	600	Avg	L	37.5	75	150	Avg
• Red, Green, Blue	E_h @2' 6" AFF; E_v @4' AFF[k]	Q	200	400	800	Avg	L	37.5	75	150	Avg

3.2 Types of Ceiling:

3.2.1 True Ceiling:

Ceiling which can't be cut and hence surface mounted or suspended luminaires are used is known as True Ceiling as shown in Fig 3.1. [16]

Fig 3.1: True Ceiling

3.2.2 False Ceiling:

A false Ceiling adds lot of value to look & feel of the home. It allows arrangement for direct light & indirect light. A false ceiling conceals all the wires, water pipes and air conditioning ducts running along the roof thus maintaining aesthetics. Various types of False Ceilings are shown in Fig 3.2 to Fig 3.5. [16]

Fig 3.2: Grid Ceiling

Fig 3.3: Techzone Ceiling

Fig 3.4: POP Ceiling

Fig 3.5: Gypsum Ceiling

3.3 Types of Luminaire:

Different types of luminaires are needed for classroom lighting, their selection depending on the nature of the building, the kind of visual activity performed, room dimensions, daylight incidence and interior decoration and furnishings. Various types of light fixtures are available which distribute light in different ways. They are as follows:

3.3.1 Direct Luminaire:

This type of luminaire project 90 to 100 percent of their light down towards the work area. Direct lighting tends to create shadows and glare. [Fig 3.6 & 3.7] [16]

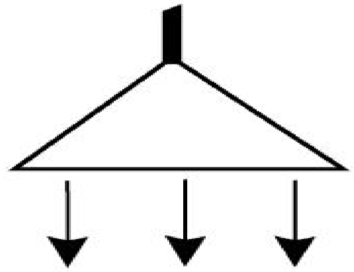


Fig 3.6: Direct Light Fixture

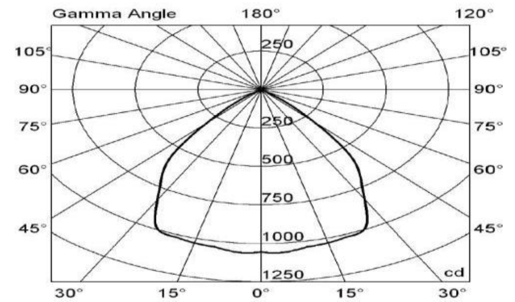


Fig 3.7: Light Distribution Curve (LDC) for direct light fixture

3.3.2 Direct-Indirect Luminaire:

These luminaire distribute light upward and as well as downward. They reflect light off the ceiling and also emit towards the work plane. Less light is emitted downwards and hence direct glare is reduced. [Fig 3.8 & 3.9] [16]

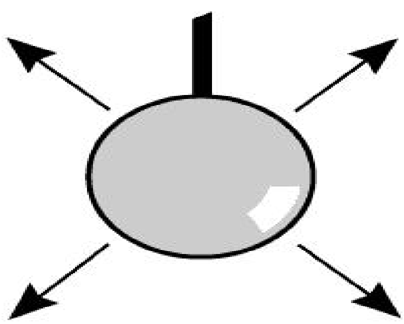


Fig 3.8: Direct-Indirect Light Fixture

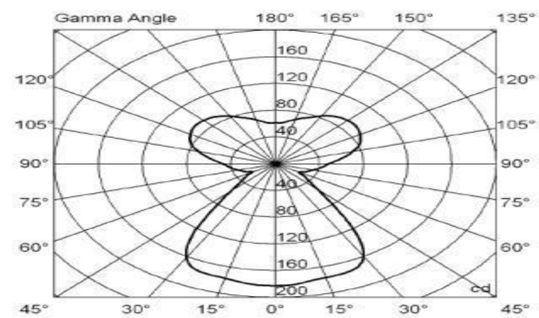


Fig 3.9: Light Distribution Curve (LDC) for direct-indirect light fixture

3.3.3 Indirect Luminaire:

Indirect luminaire distribute 90 to 100 percent of the light upward. The ceiling and upper walls must be clean and have high reflectance to allow the light to reach the work area. Of all the types of fixtures, these luminaire provide the most even illumination and the least direct glare. [Fig 3.10 & 3.11] [16]

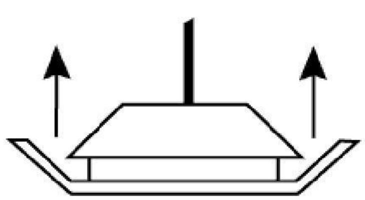


Fig 3.10: Indirect Light Fixture

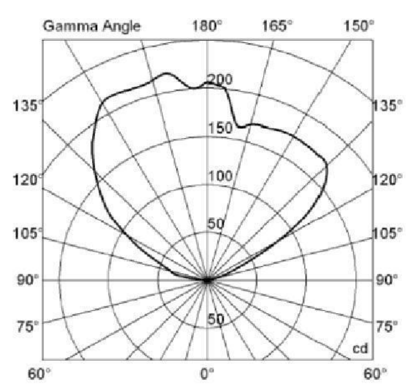


Fig 3.11: Light Distribution Curve (LDC) for indirect light fixture

Types of lighting can also be classified based on how the area is illuminated. This classification is as given below:.

3.3.4 General Lighting:

Uniform lighting throughout the room creating roughly the same visual conditions at all points. This is recommended where the arrangement of task areas is unknown during the planning phase or where the arrangement of task areas needs to be flexible. [Fig 3.12] [16]

Fig 3.12: Room related lighting

3.3.5 Task Area Lighting:

Different lighting for task areas and the space around them. This is recommended where a room contains several task areas which are used to address different visual tasks and thus have different lighting requirements. It is also an option where visual divisions are needed to identify different workplace clusters. [Fig 3.13] [16]

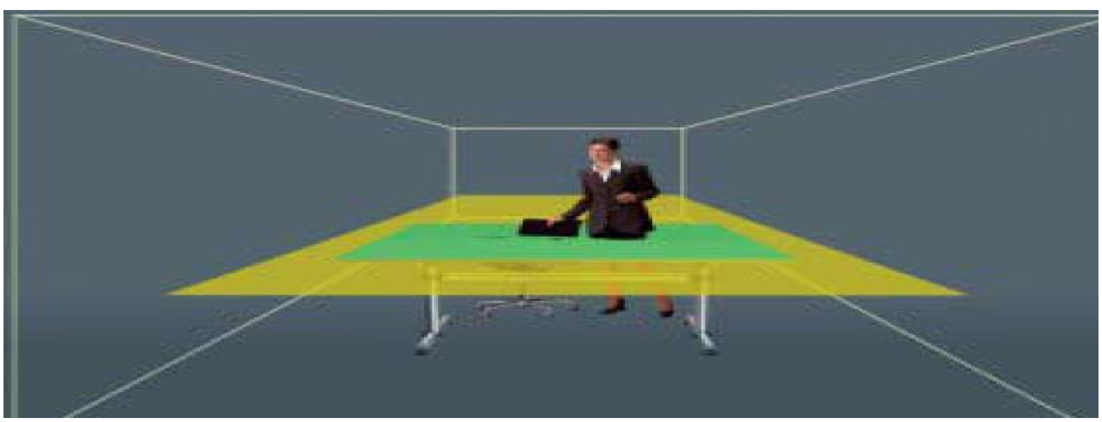


Fig 3.13: Task area lighting

3.3.6 Work Surface Lighting:

Workplace luminaires can be used to supplement "basic lighting" – which can be either room-related or task area lighting – to achieve a level of lighting finely tuned to the requirements of the visual task or personal needs. [Fig 3.14] [16]

Fig 3.14: Work surface lighting

3.4 Types of Sensors:

For any classroom, generally two types of sensors are used: an occupancy or a vacancy sensor and another light/photocell sensor.

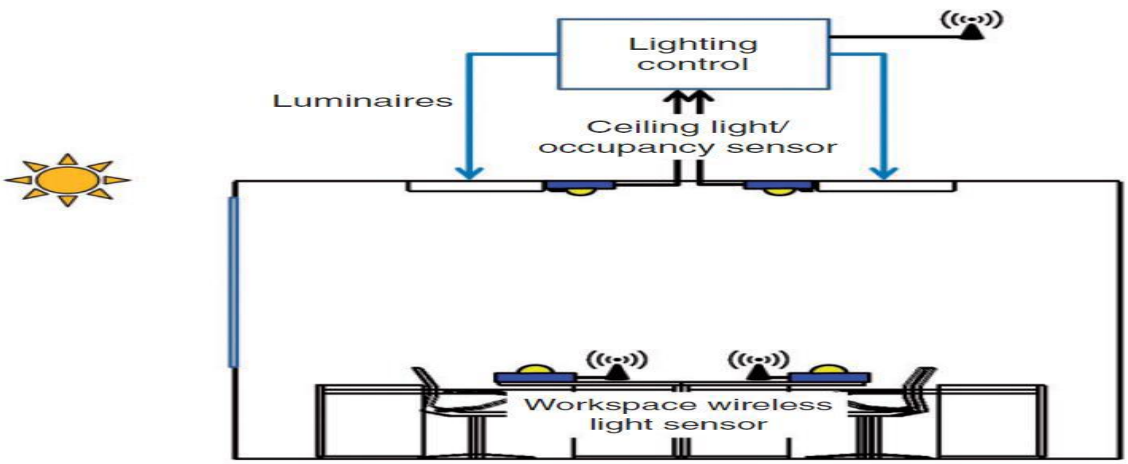


Fig 3.15: Classroom Lighting with Sensor Control

3.4.1 Occupancy Sensor:

An occupancy sensor provides information about the occupancy within its detection range. The occupancy state is a binary value, 0 or 1, determined by the occupancy sensor corresponding to whether there is local un occupancy or occupancy within the sensor field of view. Depending on the occupancy, the sensor sends information to the light controller to turn the light on or off. Occupancy sensing technology types include: [17]

3.4.1.1 Passive Infrared (PIR):

The PIR sensor senses the presence and motions of occupant by detecting the change of infrared energy emitted from a warm object (human body or vehicle) in motion and the background space. Every PIR sensor is equipped with an optical device, generally a plastic lens with multiple segments called Fresnel lens, to collect the infrared energy emitted by the occupant to the infrared sensing component. The Fresnel lens divides the detection coverage into multiple zones corresponding to the respective segments. PIR sensor requires an unobstructed line-of-sight for effective operation. They are more sensitive to the movements across the detection zones than towards or away from the sensors. In general, the closer the occupant is to the sensor, the better the sensor could detect minor motion. [Fig 3.16] [17]

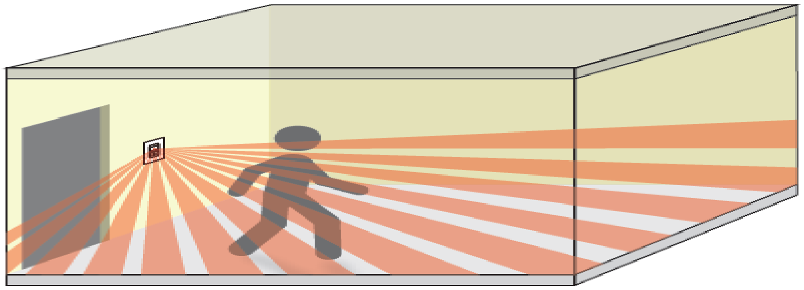


Fig 3.16: Wall mounted PIR sensor

High ambient temperature reduces the sensitivity of PIR sensors which could result in smaller coverage or shorter range. Hence, a discernible temperature difference between the occupant and ambient temperature is required.

3.4.1.2 High Frequency Doppler (HFD):

High Frequency Doppler technology operates on the principle of Doppler Effect. It senses the presence and motions of occupant by detecting the frequency shift bounced back from a moving object. Ultrasonic (US) sensors also operate on the same principle but with ultrasonic sound waves (typically 32KHz– 45KHz) whereas HFD sensors operate with high frequency radio waves (typically 4GHz – 12GHz). Therefore, the HFD sensor does not require openings on the front cover like conventional ultrasonic sensor, which have been considered negative factors for interior decoration, sensor operation, high moisture application, vandalism prevention, and facility management. HFD sensors are better at detecting minor motions (e.g. typing, reading) and do not require an unobstructed line-of-sight placement like PIR sensors, thus making them more suitable for applications such as an office with partitions, a library with cubicles or a restroom with stalls. [Fig 3.17] [17]

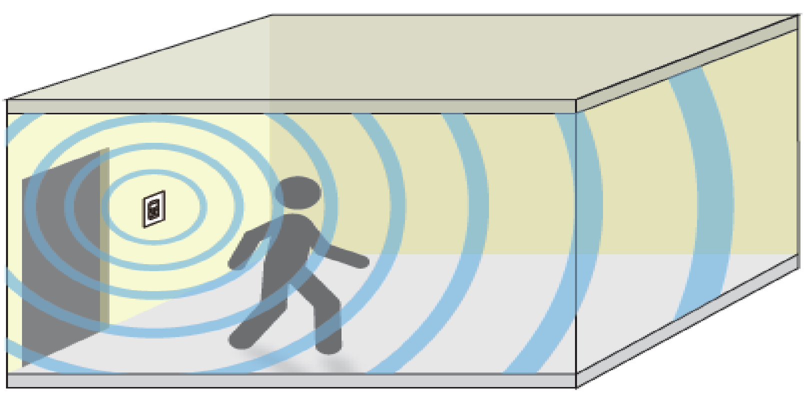


Fig 3.17: Wall mounted PIR sensor

HFD sensors shouldn't be placed facing doors, corridors or exits as they may detect the traffics at adjacent areas. HFD sensors are more sensitive to the movements "toward" than "across" the sensor.

3.4.1.3 Dual Technology (DT):

As no single occupancy sensing technology is perfect, thus dual technology sensors are created for better reliability and performance by utilizing the advantages of each single sensor and advanced processing logic. They not only provide superior sensing performances, but also greatly reduce the possibility of false activating caused by environmental interference. [Fig 3.18] [17]

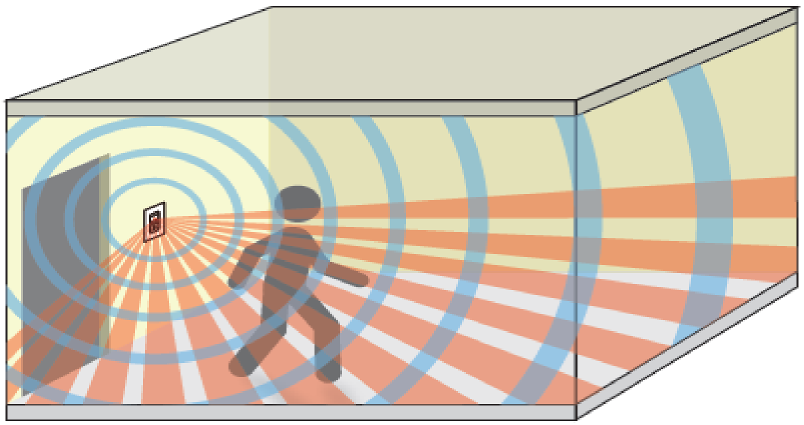


Fig 3.18: Wall mounted DT sensor

3.4.2 Photo Sensor:

A photo sensor is an electronic component that detects the presence of visible light, infrared transmission (IR), and/or ultraviolet (UV) energy. Most photo sensors consist of semiconductors having a property called photoconductivity, in which the electrical conductance varies depending on the intensity of radiation striking the material. Photocell sensor measures either the level of daylight contribution or the overall combined natural and electric light as the key component and then inhibits or dims the controlled lights in one or multiple zones to achieve an optimal lighting level based on pre-determined parameters. [Fig 3.19] [17]

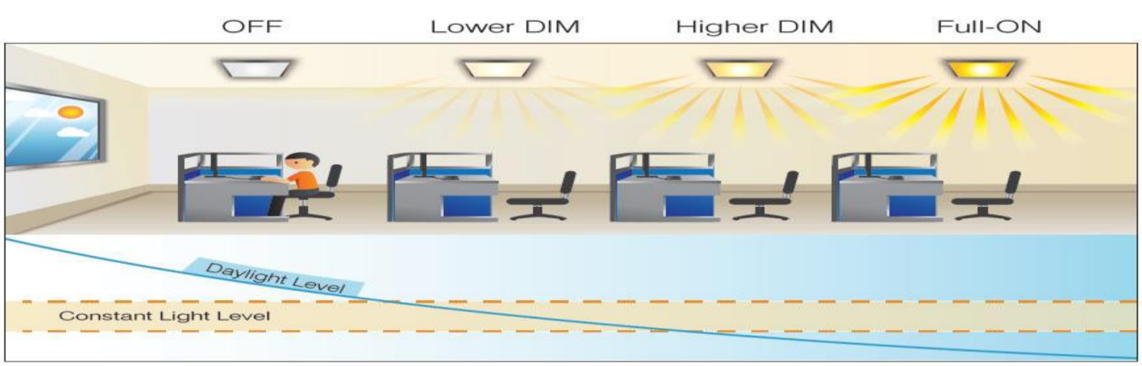


Fig 3.19: Daylight Sensing Control Strategy

3.5 Digital Timers:

A time switch (also called a timer switch, or simply timer) is a timer that operates an electric switch controlled by the timing mechanism.

The switch may be connected to an electric circuit operating from mains power, including via a relay or contactor. It may be built into power circuits (as with a central heating or water heater timer), plugged into a wall outlet with equipment plugged into the timer instead of directly into the power point; or built into equipment.

The timer may switch equipment on, off, or both, at a preset time or times, after a preset interval, or cyclically. A countdown time switch switches power, usually off, after a preset time. A cyclical timer switches equipment both on and off at preset times over a period, then repeats the cycle; the period is usually 24 hours or 7 days.

Timers may do other processing or have sensors; for example, a timer may switch on lights only during hours of darkness, using a seasonal algorithm or light sensor. Combining the two allows a light to come on at sundown and go off at midnight.

The programmable timers (Fig 3.20) allow to set the switch to turn on and off at specific times. They are like some mechanical timers since they can have multiple on/off cycles in a 24-hour period, but they can be scheduled for more than one day. Like a programmable thermostat, a 7-day schedule can be set with the exact on/off times.

There are also **smart digital timers** available that allow users to use Smartphone as a remote-control device to set timers, turn lights on/off, and more. Many can pair with Alexa or Google Home for control.

Time switches can be used for many purposes, including saving electric energy by consuming it only when required, switching equipment on, off, or both at times required by some process, and home security (for example switching lights in a pattern that gives the impression that premises are attended) to reduce the likelihood of burglary or prowling.

Fig 3.20: Hour Electromechanical Time Switch

3.6 Photo Sensor:

A photoelectric sensor, or photo eye, is an equipment used to discover the distance, absence, or presence of an object by using a light transmitter, often infrared, and a photoelectric receiver. A sensor emits a light beam (visible or infrared) from its light-emitting element. A beam of light is emitted from the light emitting element and is received by the light receiving element. A self-contained photoelectric sensor contains the optics, along with the electronics. It requires only a power source. The sensor performs its own modulation, demodulation, amplification, and output switching. Some self-contained sensors provide such options as built-in control timers or counters. Because of technological progress, self-contained photoelectric sensors have become increasingly smaller.

There are three different useful types: opposed (through beam), retro-reflective, and proximity-sensing (diffused).

Reflective Model (Fig 3.21): Both the light emitting and light receiving elements are contained in a single housing. The sensor receives the light reflected from the target

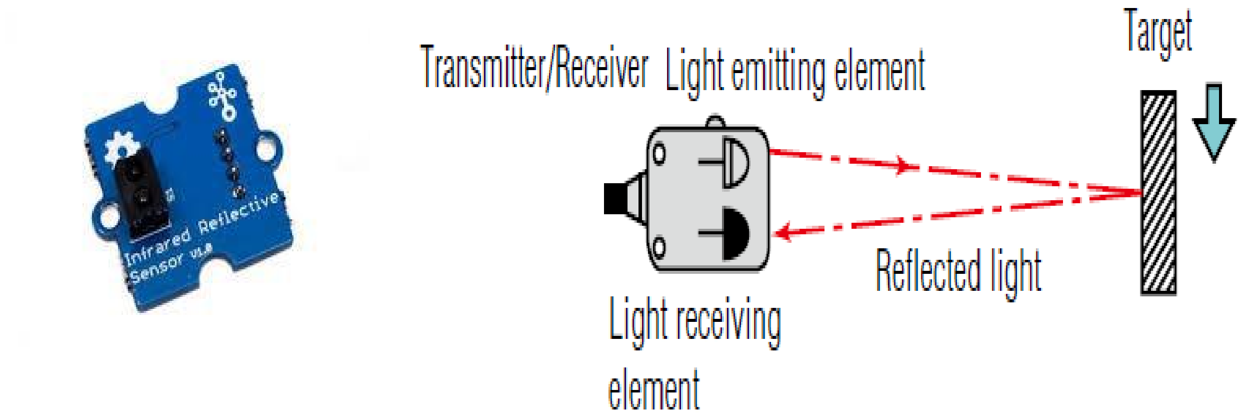


Fig 3.21: Reflective Model Photo Sensor

Opposed (Through beam) model (Fig 3.22): The transmitter and receiver are separated. When the target is between the transmitter and receiver, the light is interrupted.

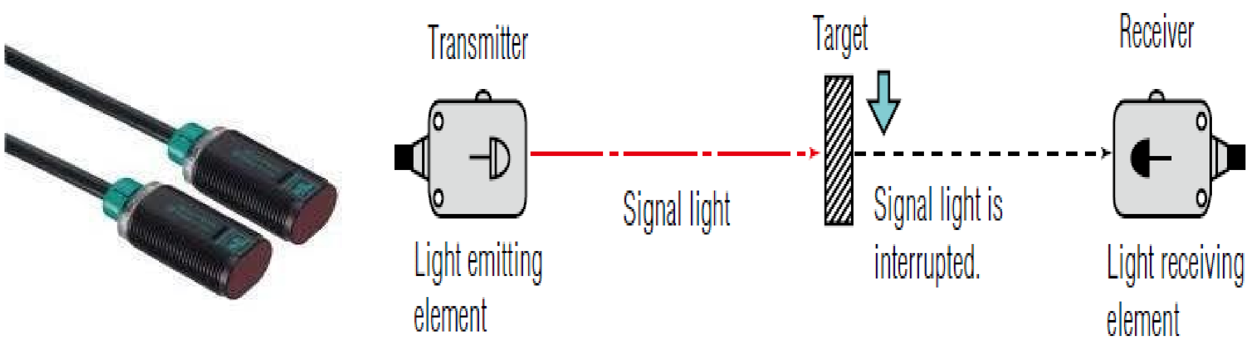


Fig 3.22: Through Model Photo Sensor

A proximity-sensing Diffused (Fig 3.23) arrangement is one in which the transmitted radiation must reflect off the object to reach the receiver. In this mode, an object is detected when the receiver sees the transmitted source rather than when it fails to see it.

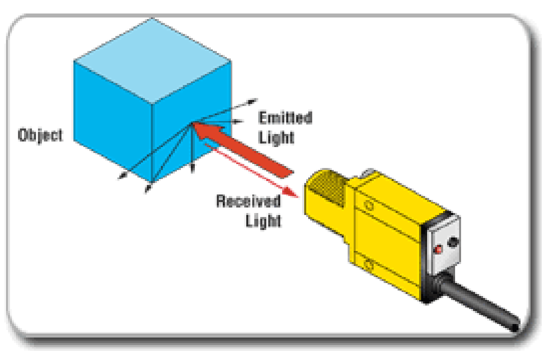


Fig 3.23: Diffused Photo Sensor

As in retro-reflective sensors (Fig 3.24), diffuse sensor emitters and receivers are located in the same housing. But the target acts as the reflector, so that detection of light is reflected off the disturbance object. The emitter sends out a beam of light (most often a pulsed infrared, visible red, or laser) that diffuses in all directions, filling a detection area. The target then enters the area and deflects part of the beam back to the receiver. Detection occurs and output is turned on or off when sufficient light falls on the receiver. [18]

Fig 3.24: Retro Reflective Sensor

3.7 Comparison of photo sensors:

Table 3.7: Comparison of Photo Sensors

Different models	Advantages	Disadvantages
Through-beam	Most accurate, Very reliable Longest sensing range	Must install at two points on system: emitter and receiver
Reflective	Only slightly less accurate than through-beam. Sensing range better than diffuse, Very reliable	Must install at two points on system: sensor and reflector Slightly more costly than diffuse Sensing range less than through-beam
Diffuse	Only install at one point Cost less than through-beam or reflective	Less accurate than through-beam or reflective More setup time involved

3.8 Lighting Design Methodology:

The key steps in the design process are: [19]

- Identification of the requirements.
- Determination of the method of lighting.
- Selection of the lighting equipment.
- Calculation of the lighting parameters and adjust the design as required.
- Determination of the control system.
- Choice of luminaire.
- Inspection of the installation upon completion.

3.8.1 Identification of the requirements:

This involves gaining a full understanding of what the lighting installation is intended to achieve. This includes the following:

- Task requirement: -Illuminance, Glare.
- Mood of the space.

- Relation to shape of space.
- Things to be emphasised.
- Things to hide.
- Direction of light.
- Interaction of daylight.

3.8.2 Determination of the method of lighting:

At this stage, consideration is given to how the light is to be delivered, e.g. will it be recessed, surface mounted, direct or indirect, or will up-lighting be used, and its primary characteristics, e.g. will it be prismatic, low brightness or mellow light. Consideration should be given at this stage to the use of daylight to minimise the need for artificial light.

3.8.3 Selection of the lighting equipment:

Once the method of lighting has been selected, the most appropriate light source can then be chosen followed by the luminaire. The following attributes should be studied when choosing the light source:

- Luminous flux output (lumens)
- Total input wattage
- Luminous Efficacy (lumens per Watt)
- Lifetime
- Physical size
- Surface brightness / glare
- Color characteristics
- Electrical characteristics
- Requirement for control gear
- Compatibility with existing electrical system
- Suitability for the operating environment

Several factors also affect luminaire choice:

- Characteristics of the light source and control gear
- Luminaire efficiency
- Light distribution
- Glare control
- Finish and appearance
- Size
- Accessibility of components for maintenance
- Ability to handle adverse operating conditions
- Aesthetics
- Thermal management

3.8.4 Calculation of the lighting parameters:

Lighting calculation methods fall into three broad categories:

- Manual calculation method
- Three-dimensional modelling
- Visualisation

3.8.4.1 Manual calculation methods:

There are a wide range of manual computation methods for the calculation of different lighting aspects. These include complex methods for calculating the illuminance from a wide variety of shapes of luminous objects. The majority of these have now been superseded by computer programs.

The Lumen Method was the mainstay for interior lighting and has remained in use as a quick and relatively accurate method of calculating interior illuminance. The Lumen Method calculates the average illuminance at a specific level in the space**,** including an allowance for the light reflected from the interior surfaces of the room. The calculation method has a set of assumptions that, if followed, gives a reasonable visual environment. Inadequate attention to the assumptions will produce poor results**.**

The basic assumptions are:

- All the luminaires in the room are the same and have the same orientation.
- The luminaires do not have a directional distribution and are aimed directly to the floor.
- The luminaires are arranged in a uniform array on the ceiling and have the same mounting height.
- The luminaires are spaced less than the maximum spacing to mounting height ratio nominated in the coefficient of utilisation tables.
- The average illuminance produced by a lighting installation, or the number of luminaires required to achieve a specific average illuminance, can be calculated by means of utilization factors (UF), a UF being the ratio of the total flux received by a particular surface to the total lamp flux of the installation.

UF(s) – the utilization factor for the reference surfaces of the chosen luminaire. Utilization factors can be determined for any surface or layout of luminaires. UF(F) is the utilisation factor for the floor cavity and UF(W) is the utilisation factor for the walls.

Utilization factors are, in practice, only calculated for general lighting systems with regular arrays of luminaires and for three main room surfaces. The highest of these surfaces, the C surface (for ceiling cavity)**,** is an imaginary horizontal plane at the level of the luminaires having a reflectance equal to that of the ceiling cavity.

The lowest surface, the F surface (for floor Cavity), is a horizontal plane at normal working height (i.e. table height), which is often assumed to be 0.85 m above the floor**.** The middle surface, the W surface (for walls)**,** consists of all the walls between the C and F planes. Although the lighting designer can calculate utilization factors, lighting companies publish utilization factors for standard conditions for their luminaires. The standard method of presentation is shown below. To use this table, it is only necessary to know the Room Index and the effective reflectance (Fig 3.25) of the three standard surfaces (floor cavity, walls and ceiling cavity).

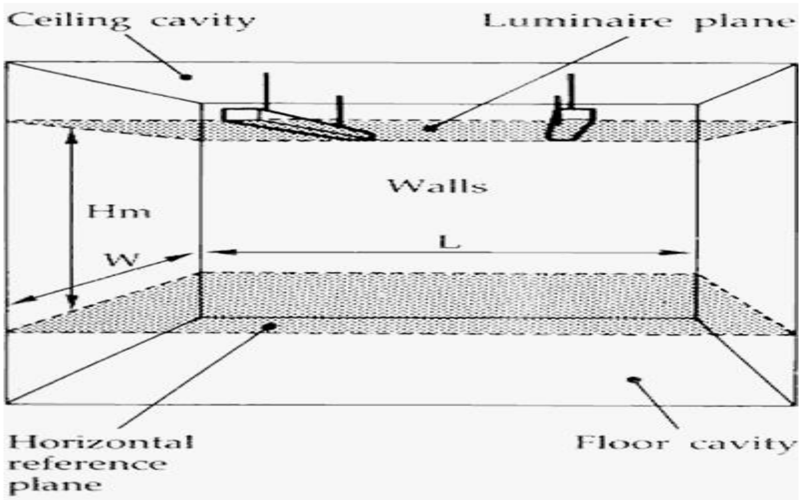


Fig 3.25: Room Index and Effective Room Reflectance

3.8.4.2 Three-dimensional modeling:

Although it was possible to calculate the luminance of all the surfaces in a room, the calculations were extremely laborious and could only be justified in the most special cases. However, the advent of computer modelling (Fig 3.26) enabled a more flexible approach to lighting design and significantly increased the information available to the designer.

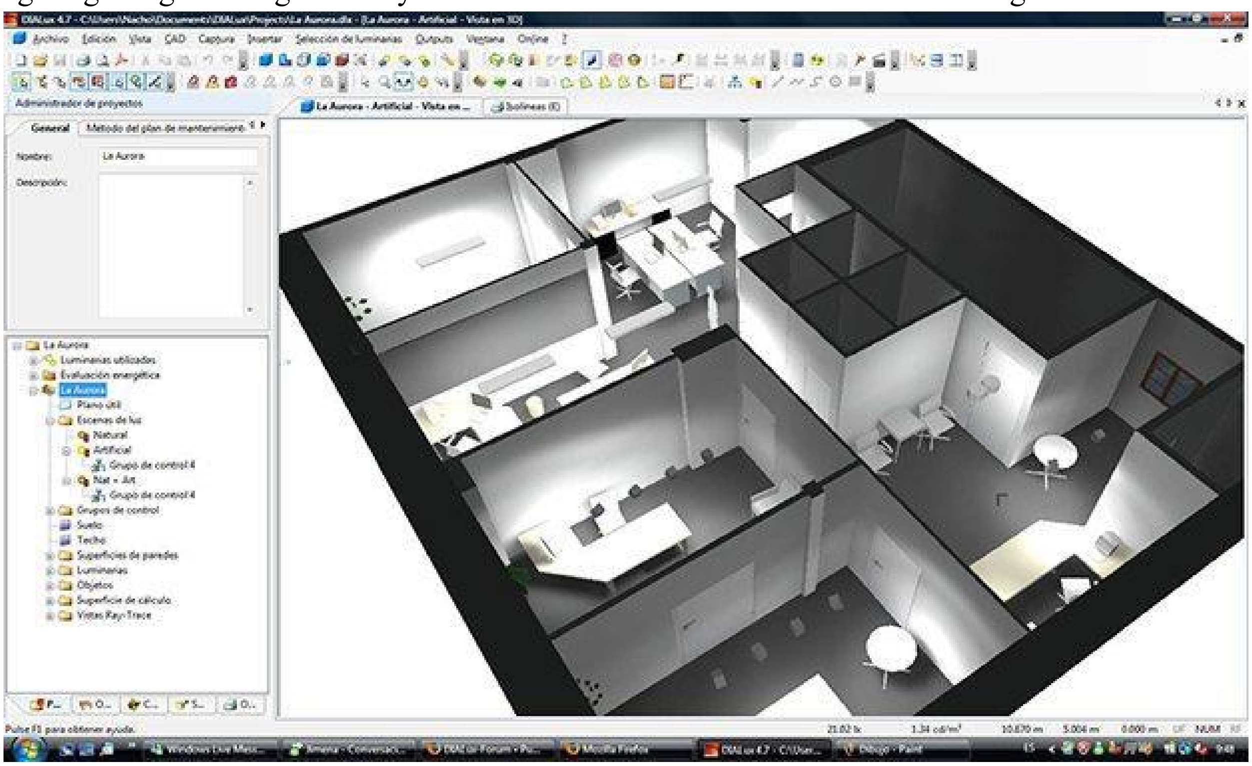


Fig 3.26: DIALux work plane

In contrast to the Lumen Method, lighting programs enable the lighting designer to broaden the assumptions:

- A mixture of luminaires can be used,
- The luminaires no longer must be arranged in a regular array,
- Directional luminaires can be modelled,
- Many calculation points can be considered to give a meaningful uniformity calculation,
- The illuminance and luminance of all surfaces can be calculated.

This gives the lighting designer a much greater understanding of what is happening in the room.

3.8.4.3 Visualization:

These are programs that create a perspective rendering of the space in levels of detail that vary from a block representation of the space, to photographic quality renderings, depending on the sophistication of the program and the level of detail of the interior to be entered.

The programs fall into two basic types:

- Flux transfer or radiosity calculations
- Ray tracing calculations

The major difference being in how they interpret light from reflective surfaces**.**

3.8.5 Determination of the control system:

The effectiveness and efficiency of any lighting installation is affected as much by the control system as by the light sources and fixtures chosen. Various aspects are already discussed in the previous section.

3.8.6 Choice of Luminaire:

The performance of a luminaire should be considered just as carefully as its cost. In the long term a well-designed, well-constructed luminaire will be cheaper than a poor-quality unit; and the salient features of a good quality luminaire are:

- Sound mechanical and electrical construction and a durable finish.
- Adequate screening of high luminance lamps to minimize discomfort and glare.
- Adequate heat dissipation to prevent over-heating of the lamp, wiring and ancillary equipment.
- High light output ratio with the appropriate light distribution.
- Ease of installation, cleaning, and maintenance.

3.9 Softwares Used for the Lighting Design:

Lighting designers use software as a design tool to complement and contribute to the design process, for everything from complex calculations to presentation renderings. In choosing lighting software, it is important to determine the designer's required purpose i.e. whether the software being selected can perform simple calculations, assist in space analysis, or to provide photo-realistic rendering. [20]

Benefit of using lighting design software for any lighting design in indoor areas as compared to mathematical calculation for determination of illuminance level are:-

- Faster time to calculate the illuminance level and uniformity
- Better accuracy
- Able to view 3D and 2D of a room.
- Import luminaires' photometric data sheet.
- Use objects, textures and surface colors.
- Able to view luminaire' layout plan.
- Able to view Isolines of illuminance value.
- Evaluate energy evaluation.

3.9.1 Different Types of Lighting Simulation Softwares:

There are different types of lighting simulation Softwares available as appended below.

Table 3.8: Lighting design Softwares

Sl. No.	Title	Description
1	DIALux	DIALux is a free light planning software for both indoor and outdoor lighting with daylight and artificial light scenarios.
2	Trace Pro	A software tool for modelling the propagation of light in imaging and non- imaging opto-mechanical systems. The models are created by importing from a design or CAD program, or through directly creating the solid geometry in Trace Pro. Designers can analyse from the model: Light distributions in illumination and imaging systems Lumens exiting, absorbing, and incident at the component and system levels Candela distributions Optical efficiency, luminance, and radian cemeteries Photorealistic rendering
3	Lite Star 4D	A software for interior and exterior lighting design
4	MA Lighting software	Lighting design software for indoor and outdoor stage lighting
5	Relux	Free lighting design software for indoor, outdoor and tunnel lighting.
6	Radiance	Radiance is a free open-source suite of programs for the analysis of lighting in design. Its input files specify the scene geometry, luminaires, time, date, and sky conditions. Calculated values include illuminance values, luminance values include glare indices.
7	Ray front	This type of software is used for lighting design in educational institutions and industries with daylight to compute daylight factors, work-plane illuminance and evaluate glare distribution.
8	Microlux	Lighting design software for indoor stage lighting
9	Lighting Reality	Lighting software for street and outdoor area lighting

Out of the above-mentioned lighting design Softwares, **DIALux 4.13** software has been adopted for present study.

3.9.1.1 DIA Lux:

DIALux, created in 1994, is a free of charge, Windows XP–based radiosity lighting calculation software. A group of more than 90 international luminaire manufacturers funded the development of DIALux and pay to have their luminaires included with the software package. Updated and maintained by an independent company, DIAL GmbH, DIALux is frequently modified and refined to the requirements of designers. Because the software includes so many different manufacturer fixture libraries, the program retains a type of neutrality. The current release, DIALux 4.13, can be downloaded at dialux.com and is available in 26 languages. Widely used in Europe, DIALux recently began breaking into the North American market.

DIALux also supports the data formats of all luminaire manufacturers globally. Features include day lighting calculations, emergency and street lighting assistants, interior scene planning and documentation, and photo-realized images with an added ray tracing module for visualization of speculer and transparent surfaces. Imports and exports can be done as both .dwg and .dxf files, and results can be printed or saved as a PDF. Views and renderings are saved in JPEG format with or without added ray tracing. DIALux is quickly gaining notoriety as the most cost-effective software for all lighting calculations because there is no license fee. The software is applicable for complex qualitative calculations as well as photo-realistic renderings. Some of the advantages of this software is as appended below.

- Simple, effective, and professional light planning.
- Latest luminaire data of the world's leading manufacturers.
- Latest state of the art software always available free of charge.
- Energy evaluation facility and lighting control system facility.
- Lux level calculation in presence of integrated daylight and electrical light sources.
- Colored light scenes with LED or other color changing luminaires.

3.9.1.1.1 Procedure for Indoor Lighting Design Using DIALux Software:

While designing indoor lighting system using light simulating software to achieve desired lux level and maintaining good uniformity recommended by recommended codes and practices, some basic steps will have to be followed. The key steps in the design process are:

- Import of architectural drawing of interior building to the software.
- Room dimension (i.e. length, width and height).
- Identification of type of task in each room.
- Consideration of proper value of reflectance of floor, ceiling and wall.
- Consideration of proper value of light loss factor depending on degree of pollution factor in different types of interior area.
- Identification of type of ceiling (i.e. RCC type, Armstrong grid based false ceiling or gyp board false ceiling).
- Proper selection of surface mounted and recessed mounted luminaires with proper CCT and CRI of lamps having energy efficient and long lifespan and insert its IES file to the software.
- Requirement of proper fixture quantity and arrange the fixtures in matrix form that create fixtures' position symmetric.
- Maintaining actual fixture-to-fixture spacing with respect to their wattage along row and column wise.
- Utilization of daylight with energy efficient electrical light source by using building management system i.e. dimming system wherever it should be required in a zone of a space
- Calculation to determine lighting parameters i.e. lux level, LPD and uniformity required to perform a task as per the standard.
- Calculation of monthly energy consumption by determining total luminaires' quantity with total power consumption needed in an interior building.

Chapter-4

Design Of a Typical Classroom

4.1 Classroom Details:

A typical classroom of a Indian School (Fig 4.1 & Fig 4.2) is taken for lighting design consideration, which is located at semi-urban area and surrounded by no other big buildings, i.e. located in open space. Atmosphere around the considered school is low to moderate polluted. Classroom design details are as follows:

Fig 4.1: 3D View of the Classroom

Fig 4.2: 3D View of the Classroom

4.1.1 Classroom Dimension:

- Room Length: 12 Meter
- Room Width: 10 Meter
- Room Height: 3 Meter

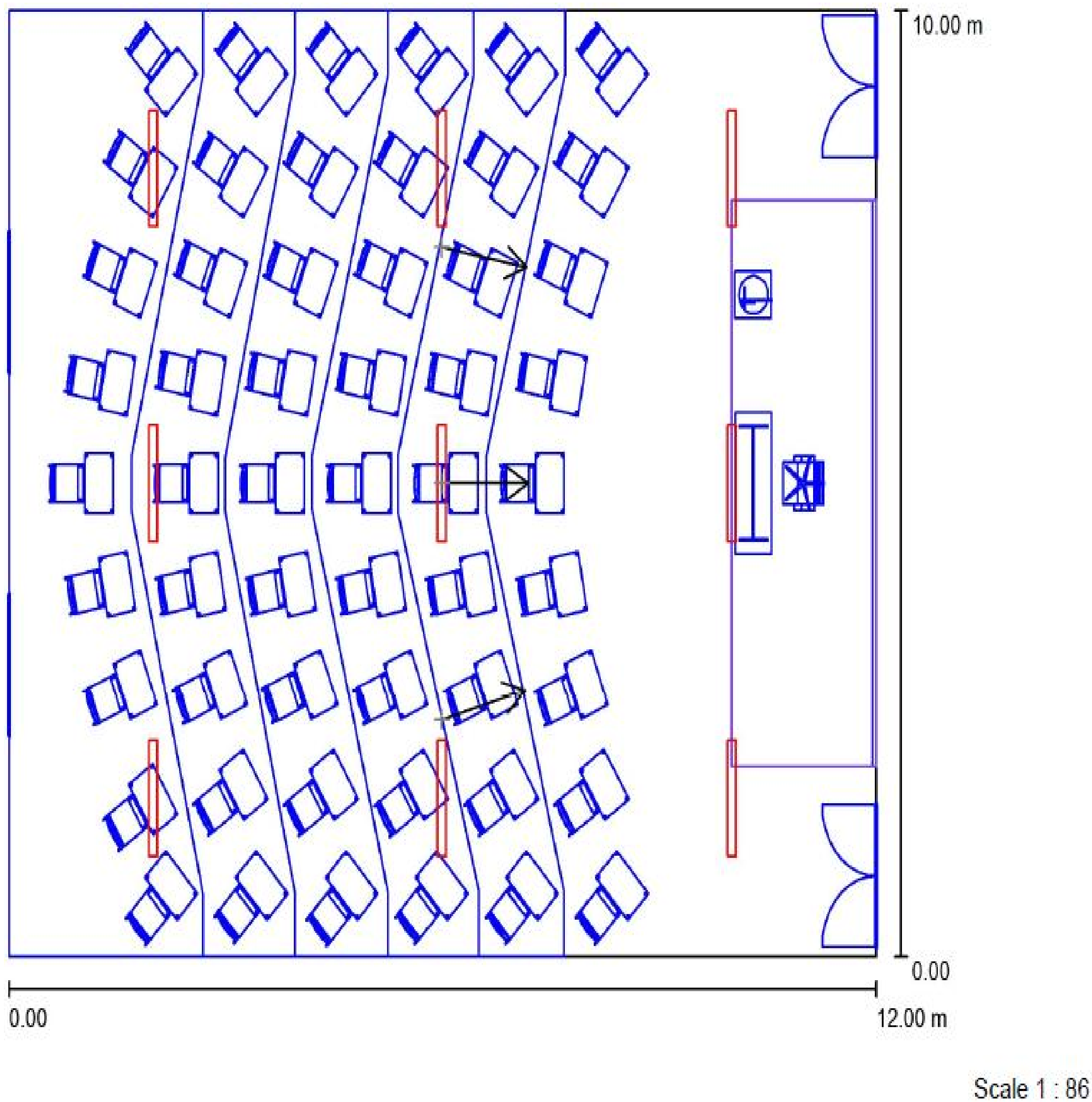


Fig 4.3: 2D View of the Classroom Dimension

4.1.2 Classroom Floor:

Class room Floor is made of marble of light bluish white color, its reflectance factor is 68%. It has following parts:

4.1.2.1 Dais:

In Blackboard Side there is Dais for teachers which is made of marble of light bluish white color, its reflectance factor is 68%. (Fig 4.4)

- The dais is 6 meter long, 2 meter width and 100 mm in height.
- It is located at 2 meter apart from both side wall.

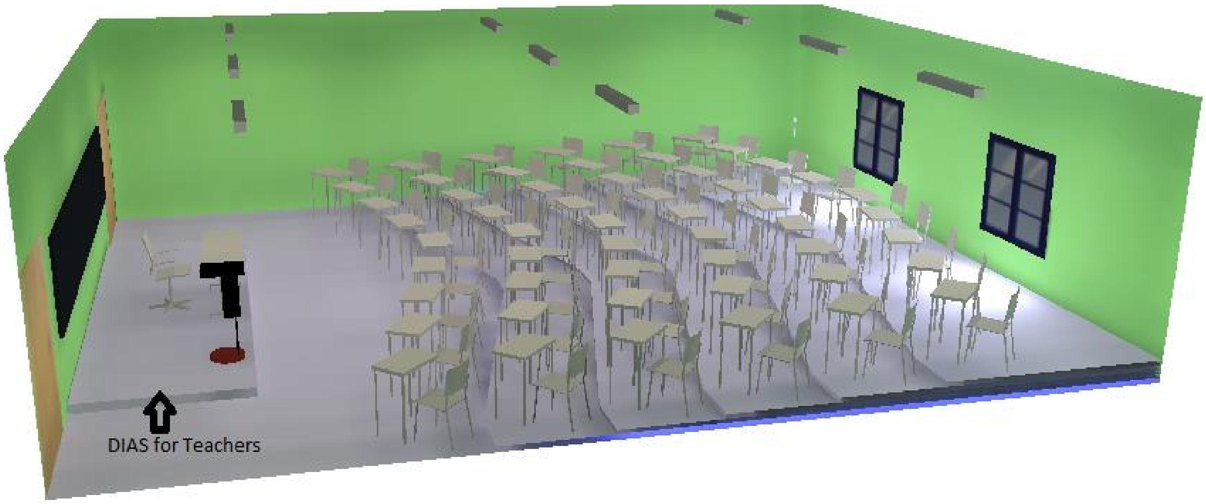


Fig 4.4: 3D View of the Classroom Dais

4.1.2.1 Steps in Student Side:

There are 5 steps in the student side of the classroom. Each step is 50 mm higher from previous steps. This type design consideration is taken for better view of blackboard from back side of the class. These step design also helps teacher for better control of class. (Fig 4.5)

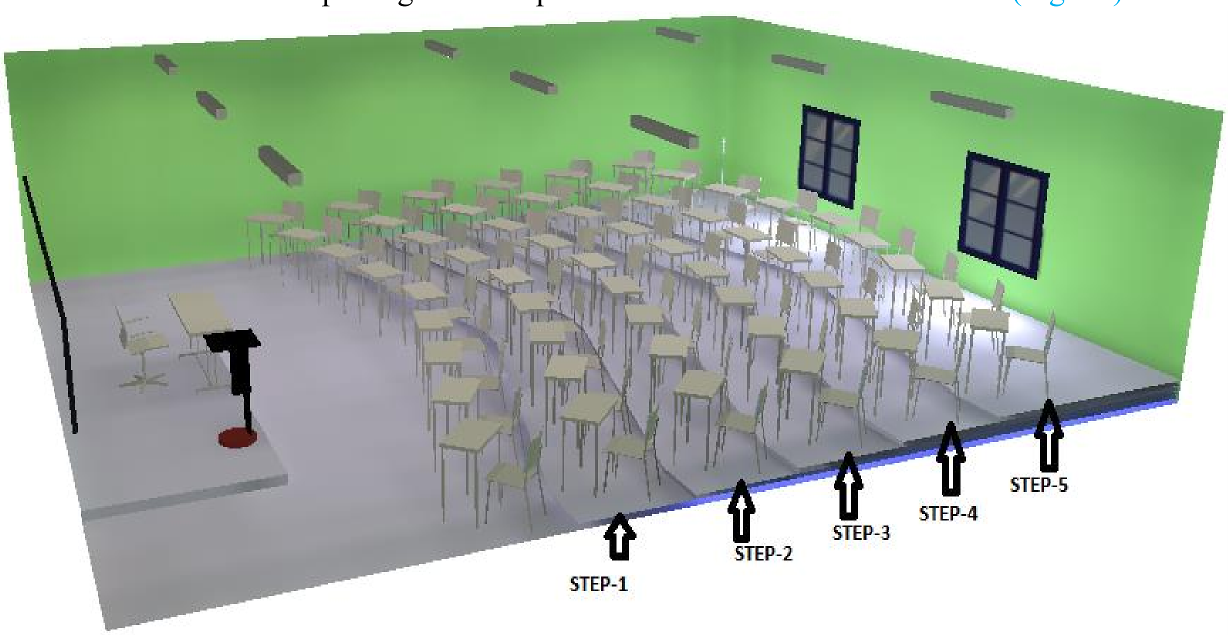


Fig 4.5: 3D View of the Classroom Steps

4.1.3 Classroom Wall:

Classroom walls are in pastel green in color, which reflection factor of 59%. It has four sides and the sides have following objects:

- North side wall has two doors in each side, each doors have dimension of 1.5 meter width and 2 meter long. Doors are made of light colored wood, with reflection factor of 55% and roughness of 10%. (Fig 4.6)

- North side wall also has a blackboard of dimension 6 meter long, 1meter width and thickness of 50 mm. It is situated at 2 meter away from each side wall and 800 mm above the floor. It is black in color and reflection factor is 5%.(Fig 4.6)
- East and west side walls have no objects.
- South side wall has two windows of dimension 1.5 meter width and 1.25 meter height. It is made of glass, which have reflection factor 6% and transparency 70%. (Fig 4.7)

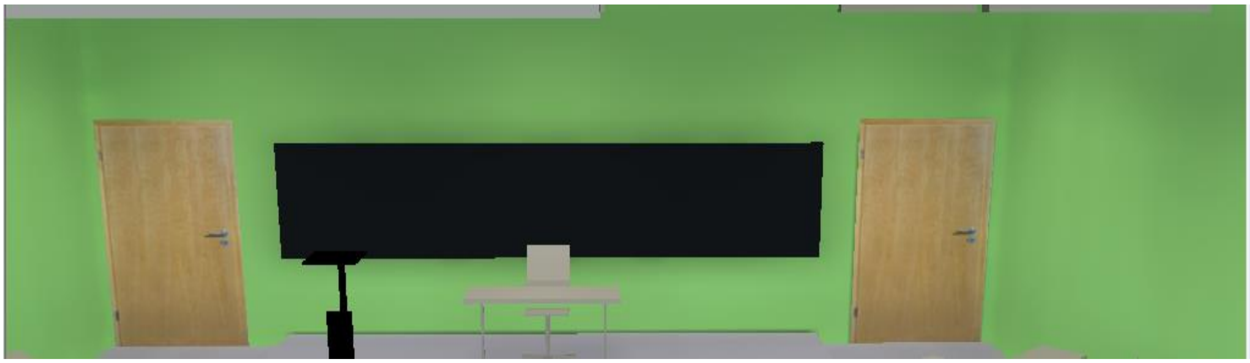


Fig 4.6: 3D View of the North Side wall

Fig 4.7: 3D View of the South Side wall

4.1.3 Classroom Ceiling:

Classroom ceiling is traffic white in color. It has reflection factor of 88 %. Ceiling have lighting fixtures.

4.1.4 Classroom Objects:

These classrooms have following objects:

4.1.4.1 Chair and Table for Teachers:

- Chair for teacher is pale brown in color and its reflectance factor is 14%. Its seating height is 450 mm above from dais.
- Table for teacher is light wooden color. It has reflection factor of 52%. Table top is 715 mm high from dais. It is 1.5 meter in length and 500 mm in width.
- Table & Chair are located in the front middle position of the dais.
- In the right hand side of dais there is a stand alone desk, which has dark wooden color on top and black color in bottom portion. Its desk height is 1 meter from dais. It has reflection factor of 15%.

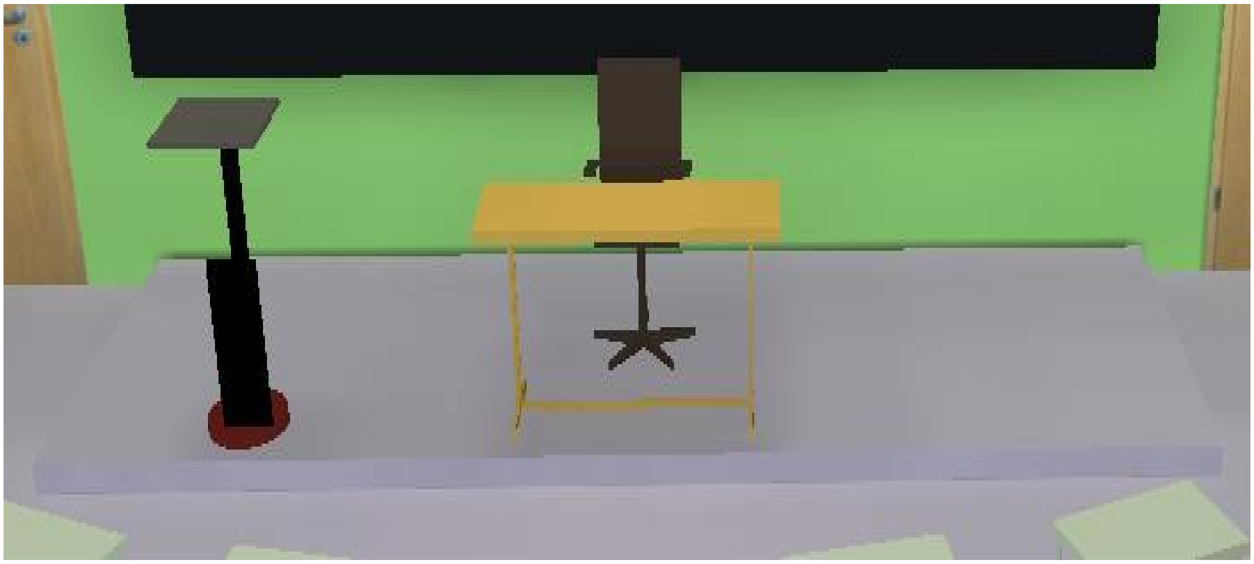


Fig 4.8: 3D View of Table, Chair & Stand Alone Desk For Teachers

4.1.4.2 Chair and Table for Students:

- In this class room there is 6 nos of row of table and chair set for students.
- In this classroom each row has 9 nos set of table and chair.
- Each row is 50mm in extra height from previous row due to steps from front side to back side.
- Each table and chair set is directed towards the blackboard for better viewing capacity from back side rows.
- Table for students is papyrus white in color. Table top is 720 mm high from base. Its dimension is 630 mm long and 400 mm width.
- Tabletop has 61% reflectance factor.
- Chair for students is dark wooden color and have reflectance factor of 15%.
- Chair have seating height of 400 mm from ground.

Fig 4.9: 3D View of Table, Chair For Students

Fig 4.10: 2D View of Overall Floor Plan of Classroom

4.1.5 Classroom Work plane:

Classroom work plane is a plane where illuminance value is measured. In this class room table top height for students is considered as a work plane. As 1st row table top height from base level is 720 mm and 6th row table top height from base level is 970 mm, so maximum height of this two i.e. 720 & 970, 970 mm height from base level a work plane is taken for consideration.

In this work plane other lighting parameters are measured.

Chapter-5

Existing Lighting Design

5.1 Design Consideration:

- In existing lighting system both daylight and artificial light are taken for lighting calculation.
- But there is no control of artificial light present in the existing system. All artificial light can be manually switch off or switch on.
- Daylight transmittance factor is low i.e., 70%.
- Lighting parameters are calculated for Four times a day i.e.10.30 AM, 12.30 PM, 02.30 PM & 04.30 PM.

5.2 Details of Luminaire:

In existing lighting design T8 FTL luminaire are used and details of these luminaire are as follows:

Name of Luminaire:

Luminaire Name: Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS]

Luminous Flux of the Luminaire:

- Luminous flux (Lamps): 6500 lm
- Luminous flux (Luminaire): 4479 lm

Wattage of the Luminaire:

Luminaire Wattage: 84.7 W

Luminaire Classification according to CIE:

Luminaire classification according to CIE: 100

Luminaire CIE Flux Code:

CIE flux code: 44 82 98 100 69

Luminaire Fittings:

Fitting: 2 x TL'D'36W;865 (Correction Factor 1.000).

Luminaire LDC (Polar):

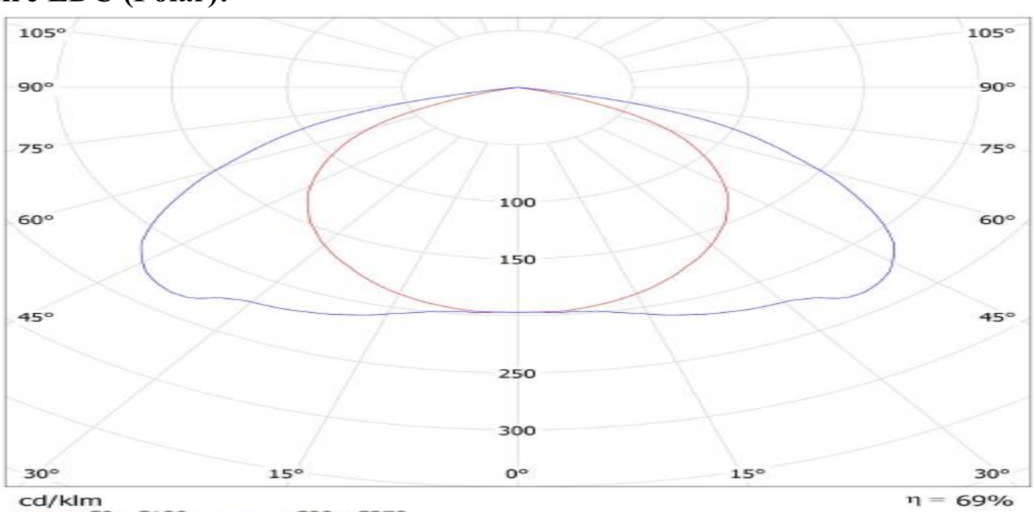


Fig 5.1: LDC (Polar) of the Luminaire

Luminaire LDC (Linear):

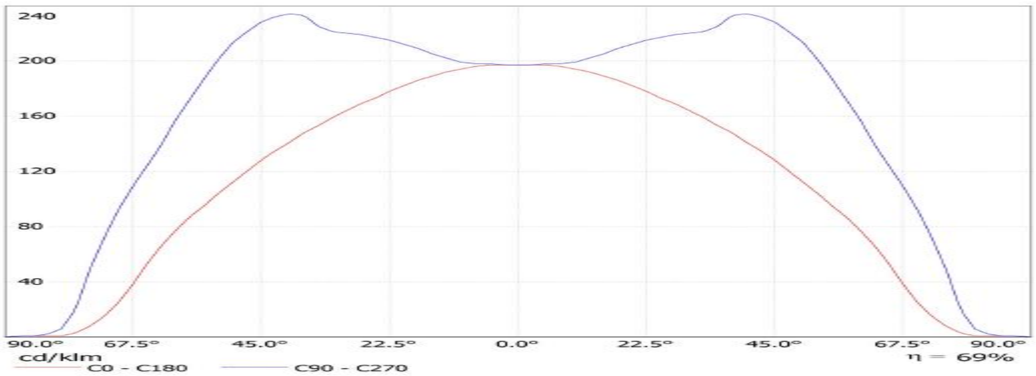


Fig 5.2: LDC (Linear) of the Luminaire

Luminaire UGR-Table:

Table 5.1: Luminaire UGR-Table

Glare Evaluation According to UGR											
ρ Ceiling		70	70	50	50	30	70	70	50	50	30
ρ Walls		50	30	50	30	30	50	30	50	30	30
ρ Floor		20	20	20	20	20	20	20	20	20	20
Room Size X	Y	Viewing direction at right angles to lamp axis					Viewing direction parallel to lamp axis				
2H	2H	20.3	21.6	20.6	21.9	22.1	22.8	24.1	23.1	24.4	24.6
	3H	20.9	22.2	21.3	22.4	22.7	24.3	25.5	24.6	25.8	26.0
	4H	20.9	22.1	21.3	22.4	22.7	24.6	25.8	25.0	26.1	26.3
	6H	20.9	21.9	21.2	22.2	22.5	24.6	25.7	25.0	26.0	26.3
	8H	20.8	21.8	21.2	22.2	22.5	24.6	25.6	25.0	25.9	26.2
	12H	20.8	21.8	21.2	22.1	22.4	24.6	25.5	24.9	25.8	26.2
4H	2H	21.3	22.5	21.7	22.7	23.0	23.2	24.4	23.6	24.7	25.0
	3H	22.1	23.1	22.5	23.4	23.7	24.8	25.8	25.2	26.1	26.5
	4H	22.1	23.0	22.5	23.3	23.7	25.3	26.1	25.6	26.4	26.8
	6H	22.1	22.8	22.5	23.2	23.6	25.3	26.0	25.7	26.4	26.8
	8H	22.1	22.7	22.5	23.1	23.5	25.2	25.9	25.7	26.3	26.7
	12H	22.0	22.6	22.5	23.0	23.5	25.2	25.8	25.7	26.2	26.7
8H	4H	22.3	23.0	22.7	23.4	23.8	25.2	25.9	25.7	26.3	26.7
	6H	22.2	22.8	22.7	23.2	23.7	25.3	25.8	25.7	26.2	26.7
	8H	22.2	22.7	22.7	23.1	23.6	25.2	25.7	25.7	26.1	26.6
	12H	22.2	22.6	22.7	23.1	23.6	25.2	25.6	25.7	26.1	26.6
12H	4H	22.3	22.9	22.7	23.3	23.7	25.2	25.8	25.6	26.2	26.6
	6H	22.2	22.7	22.7	23.1	23.6	25.2	25.7	25.7	26.1	26.6
	8H	22.2	22.6	22.7	23.1	23.6	25.2	25.6	25.7	26.1	26.6
Variation of the observer position for the luminaire distances S											
S = 1.0H		+0.2 / -0.3					+0.2 / -0.1				
S = 1.5H		+0.9 / -1.2					+0.4 / -0.5				
S = 2.0H		+1.6 / -3.0					+0.8 / -0.9				
Standard table		BK02					BK03				
Correction Summand		2.9					6.3				
Corrected Glare Indices referring to 6500lm Total Luminous Flux											

Luminaire Luminance Diagram:

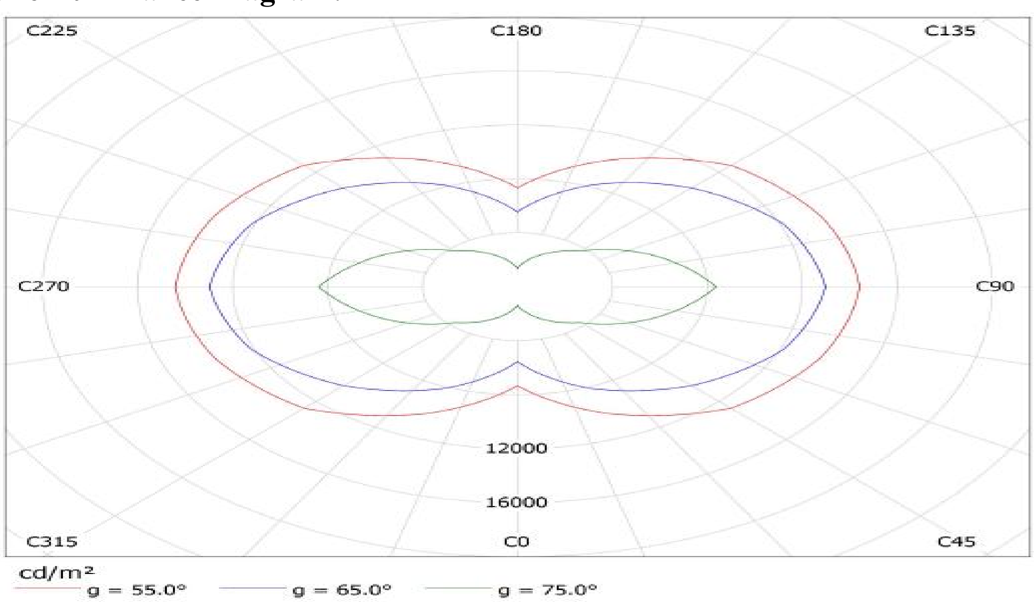


Fig 5.3: Luminaire Luminance Diagram

Luminaire Cone Diagram:

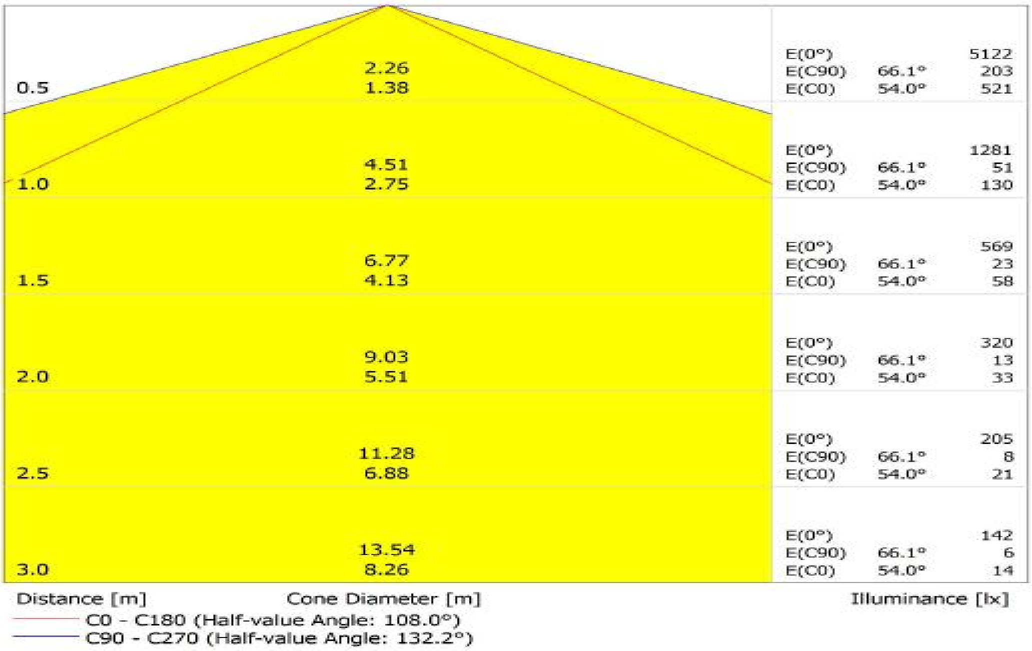


Fig 5.4: Luminaire Cone Diagram

Luminaire Luminous Intensity Table:

Table 5.2: Luminaire Luminous Intensity Table

Gamma	C 0°	C 15°	C 30°	C 45°	C 60°	C 75°	C 90°
0.0°	197	197	197	197	197	197	197
5.0°	197	198	198	197	198	198	198
10.0°	194	195	196	197	199	200	199
15.0°	189	191	194	197	201	204	205
20.0°	182	185	190	197	204	209	212
25.0°	173	178	187	198	208	214	217
30.0°	164	171	182	197	210	217	220
35.0°	153	163	177	195	209	219	225
40.0°	141	154	171	190	212	227	234
45.0°	128	145	164	187	208	222	228
50.0°	112	133	156	182	197	207	213
55.0°	95	120	143	165	174	182	187
60.0°	77	98	118	136	144	151	157
65.0°	53	70	85	99	110	119	124
70.0°	25	38	50	61	75	85	92
75.0°	8.00	13	17	22	31	40	49
80.0°	1.00	1.67	2.33	3.00	3.67	4.67	6.00
85.0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00
90.0°	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Values in cd/klm

Luminaire Luminance Table:

Table 5.3: Luminaire Luminance Table

Gamma	C 0°	C 15°	C 30°	C 45°	C 60°	C 75°	C 90°
0.0°	8711	8711	8711	8711	8711	8711	8711
5.0°	8744	8774	8774	8744	8774	8789	8789
10.0°	8711	8770	8815	8845	8935	8965	8935
15.0°	8652	8744	8866	9018	9201	9323	9384
20.0°	8564	8721	8956	9270	9615	9850	9976
25.0°	8440	8701	9107	9660	10148	10457	10587
30.0°	8374	8714	9276	10058	10705	11097	11233
35.0°	8259	8799	9554	10526	11282	11822	12145
40.0°	8139	8908	9851	10967	12237	13084	13507
45.0°	8004	9046	10276	11694	13028	13882	14258
50.0°	7705	9126	10731	12520	13529	14240	14652
55.0°	7324	9225	11024	12720	13440	14005	14416
60.0°	6810	8696	10435	12027	12735	13354	13884
65.0°	5545	7289	8893	10358	11544	12416	12974
70.0°	3232	4870	6421	7886	9696	11032	11894
75.0°	1367	2164	2961	3759	5353	6891	8371
80.0°	255	424	594	764	934	1188	1528
85.0°	507	507	507	507	507	507	507

Values in Candela/m².

5.3 Arrangement of Luminaire:

Details of luminaire arrangement are as follows:

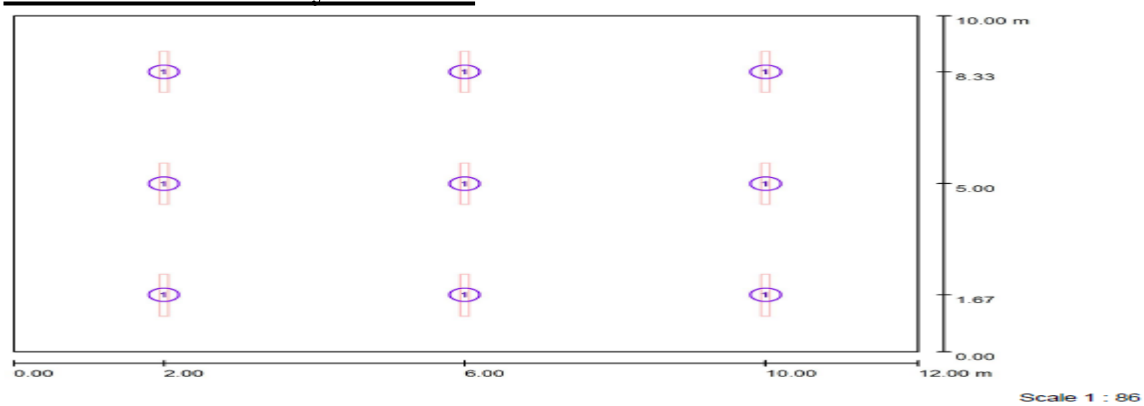
5.3.1 No of Luminaire Used in the Classroom:

In the above mentioned classroom 9 nos luminaires with Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS] FTL used for lighting up the classroom in the symmetric way.

5.3.2 Mounting of Luminaire Used in the Classroom:

In the above mentioned classroom luminaires are surface mounted in the ceiling of the classroom.

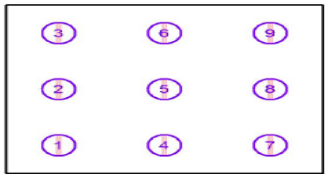
5.3.3 Luminaire Layout Plan:



Luminaire Parts List

No.	Pieces	Designation
1	9	Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS]

Fig 5.5: Luminaire Layout Plan



No.	Position [m] X	Y	Z	Rotation [°] X	Y	Z
1	2.000	1.667	3.000	0.0	0.0	90.0
2	2.000	5.000	3.000	0.0	0.0	90.0
3	2.000	8.333	3.000	0.0	0.0	90.0
4	6.000	1.667	3.000	0.0	0.0	90.0
5	6.000	5.000	3.000	0.0	0.0	90.0
6	6.000	8.333	3.000	0.0	0.0	90.0
7	10.000	1.667	3.000	0.0	0.0	90.0
8	10.000	5.000	3.000	0.0	0.0	90.0
9	10.000	8.333	3.000	0.0	0.0	90.0

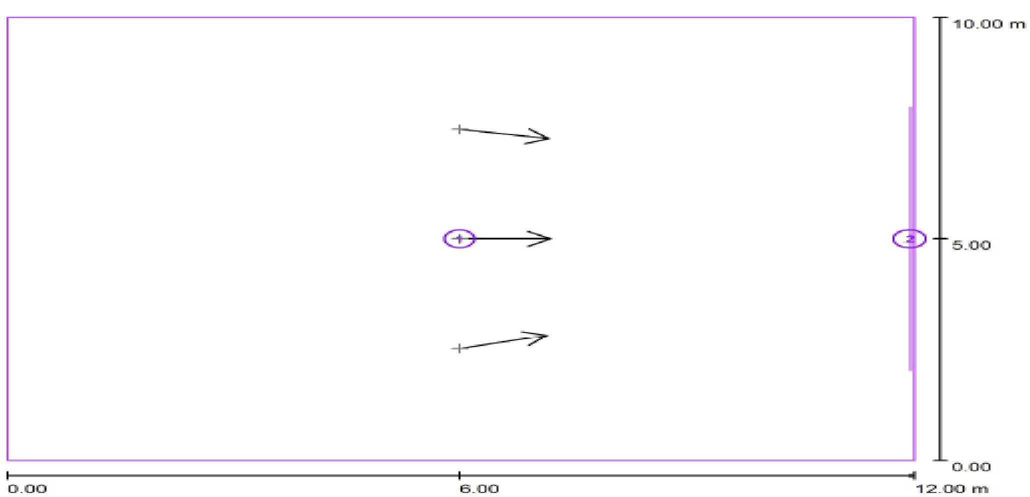
Fig 5.6: Luminaire Position Co-ordinate

5.4 Lighting Parameters Measurement:

5.4.1 Consideration for Measurement of Lighting Parameters:

For measurement of lighting parameters of the mentioned classroom following consideration is taken:

- Height of the work plane is 970 mm from base ground.
- Lighting parameters are measured for four times a day i.e. at 10.30 AM, 12.30 PM, 02.30 PM & 04.30 PM.
- For calculation of lighting parameters on Student Work plane a Grid of 11X9 points in Horizontal Plane is considered. The size is 12 meter X 10 meter and positioned at 6m, 5m & 0.970m.
- For calculation of lighting parameters on Blackboard a Grid of 1X9 points in Vertical Plane is considered, which size is 1 meter X 6 meter and positioned at 11.950m, 5m & 1.3m.



Scale 1 : 86

List of the Calculation Grids

No.	Designation	Position [m] X	Y	Z	Size [m] L	W	Rotation [°] X	Y	Z
1	Workplane Grid for students	6.000	5.000	0.970	12.000	10.000	0.0	0.0	0.0
2	Horizontal Calculation Grid on Board	11.950	5.000	1.300	1.000	6.000	0.0	-90.0	0.0

Fig 5.7: Calculation Grid Layout Plan & Position

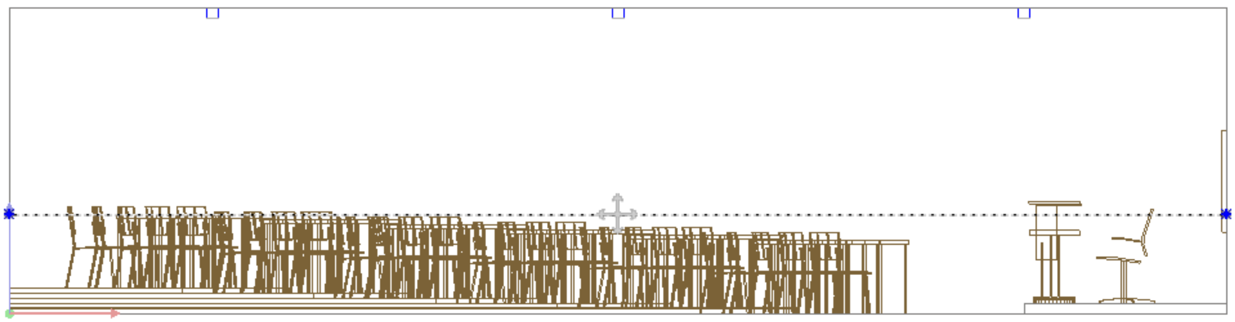


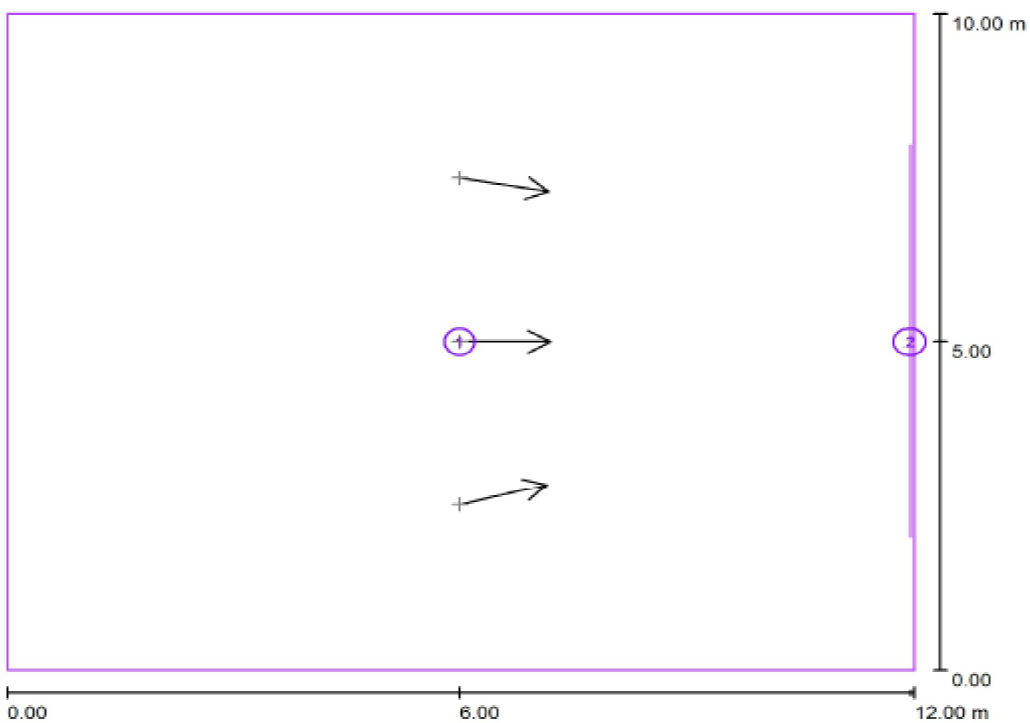
Fig 5.8: Work plane Grid for students

- For calculation of UGR 3 nos UGR Observer are considered, positioned as following table:

Table 5.4: UGR Observer Position Table

UGR Calculation Points List

No.	Designation	Position [m] X	Position [m] Y	Position [m] Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	21
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	21
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	21



Scale 1 : 86

List of the Calculation Grids

No.	Designation	Position [m] X	Position [m] Y	Position [m] Z	Size [m] L	Size [m] W	Rotation [°] X	Rotation [°] Y	Rotation [°] Z
1	Workplane Grid for students	6.000	5.000	0.845	12.000	10.000	0.0	0.0	0.0
2	Horizontal Calculation Grid on Board	11.950	5.000	1.300	1.000	6.000	0.0	-90.0	0.0

Fig 5.9: UGR Observer Layout Plan

5.4.2 Measurement of Lighting Parameters at 10.30 AM:

5.4.2.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°.
- Date: 21.03.2022, Time: 10:30:00 (+5 hours difference to GMT).
- Reference sky type: Clear sky.

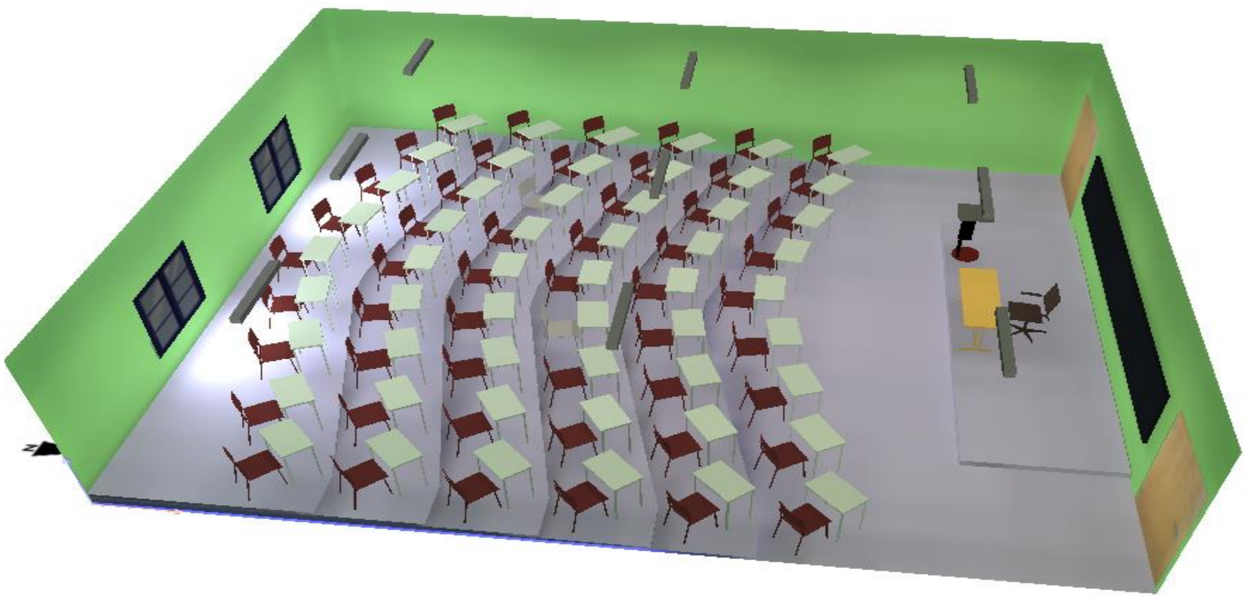


Fig 5.10: Window Orientation of the classroom at 10.30 AM

Table 5.5: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	Control group 28 (Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS])	100
	All other luminaires	0

From above table it can be seen that all FTL luminaire have no dimming, they are fully turn on.

5.4.2.2 Work plane Grid for Students Summary:

Summary of work plane grid for students is as following table:

Table 5.6: Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	453	210	2172	0.46	0.10	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on work plane grid for students is 453 lx.
- Maximum illuminance (E_{max}) on work plane grid for students is 2172 lx.
- Minimum illuminance (E_{min}) on work plane grid for students is 210 lx.
- Uniformity on work plane grid for students is 0.46.
- E_{min} / E_{max} = 0.10.

5.4.2.3 Isolines (E, Perpendicular) on Work plane Grid for Students:

Isolines (E, perpendicular) on work plane Grid for students is as follows:

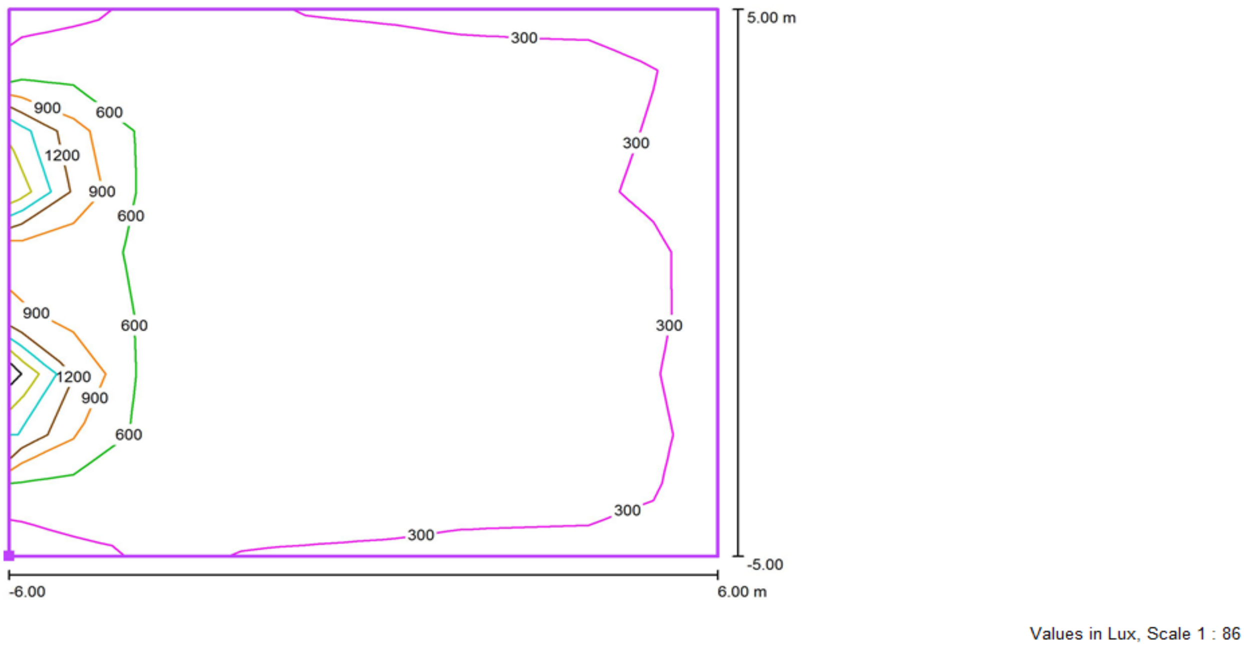


Fig 5.11: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the high value isolines are concentrated near the windows.
- But 300 lx isoline can cover maximum of the classroom.

5.4.2.4 Value Chart (E, Perpendicular) on Work plane Grid for Students:

Value Chart (E, Perpendicular) on Work plane Grid for students is as follows:

5.00 m

318	385	381	344	337	333	315	298	307	293	244
584	590	506	429	425	442	401	370	399	386	296
2172	697	508	441	416	399	387	370	367	210	268
1123	628	516	452	427	411	396	380	375	345	269
269	621	563	476	463	476	436	405	428	408	287
1495	662	515	450	426	409	396	380	375	348	271
2030	668	495	432	412	397	385	370	367	343	270
496	543	486	417	420	439	400	369	400	388	298
302	363	365	335	328	329	312	298	306	293	245

-5.00

-6.00 6.00 m

Values in Lux, Scale 1 : 86

Fig 5.12: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is well illuminated.
- Window side portion is very highly illuminated.

5.4.2.5 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 5.7: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	189	176	209	0.93	0.84	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 189 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 209 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 176 lx.
- Uniformity on calculation gird for board is 0.93.
- E_{min} / E_{max} = 0.84.

5.4.2.6 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 5.13: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is lower than the recommended average illuminance, 200 lx. (Ref. 3.1.5)
- Uniformity is good, 0.93.

5.4.2.7 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 5.8: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	21
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	21
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	21

From above UGR Observer Table it can be seen UGR value is 21. It is under the specified recommendation limit. (Ref: 3.1.4)

5.4.2.8 Photometric Result:

Table 5.9: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	457	103	4410	0.226
Floor	68	592	19	1851	0.033
Ceiling	88	174	109	324	0.628
Walls (4)	59	233	28	582	/

Table 5.10: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	Surface Description	E_{max} (lx)	E_{min} (lx)	E_{av} (lx)	Uniformity (u_o)
1	Floor Surface	1851	19	592	0.033
2	Ceiling	324	109	174	0.628
3	Four Walls	582	28	233	-

Table 5.11: Luminaire Output

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	9	Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS] (1.000)	4479	6500	84.7
			Total: 40311	Total: 58500	762.3

- Total Luminous Flux: 40311 lm.
- Total Load: 762.3 W.
- Ground area: 120.00 m².
- LPD: 6.35 W/m².

5.4.3 Measurement of Lighting Parameters at 12.30 PM:

5.4.3.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°.
- Date: 21.03.2022, Time:12:30:00 (+5 hours difference to GMT).
- Reference sky type: Clear sky.

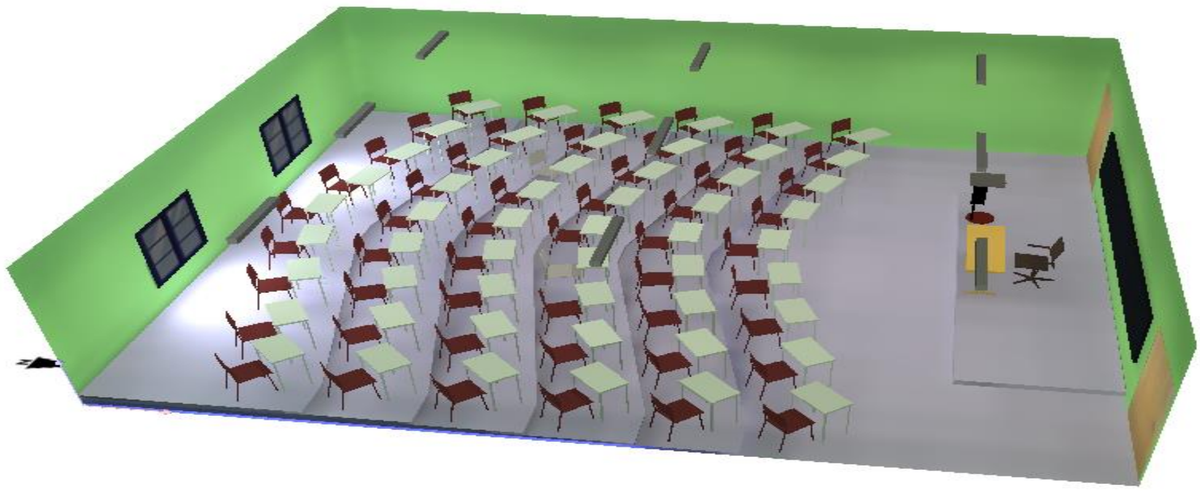


Fig 5.14: Window Orientation of the classroom at 12.30 PM

Table 5.12: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	Control group 28 (Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS])	100
	All other luminaires	0

From above table it can be seen that all FTL luminaire have no dimming, they are fully turn on.

5.4.3.2 Work plane Grid for Students Summary:

Summary of work plane grid for students is as following table:

Table 5.13: Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	452	209	2174	0.46	0.10	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on work plane grid for students is 452 lx.
- Maximum illuminance (E_{max}) on work plane grid for students is 2174 lx.
- Minimum illuminance (E_{min}) on work plane grid for students is 209 lx.
- Uniformity on work plane grid for students is 0.46.
- E_{min} / E_{max} = 0.10.

5.4.3.3 Isolines (E, Perpendicular) on Work plane Grid for Students:

Isolines (E, perpendicular) on work plane Grid for students is as follows:

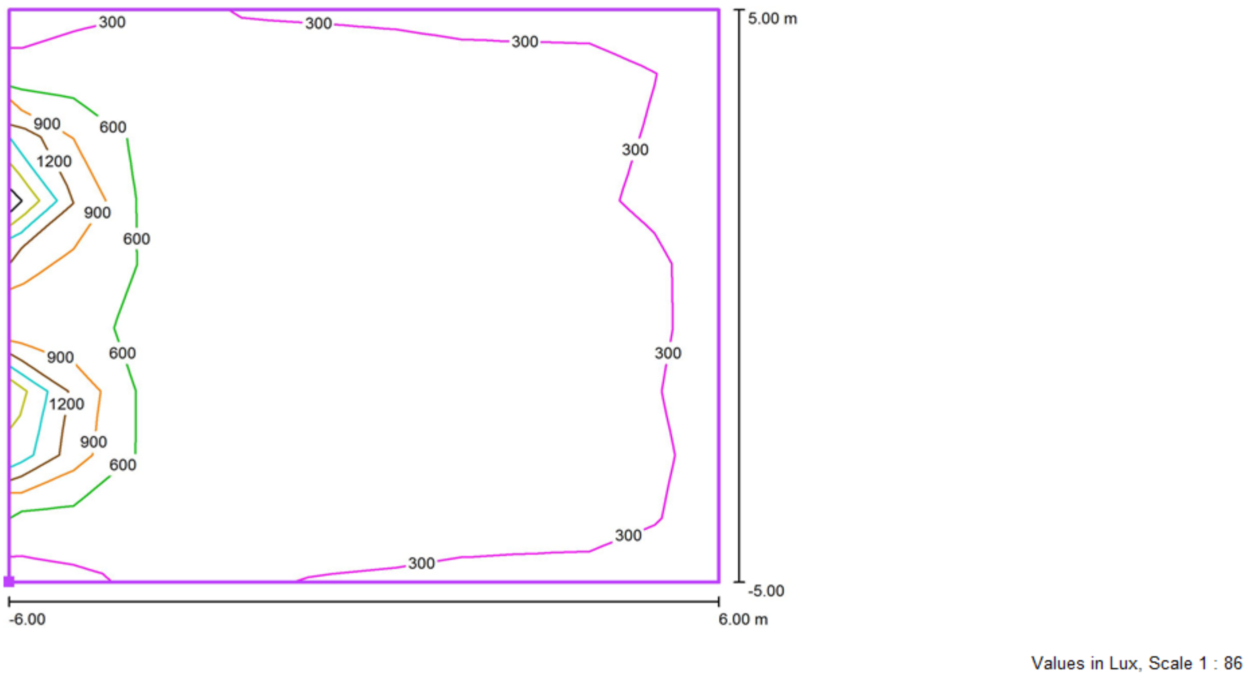


Fig 5.15: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the high value isolines are concentrated near the windows.
- But 300 lx isoline can cover maximum of the classroom.

5.4.3.4 Value Chart (E, Perpendicular) on Work plane Grid for Students:

Value Chart (E, Perpendicular) on Work plane Grid for students is as follows:

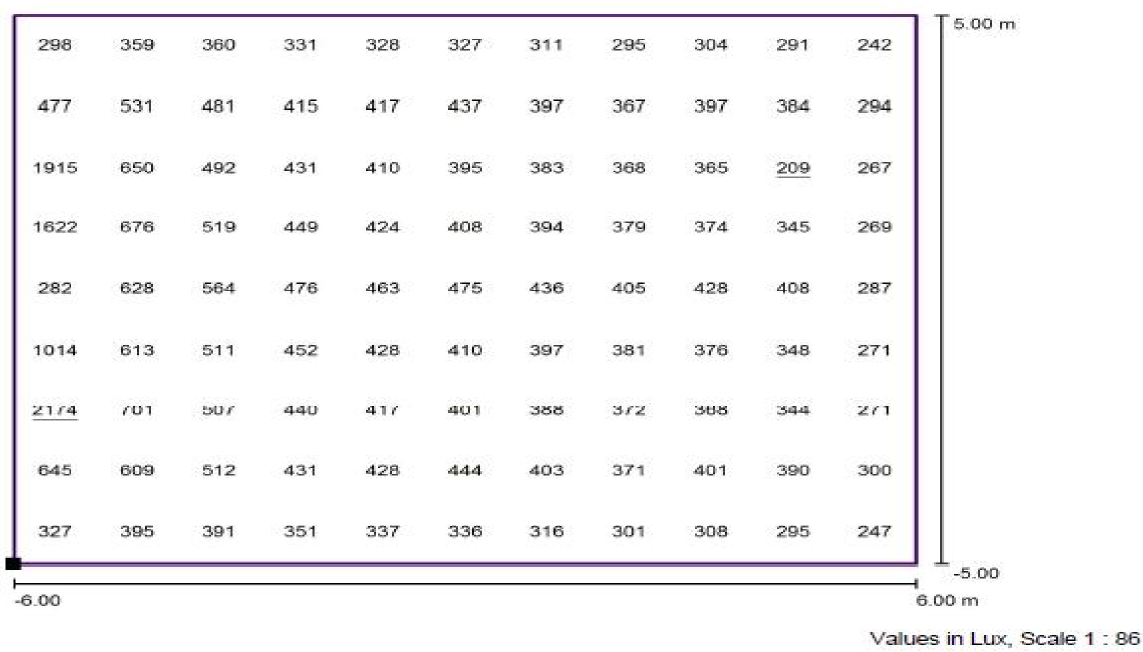


Fig 5.16: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is well illuminated.
- Window side portion is very highly illuminated.

5.4.3.5 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 5.14: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	189	175	209	0.93	0.84	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 189 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 209 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 175 lx.
- Uniformity on calculation gird for board is 0.93.
- E_{min} / E_{max} = 0.84.

5.4.3.6 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 5.17: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is lower than the recommended average illuminance, 200 lx. (Ref. 3.1.5)
- Uniformity is good, 0.93.

5.4.3.7 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 5.15: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	21
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	21
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	21

From above UGR Observer Table it can be seen UGR value is 21. It is under the specified recommendation limit. (Ref: 3.1.4)

5.4.3.8 Photometric Result:

Table 5.16: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	456	103	4353	0.225
Floor	68	597	19	1911	0.032
Ceiling	88	174	109	322	0.625
Walls (4)	59	233	28	564	/

Table 5.17: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	**Surface Description**	**E_{max} (lx)**	**E_{min} (lx)**	**E_{av} (lx)**	**Uniformity (u_o)**
1	Floor Surface	1911	19	597	0.032
2	Ceiling	322	109	174	0.625
3	Four Walls	564	28	233	-

Table 5.18: Luminaire Output

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	9	Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS] (1.000)	4479	6500	84.7
			Total: 40311	Total: 58500	762.3

- Total Luminous Flux: 40311 lm
- Total Load: 762.3 W
- Ground area: 120.00 m²
- LPD: 6.35 W/m²

5.4.4 Measurement of Lighting Parameters at 02.30 PM:

5.4.4.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°
- Date: 21.03.2022, Time:14:30:00 (+5 hours difference to GMT)
- Reference sky type: Clear sky

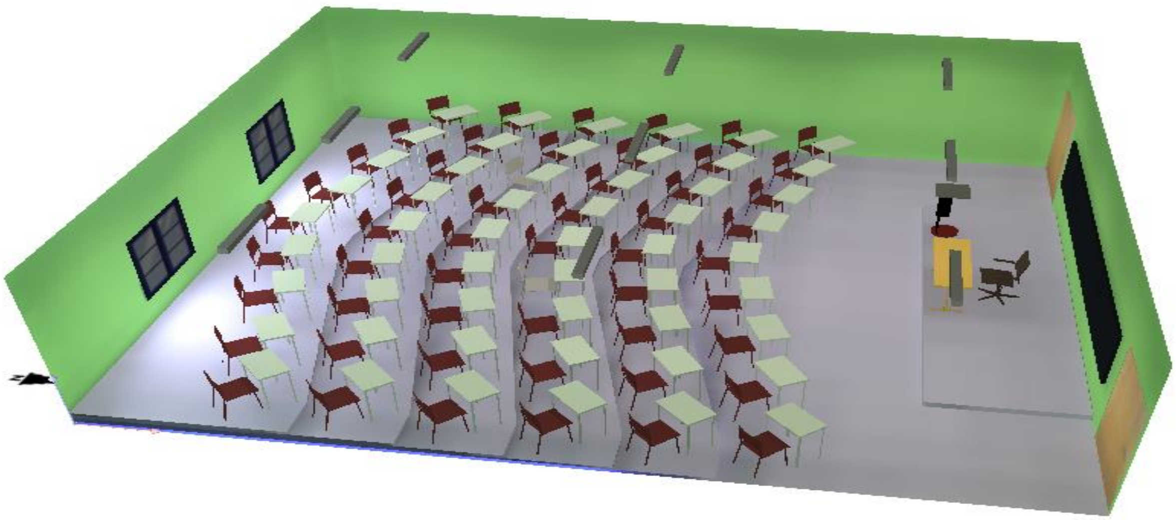


Fig 5.18: Window Orientation of the classroom at 02.30 PM

Table 5.19: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	Control group 28 (Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS])	100
	All other luminaires	0

From above table it can be seen that all FTL luminaire have no dimming, they are fully turn on.

5.4.4.2 Work plane Grid for Students Summary:

Summary of work plane grid for students is as following table:

Table 5.20: Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	435	208	1724	0.48	0.12	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on work plane grid for students is 435 lx.
- Maximum illuminance (E_{max}) on work plane grid for students is 1274 lx.
- Minimum illuminance (E_{min}) on work plane grid for students is 208 lx.
- Uniformity on work plane grid for students is 0.48.
- E_{min} / E_{max} = 0.10.

5.4.4.3 Isolines (E, Perpendicular) on Work plane Grid for Students:

Isolines (E, perpendicular) on work plane Grid for students is as follows:

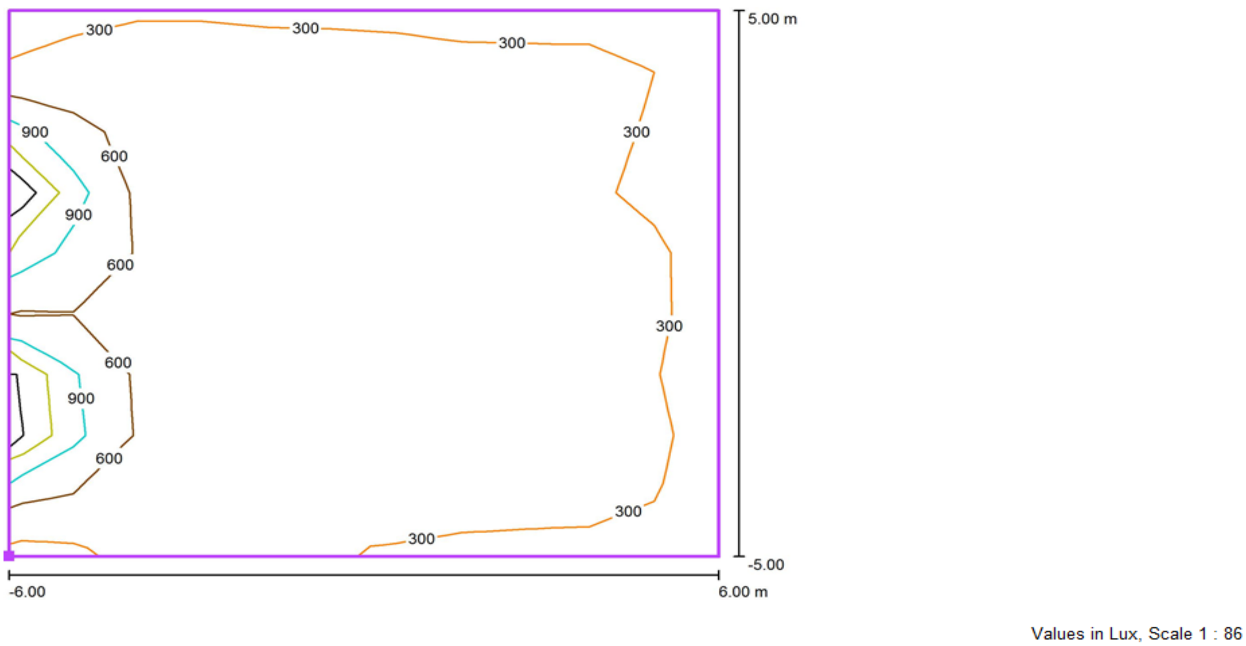


Fig 5.19: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the high value isolines are concentrated near the windows.
- But 300 lx isoline can cover maximum of the classroom.

5.4.4.4 Value Chart (E, Perpendicular) on Work plane Grid for Students:

Value Chart (E, Perpendicular) on Work plane Grid for students is as follows:

284	342	344	319	319	321	306	292	301	288	239
437	493	457	399	407	430	392	364	394	382	291
1300	562	458	412	398	388	378	364	362	208	265
1560	637	492	432	413	400	389	375	371	342	267
378	642	552	464	455	469	431	402	425	405	286
782	573	496	442	421	405	393	378	373	346	269
1724	641	491	433	412	398	385	369	366	342	269
900	635	512	430	427	443	402	370	400	388	298
370	435	409	359	341	337	316	301	307	294	246

5.00 m

-5.00

-6.00 6.00 m

Values in Lux, Scale 1 : 86

Fig 5.20: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is well illuminated.
- Window side portion is very highly illuminated.

5.4.4.5 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 5.21: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	188	174	209	0.93	0.83	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 188 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 209 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 174 lx.
- Uniformity on calculation gird for board is 0.93.
- E_{min} / E_{max} = 0.83.

5.4.4.6 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 5.21: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is lower than the recommended average illuminance, 200 lx. (Ref. 3.1.5)
- Uniformity is good, 0.93.

5.4.4.7 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 5.22: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	21
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	21
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	21

From above UGR Observer Table it can be seen UGR value is 21. It is under the specification recommendation limit. (Ref: 3.1.4)

5.4.4.8 Photometric Result:

Table 5.23: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	437	101	3456	0.230
Floor	68	582	19	1903	0.032
Ceiling	88	166	107	289	0.642
Walls (4)	59	230	27	687	/

Table 5.24: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	**Surface Description**	**E_{max} (lx)**	**E_{min} (lx)**	**E_{av} (lx)**	**Uniformity (u_o)**
1	Floor Surface	1903	19	582	0.032
2	Ceiling	289	107	166	0.642
3	Four Walls	687	27	230	-

Table 5.25: Luminaire Output

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	9	Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS] (1.000)	4479	6500	84.7
			Total: 40311	Total: 58500	762.3

- Total Luminous Flux: 40311 lm
- Total Load: 762.3 W
- Ground area: 120.00 m²
- LPD: 6.35 W/m²

5.4.5 Measurement of Lighting Parameters at 04.30 PM:

5.4.5.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°

- Date: 21.03.2022, Time:16:30:00 (+5 hours difference to GMT)
- Reference sky type: Clear sky

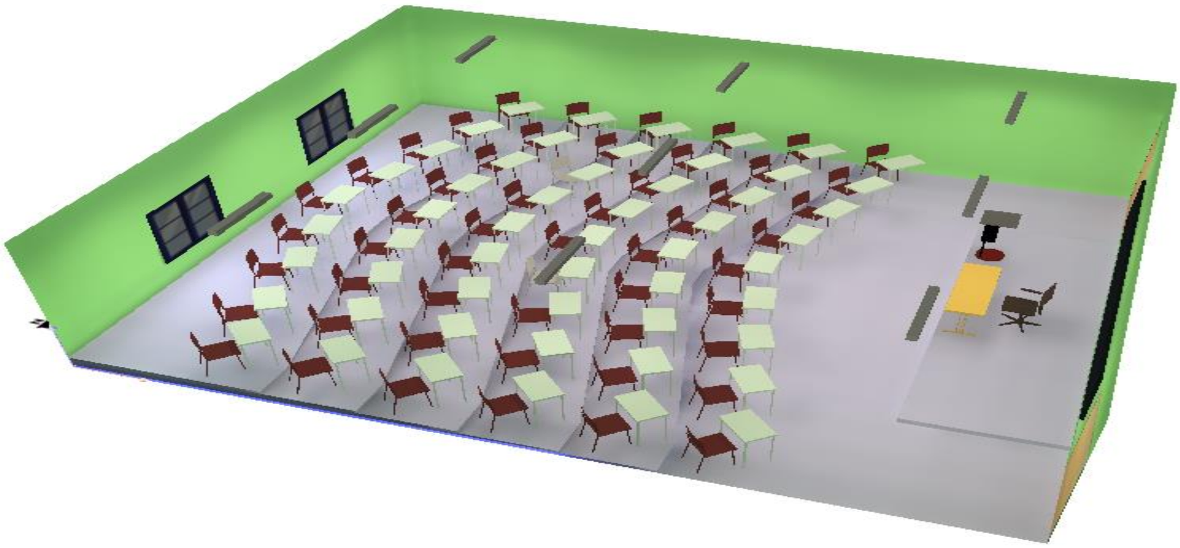


Fig 5.22: Window Orientation of the classroom at 04.30 PM

Table 5.26: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	Control group 28 (Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS])	100
	All other luminaires	0

From above table it can be seen that all FTL luminaire have no dimming, they are fully turn on.

5.4.5.2 Work plane Grid for Students Summary:

Summary of work plane grid for students is as following table:

Table 5.27: Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	362	202	676	0.56	0.30	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on work plane grid for students is 362 lx.
- Maximum illuminance (E_{max}) on work plane grid for students is 676 lx.
- Minimum illuminance (E_{min}) on work plane grid for students is 202 lx.
- Uniformity on work plane grid for students is 0.56.
- E_{min} / E_{max} = 0.30.

5.4.5.3 Isolines (E, Perpendicular) on Work plane Grid for Students:

Isolines (E, perpendicular) on work plane Grid for students is as follows:

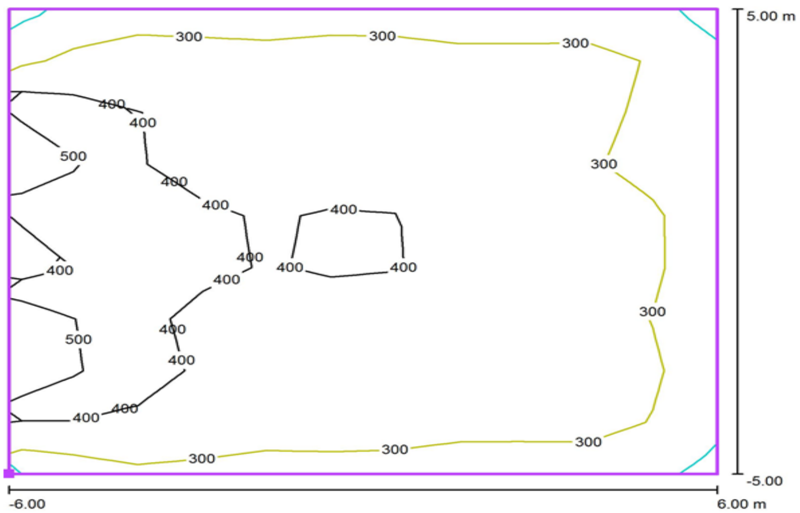


Fig 5.23: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the isolines are concentrated near the windows.
- But 300 lx isoline can cover maximum of the classroom.

5.4.5.4 Value Chart (E, Perpendicular) on Work plane Grid for Students:

Value Chart (E, Perpendicular) on Work plane Grid for students is as follows:

245	297	304	288	296	303	293	281	292	280	230
348	415	404	362	382	411	378	352	385	374	284
588	405	382	365	367	367	362	351	352	202	256
621	428	398	377	378	376	372	361	360	334	258
216	482	455	405	420	444	414	387	415	396	280
482	424	402	381	381	378	374	363	362	337	260
676	430	394	372	372	370	365	354	355	332	259
488	459	422	372	389	415	382	355	388	378	288
302	337	330	303	304	310	296	285	295	283	233

5.00 m, -5.00, -6.00, 6.00 m

Values in Lux, Scale 1 : 86

Fig 5.24: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is well illuminated.
- Window side portion is well illuminated.

5.4.5.5 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 5.28: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\ m}/E_m$	H [m]	Camera
1	horizontal	179	167	193	0.93	0.86	/	0.000	/

$E_{h\ m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 179 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 193 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 167 lx.
- Uniformity on calculation gird for board is 0.93.
- E_{min} / E_{max} = 0.86.

5.4.5.6 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 5.25: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is lower than the recommended average illuminance, 200lx. (Ref. 3.1.5)
- Uniformity is good, 0.93.

5.4.5.7 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 5.29: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	21
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	22
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	21

From above UGR Observer Table it can be seen UGR value is 21. It is under the specified recommendation limit. (Ref: 3.1.4)

5.4.5.8 Photometric Result:

Table 5.30: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	362	93	1153	0.257
Floor	68	310	12	1072	0.039
Ceiling	88	140	94	172	0.673
Walls (4)	59	192	15	495	/

Table 5.31: Details of Output on Different Plane

Lighting Parameters on Floor, Ceiling & Walls					
SL no	**Surface Description**	**E_{max} (lx)**	**E_{min} (lx)**	**E_{av} (lx)**	**Uniformity (u_o)**
1	Floor Surface	1072	12	310	0.039
2	Ceiling	172	94	140	0.673
3	Four Walls	495	15	192	-

Table 5.32: Luminaire Output

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	9	Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS] (1.000)	4479	6500	84.7
			Total: 40311	Total: 58500	762.3

- Total Luminous Flux: 40311 lm
- Total Load: 762.3 W
- Ground area: 120.00 m²
- LPD: 6.35 W/m²

5.5 Result Overview:

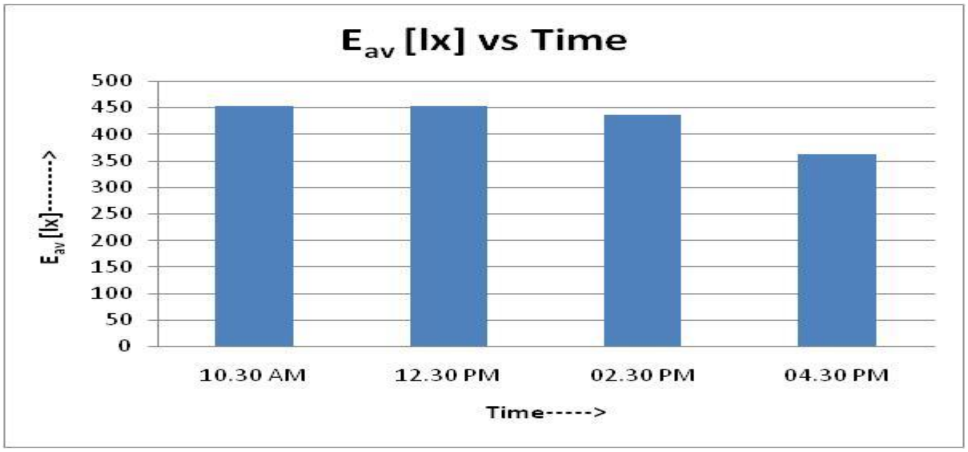
5.5.1 Illuminance on Work plane Grid For Students:

Average Illuminance on work plane Grid for Students for four times are tabulated below:

Table 5.33: Eav[lx] on Work plane Grid For Students

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
E_{av}[lx]	453	452	435	362

Chart 5.1: E_{av}[lx] on Work plane Grid For Students



From the above chart it can be summarized that:

- In morning time very high value of average illuminance can be obtained.
- As the time goes on average illuminance decreases.
- At 04.30PM minimum value of average illuminance obtained because daylight decreases.

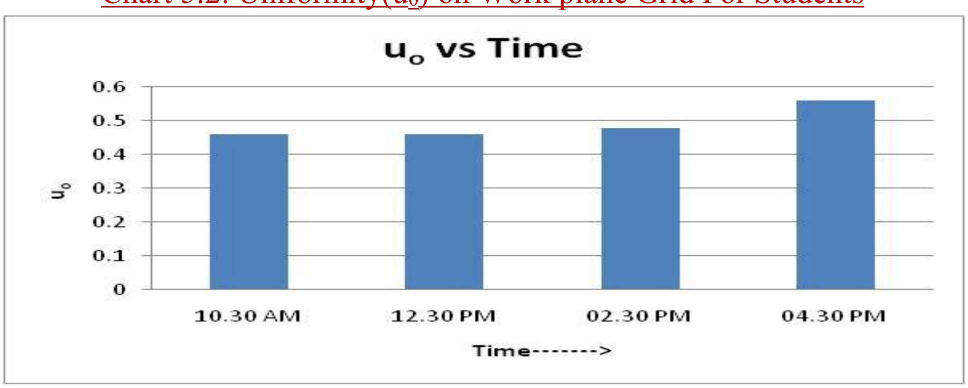
5.5.2 Uniformity on Work plane Grid For Students:

Uniformity (u_0) on work plane Grid For Students for four times are tabulated below:

Table 5.34: Uniformity(u0) on Work plane Grid For Students

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
u_o	0.46	0.46	0.48	0.56

Chart 5.2: Uniformity(u_0) on Work plane Grid For Students



From the above chart it can be summarized that:

- As the time goes on Maximum illuminance value decreases, so uniformity goes higher.

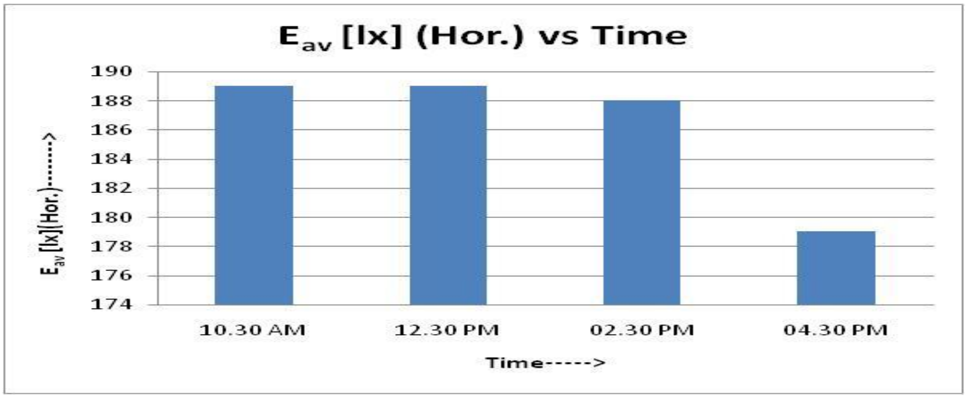
5.5.3 Illuminance on Horizontal Calculation Grid On Board:

Illuminance on Horizontal Calculation Grid on Board for four times are tabulated below:

Table 5.35: Illuminance on Horizontal Calculation Grid on Board

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
E_{av}[lx] (Hor.)	189	189	188	179

Chart 5.3: Illuminance on Horizontal Calculation Grid on Board



From the above chart it can be summarized that:

- As the days goes on average horizontal illuminance on black board decreases.
- It is lower than the recommended horizontal illuminance on blackboard,200 lx.

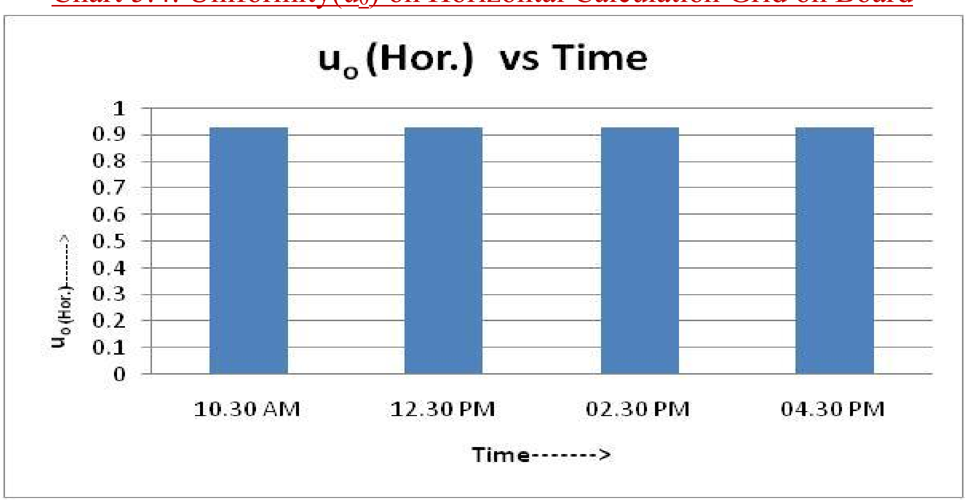
5.5.4 Uniformity on Horizontal Calculation Grid On Board:

Uniformity(u_0) on Horizontal Calculation Grid on Board for four times are tabulated below:

Table 5.36: Uniformity(u0) on Horizontal Calculation Grid on Board

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
u_o (Hor.)	0.93	0.93	0.93	0.93

Chart 5.4: Uniformity(u_0) on Horizontal Calculation Grid on Board



From the above chart it can be summarized that:

- As the time goes on both average & minimum illuminance both decreases, so uniformity remains unchanged.

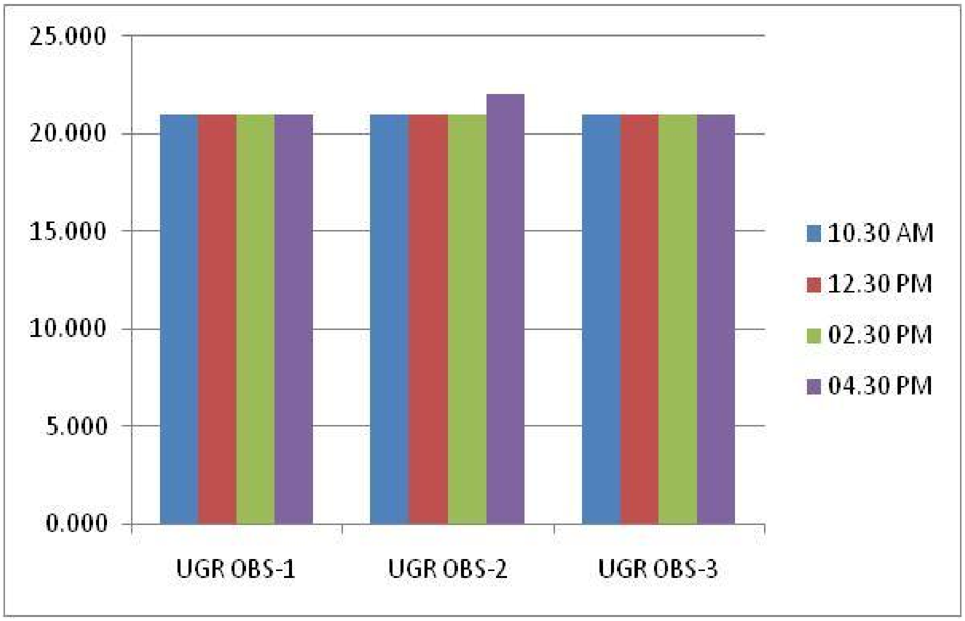
5.5.5 UGR Observer:

3 UGR Observer at four different times are tabulated below:

Table 5.37: UGR Observer Result

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
UGR OBS-1	21.0	21.0	21.0	21.0
UGR OBS-2	21.0	21.0	21.0	22.0
UGR OBS-3	21.0	21.0	21.0	21.0

Chart 5.5: UGR Observer Result



From the above table it can be seen that UGR value is within the recommendation leval for a classroom, i.e, 16-25.

5.5.6 Total wattage of Luminaire:

As the no luminaire control is used in the classroom so luminaire total wattage is same for the four measurement time.

- Total Wattage: 84.7X9=762.3 Watt

5.5.7 LPD:

Total Wattage: 84.7X9=762.3 Watt

Total Area of the room: 12X10=120 m^2

LPD: 762.3/120= 6.35W/ m^2

5.6 Summary:

Table 5.38: Average Illumination on Work Plane

SL NO	Work Plane Name	Time	Average Illuminance (lux)
1	Work Plane for Students	10.30 AM	453
2	Work Plane for Students	12.30 PM	452
3	Work Plane for Students	02.30 PM	435
4	Work Plane for Students	04.30 PM	362

Table 5.39: Average Illumination (Horz.) on Black Board

SL NO	Work Plane Name	Time	Average Illuminance (Horz.) (lux)
1	Black Board	10.30 AM	189
2	Black Board	12.30 PM	189
3	Black Board	02.30 PM	188
4	Black Board	04.30 PM	179

Table 5.40: Unified Glare Rating by Glare Observer

SL NO	Work Plane	Time	UGR (Obs. 1, Obs. 2 & Obs. 3)
1	Work Plane for Students	10.30 AM	21, 21, 21
2	Work Plane for Students	12.30 PM	21, 21, 21
3	Work Plane for Students	02.30 PM	21, 21, 21
4	Work Plane for Students	04.30 PM	21, 22, 21

Table 5.41: LPD of the Classroom

SL NO	Time	LPD (W/m^2)
1	10.30 AM	6.35
2	12.30 PM	6.35
3	02.30 PM	6.35
4	04.30 PM	6.35

- Transmittance of the window is low, 70%.
- Daylight enters in the room is low.
- No Artificial Lighting Controller is used.
- Lumen Wastage is high.
- Illuminance on the work plane is satisfy the recommendation value.
- As FTL is used so luminaire total wattage is high.
- Energy consumption of the classroom is high.

5.7 Recommendation:

- It is recommended to clean the window glass so that degree of transmittance get better.
- Use modern LED Batten for energy consumption.
- Use Dimmer for better uniformity & energy consumption.

Chapter-6

Lighting Design Using Only Daylight

6.1 Design Consideration:

- Only Daylight is used.
- No Artificial light is used.
- Window Glass are cleaned so that transmittance get better to 90%.

6.2 Lighting Parameters Measurement:

6.2.1 Consideration for Measurement of Lighting Parameters:

For measurement of lighting parameters with only daylight measurement consideration is same as Chapter-5 .

6.2.2 Measurement of Lighting Parameters at 10.30 AM:

6.2.2.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°
- Date: 21.03.2022, Time:10:30:00 (+5 hours difference to GMT)
- Reference sky type: Clear sky

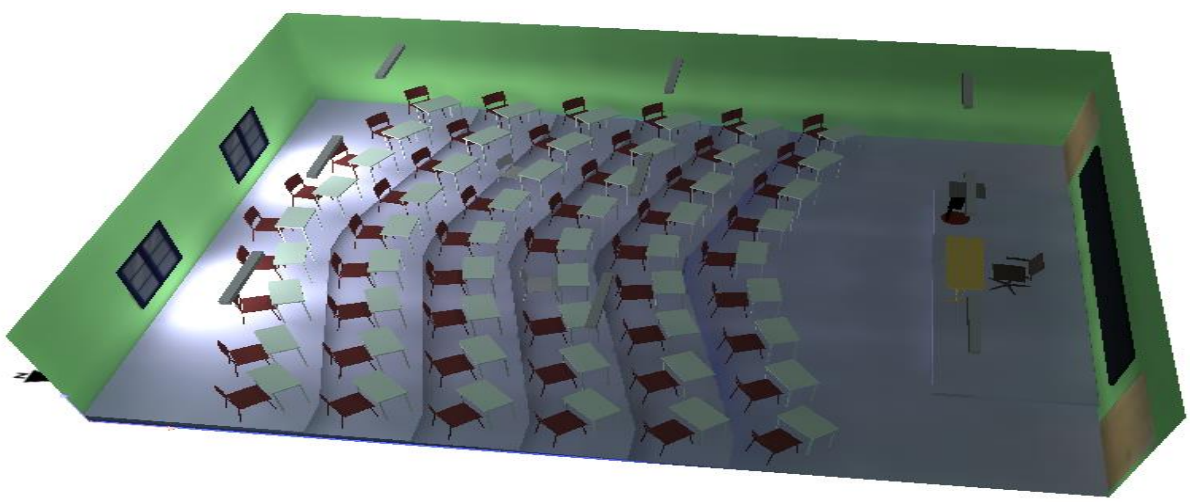


Fig 6.1: Window Orientation of the classroom at 10.30 AM

Table 6.1: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	Control group 28 (Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS])	0
	All other luminaires	0

From above table it can be seen that all FTL luminaires are switched off, they emits no lumen output.

6.2.2.2 Work plane Grid for Students Summary:

Summary of work plane grid for students is as following table:

Table 6.2: Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	176	17	2485	0.09	0.01	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on work plane grid for students is 176 lx.
- Maximum illuminance (E_{max}) on work plane grid for students is 2485 lx.
- Minimum illuminance (E_{min}) on work plane grid for students is 17 lx.
- Uniformity on work plane grid for students is 0.09.
- E_{min} / E_{max} = 0.01.

6.2.2.3 Isolines (E, Perpendicular) on Work plane Grid for Students:

Isolines (E, perpendicular) on work plane Grid for students is as follows:

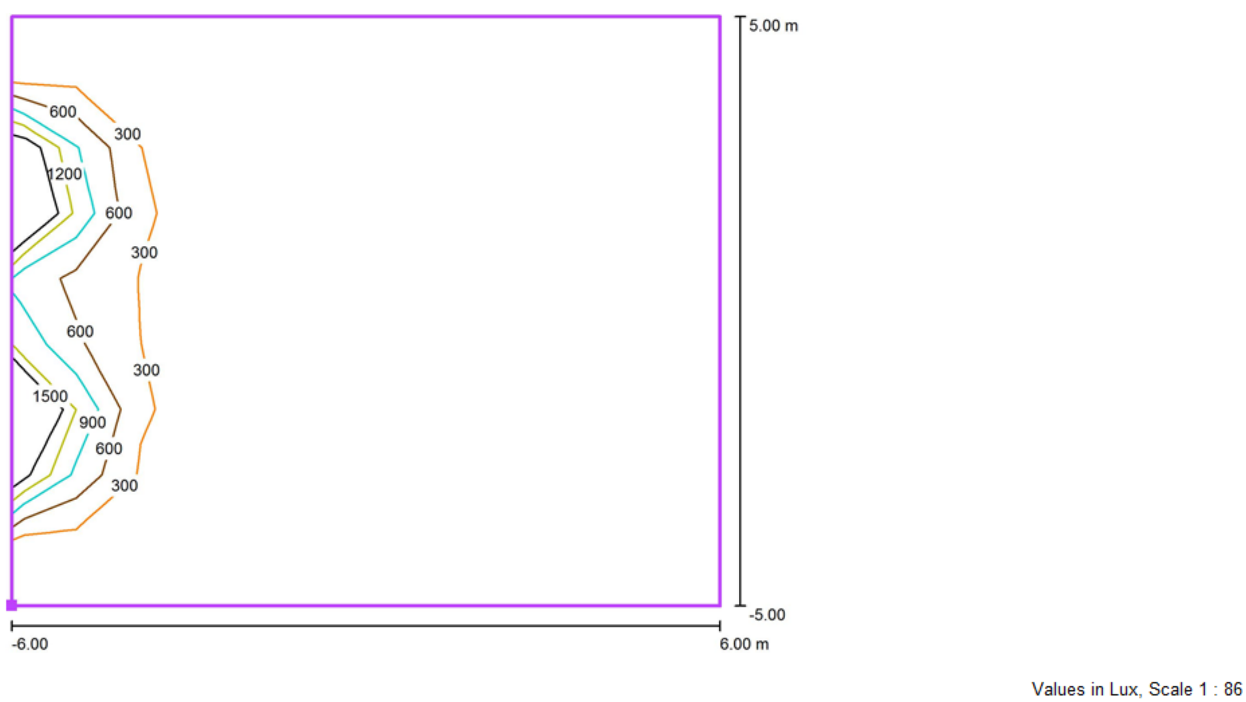


Fig 6.2: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the isolines are concentrated near the windows.
- Very bad illumination in the classroom.
- Insufficient lighting.

6.2.2.4 Value Chart (E, Perpendicular) on Work plane Grid for Students:

Value Chart (E, Perpendicular) on Work plane Grid for students is as follows:

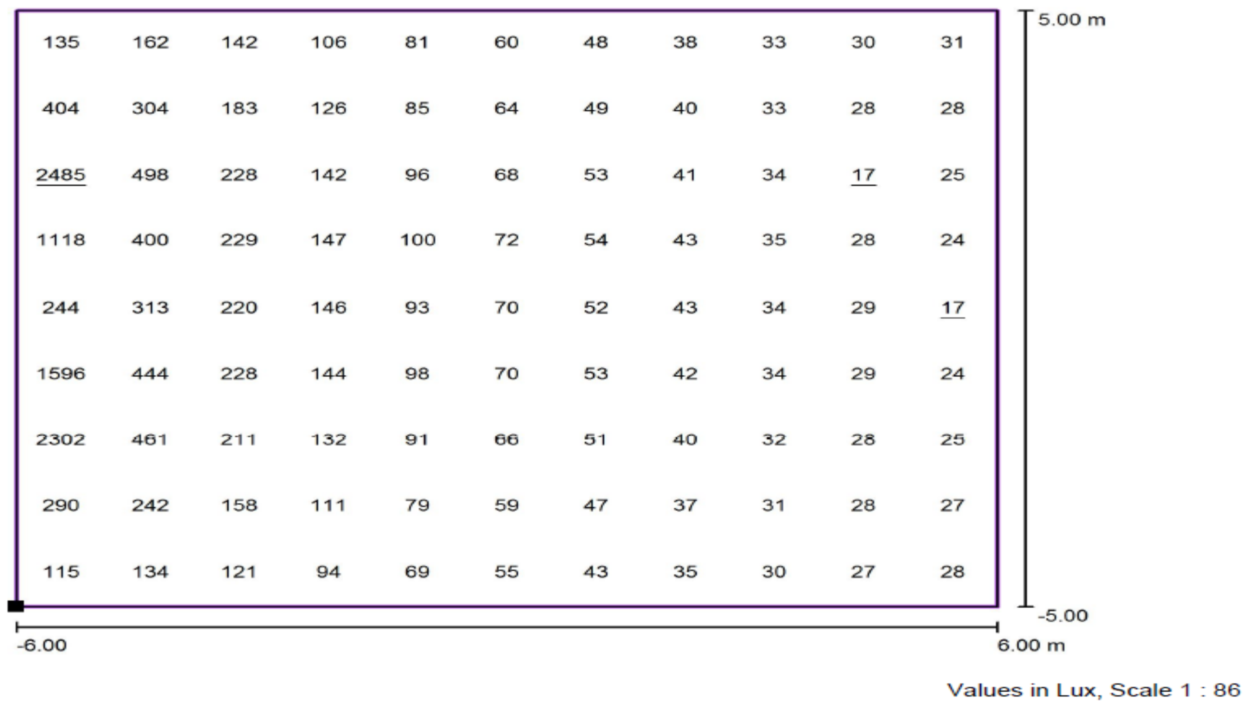


Fig 6.3: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is badly illuminated.
- Window side portion also not so goodly illuminated.

6.2.2.5 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 6.3: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\ m}/E_m$	H [m]	Camera
1	horizontal	16	15	18	0.93	0.82	/	0.000	/

$E_{h\ m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 16 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 18 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 15 lx.
- Uniformity on calculation gird for board is 0.93.
- E_{min} / E_{max} = 0.82.

6.2.2.6 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 6.4: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is lower than the recommended average illuminance.
- Uniformity is good.
- Very bad illumination on blackboard.

6.2.2.7 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 6.4: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	/
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	/
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	/

From above UGR Observer Table it can be seen UGR value is very low. It means no glare, low illumination on blackboard.

6.2.2.8 Photometric Result:

Table 6.5: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	181	18	5424	0.098
Floor	68	557	9.53	1986	0.017
Ceiling	88	73	18	245	0.251
Walls (4)	59	93	10	493	/

Table 6.6: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	Surface Description	E_{max} (lx)	E_{min} (lx)	E_{av} (lx)	Uniformity (u_o)
1	Floor Surface	1986	9.53	557	0.017
2	Ceiling	245	18	73	0.251
3	Four Walls	493	10	93	-

- Total Luminous Flux: 0 lm
- Total Load: 0 W
- Ground area: 120.00 m²
- LPD: 0 W/m²

6.2.3 Measurement of Lighting Parameters at 12.30 PM:

6.2.3.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°
- Date: 21.03.2022, Time:12:30:00 (+5 hours difference to GMT)
- Reference sky type: Clear sky

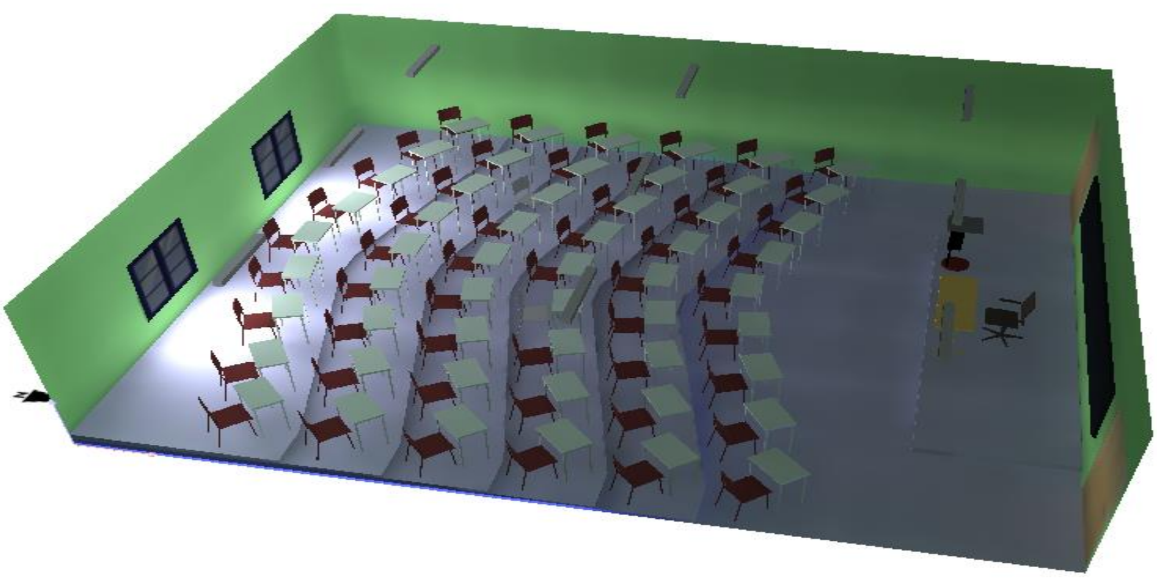


Fig 6.5: Window Orientation of the classroom at 12.30 PM

Table 6.7: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	Control group 28 (Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS])	0
	All other luminaires	0

From above table it can be seen that all FTL luminaire switched off, they emits no lumen output.

6.2.3.2 Work plane Grid for Students Summary:

Summary of work plane grid for students is as following table:

Table 6.8: Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	176	16	2488	0.09	0.01	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on work plane grid for students is 176 lx.
- Maximum illuminance (E_{max}) on work plane grid for students is 2488 lx.
- Minimum illuminance (E_{min}) on work plane grid for students is 16 lx.
- Uniformity on work plane grid for students is 0.09.
- E_{min} / E_{max} = 0.01.

6.2.3.3 Isolines (E, Perpendicular) on Work plane Grid for Students:

Isolines (E, perpendicular) on work plane Grid for students is as follows:

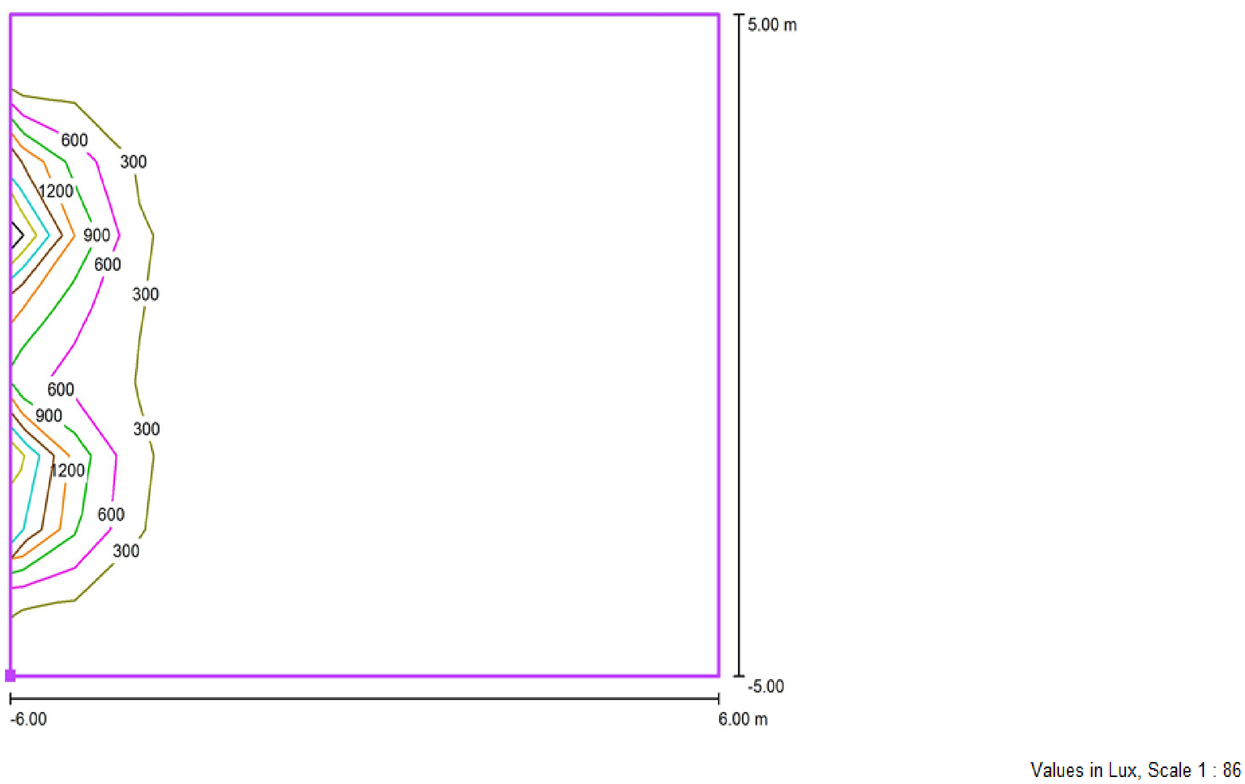


Fig 6.6: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the isolines are concentrated near the windows.
- Very bad illumination in the classroom.
- Insufficient lighting.

6.2.3.4 Value Chart (E, Perpendicular) on Work plane Grid for Students:

Value Chart (E, Perpendicular) on Work plane Grid for students is as follows:

109	128	114	89	69	52	42	34	30	27	28
266	227	151	108	75	57	44	36	30	26	26
2154	437	207	129	88	63	49	39	32	16	24
1759	462	232	143	96	69	51	42	34	27	23
260	323	222	145	93	70	52	42	34	29	17
979	382	223	147	101	72	55	44	35	29	24
2488	504	228	143	98	70	54	43	33	29	26
482	329	191	129	89	66	51	40	34	30	29
146	175	154	115	81	64	49	40	32	29	31

5.00 m

-5.00

-6.00

6.00 m

Values in Lux, Scale 1 : 86

Fig 6.7: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is badly illuminated.
- Window side portion is not well illuminated.

6.2.3.5 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 6.9: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	16	14	18	0.91	0.78	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 16 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 18 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 14 lx.
- Uniformity on calculation gird for board is 0.91.
- E_{min} / E_{max} = 0.78.

6.2.3.6 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

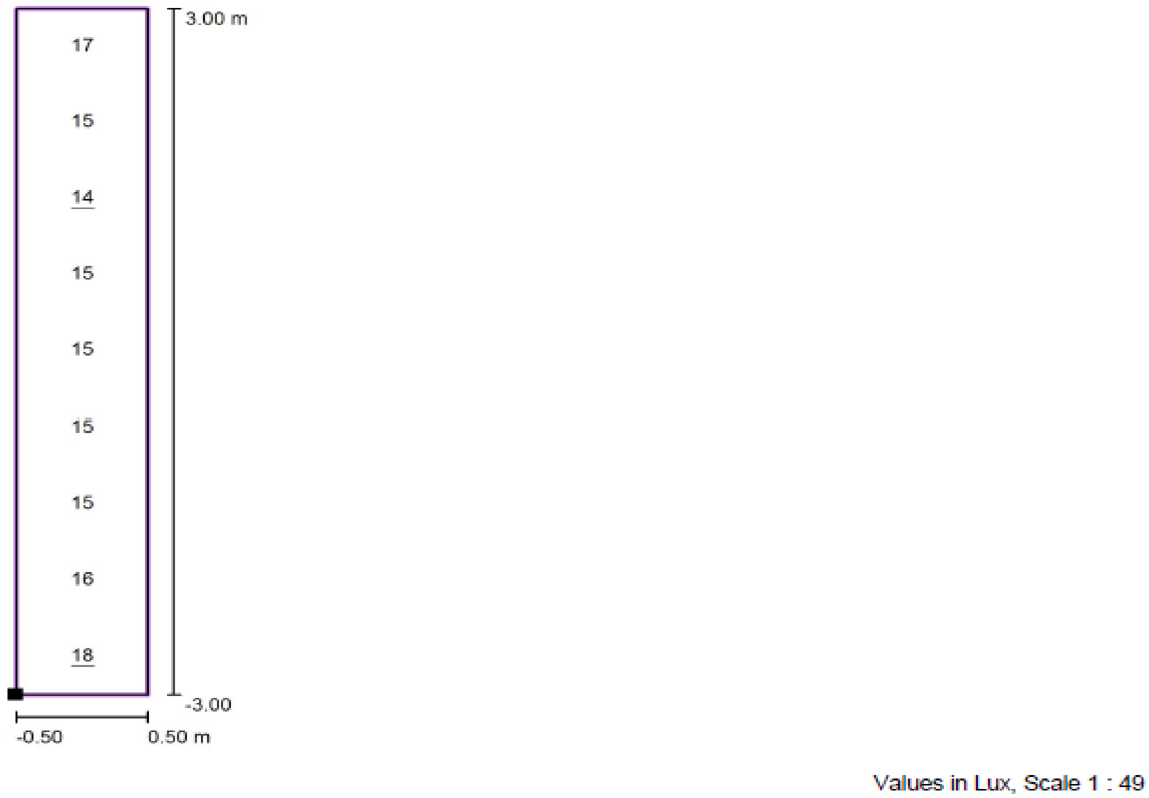


Fig 6.8: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is lower than the recommended average illuminance.
- Uniformity is good.
- Very bad illumination on blackboard.

6.2.3.7 Measurement of UGR:

3 Nos UGR Obesrver result overview is as following table:

Table 6.10: UGR Observer Result Overview

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	/
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	/
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	/

From above UGR Observer Table it can be seen UGR value is very low. It means no glare low illumination on blackboard.

6.2.3.8 Photometric Result:

Table 6.11: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	180	18	5350	0.098
Floor	68	562	9.82	2222	0.017
Ceiling	88	72	18	243	0.249
Walls (4)	59	94	11	478	/

Table 6.12: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	Surface Description	E_{max} (lx)	E_{min} (lx)	E_{av} (lx)	Uniformity (u_o)
1	Floor Surface	2222	9.82	562	0.017
2	Ceiling	243	18	72	0.249
3	Four Walls	478	11	94	-

- Total Luminous Flux: 0 lm
- Total Load: 0 W
- Ground area: 120.00 m²
- LPD: 0 W/m²

6.2.4 Measurement of Lighting Parameters at 02.30 PM:

6.2.4.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°
- Date: 21.03.2022, Time:14:30:00 (+5 hours difference to GMT)
- Reference sky type: Clear sky

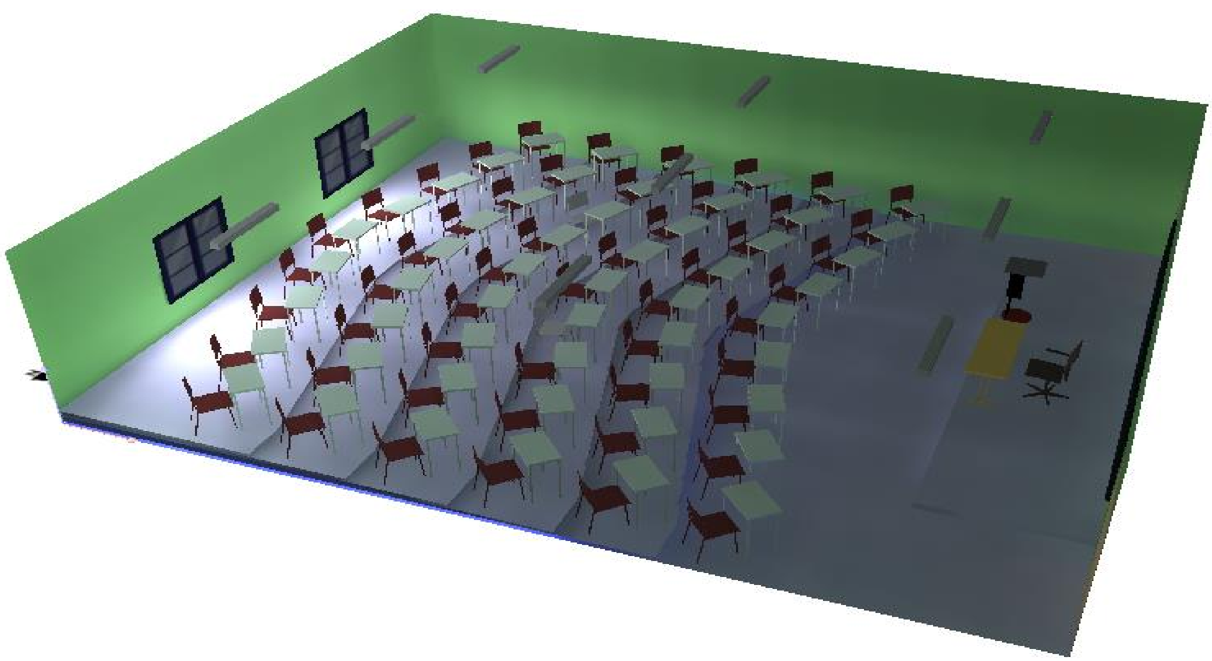


Fig 6.9: Window Orientation of the classroom at 02.30 PM

Table 6.13: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	Control group 28 (Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS])	0
	All other luminaires	0

From above table it can be seen that all FTL luminaire switched off, they emits no lumen output.

6.2.4.2 Work plane Grid for Students Summary:

Summary of work plane grid for students is as following table:

Table 6.14: Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	154	13	1909	0.09	0.01	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on work plane grid for students is 154 lx.
- Maximum illuminance (E_{max}) on work plane grid for students is 1909 lx.
- Minimum illuminance (E_{min}) on work plane grid for students is 13 lx.
- Uniformity on work plane grid for students is 0.09.
- E_{min} / E_{max} = 0.01.

6.2.4.3 Isolines (E, Perpendicular) on Work plane Grid for Students:

Isolines (E, perpendicular) on work plane Grid for students is as follows:

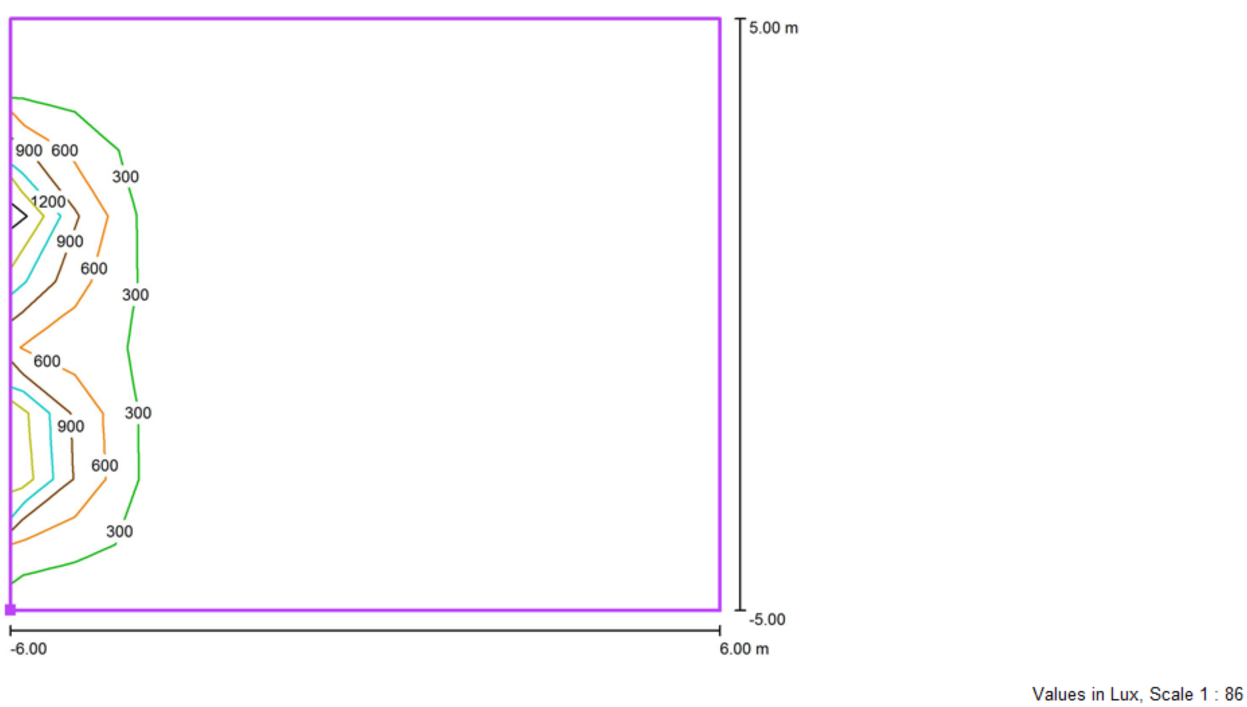


Fig 6.10: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the isolines are concentrated near the windows.
- Very bad illumination in the classroom.
- Insufficient lighting.

6.2.4.4 Value Chart (E, Perpendicular) on Work plane Grid for Students:

Value Chart (E, Perpendicular) on Work plane Grid for students is as follows:

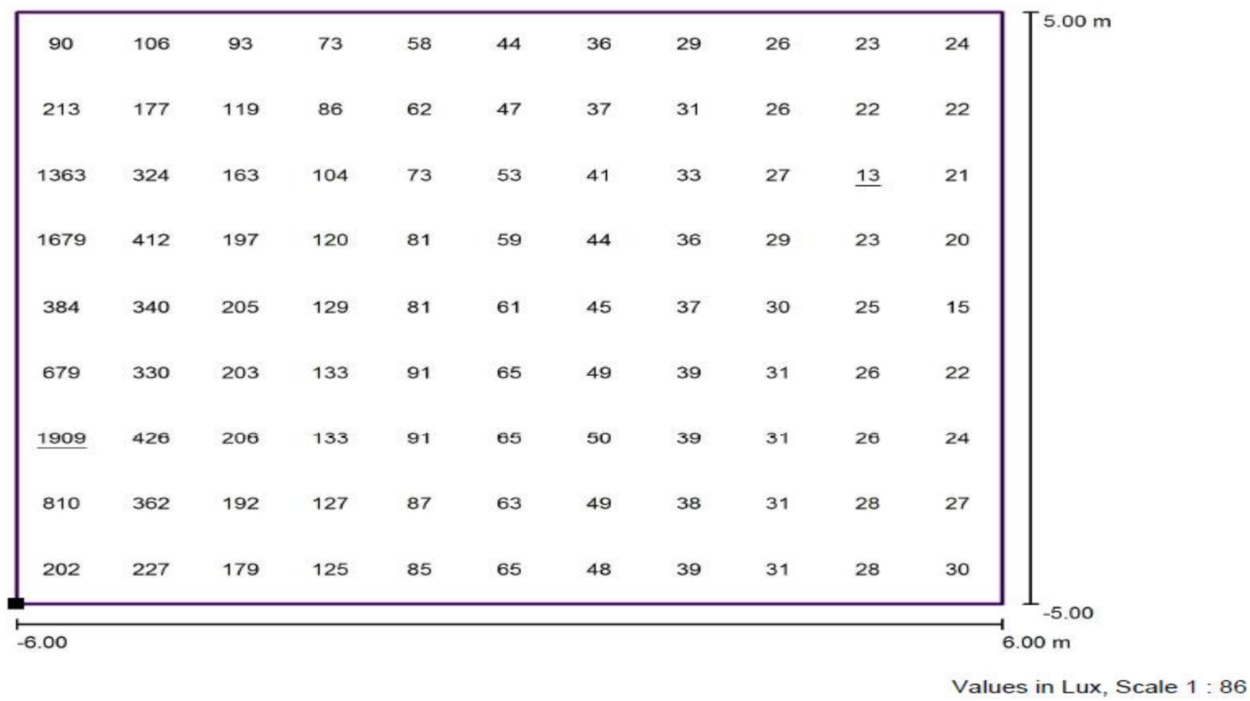


Fig 6.11: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is badly illuminated.
- Window side portion is not well illuminated.

6.2.4.5 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 6.15: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\ m}/E_m$	H [m]	Camera
1	horizontal	14	13	17	0.90	0.75	/	0.000	/

$E_{h\ m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 14 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 17 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 13 lx.

- Uniformity on calculation gird for board is 0.90.
- $E_{min} / E_{max} = 0.75$.

6.2.4.6 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

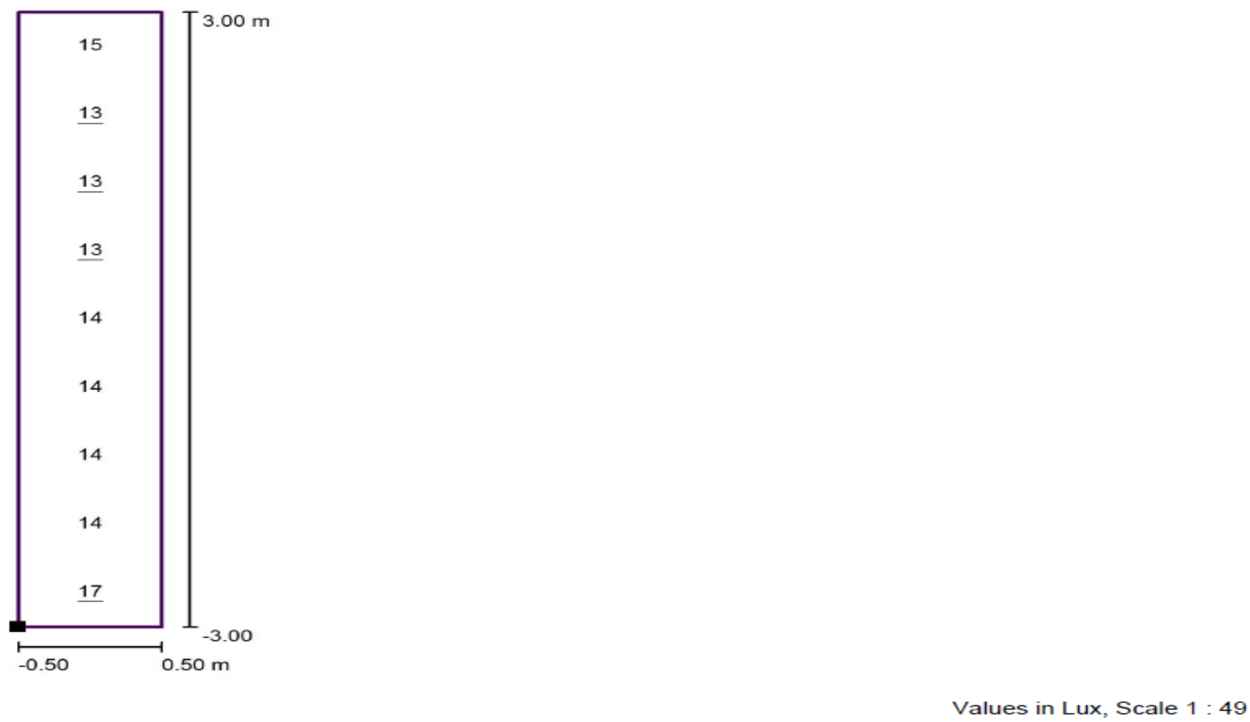


Fig 6.12: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is lower than the recommended average illuminance.
- Uniformity is good.
- Very bad illumination on blackboard.

6.2.4.7 Measurement of UGR:

3 Nos UGR Obesrver result overview is as following table:

Table 6.16: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	/
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	/
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	/

From above UGR Observer Table it can be seen UGR value is very low. It means no glare, low illumination on blackboard.

6.2.4.8 Photometric Result:

Table 6.17: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	155	16	4191	0.100
Floor	68	527	8.00	2139	0.015
Ceiling	88	62	16	203	0.257
Walls (4)	59	89	9.40	683	/

Table 6.18: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	Surface Description	E_{max} (lx)	E_{min} (lx)	E_{av} (lx)	Uniformity (u_o)
1	Floor Surface	2139	8	527	0.015
2	Ceiling	203	16	62	0.257
3	Four Walls	683	9.4	89	-

- Total Luminous Flux: 0 lm
- Total Load: 0 W
- Ground area: 120.00 m²
- LPD: 0 W/m²

6.2.5 Measurement of Lighting Parameters at 04.30 PM:

6.2.5.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°
- Date: 21.03.2022, Time:16:30:00 (+5 hours difference to GMT)
- Reference sky type: Clear sky

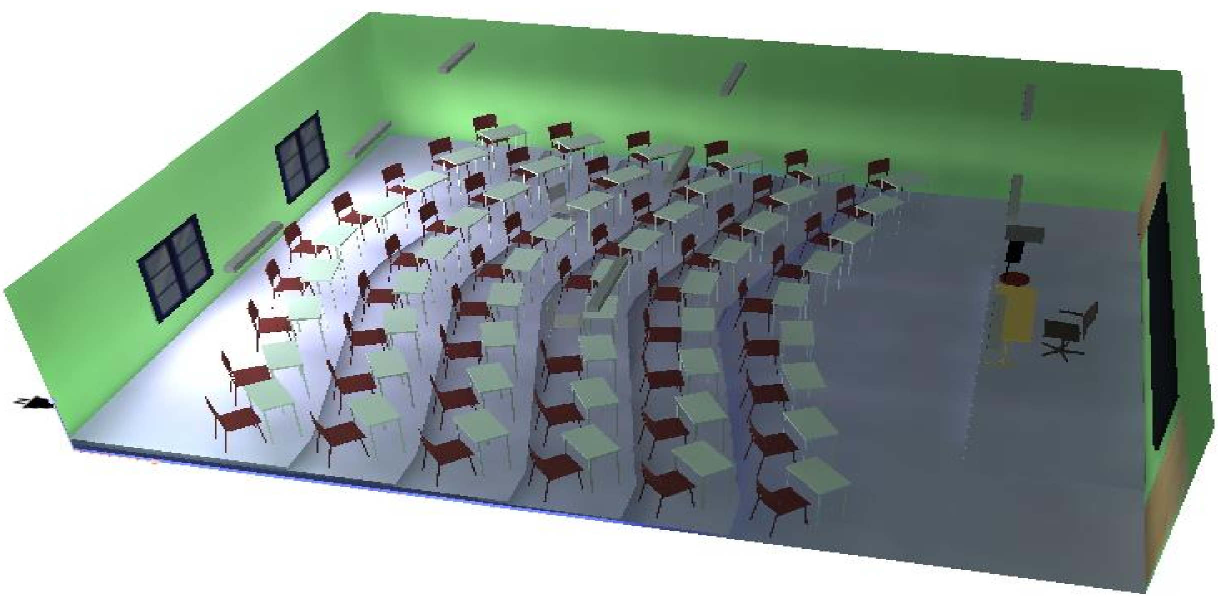


Fig 6.13: Window Orientation of the classroom at 04.30 PM

Table 6.19: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	Control group 28 (Database version IES95 2006-03-02 TCS350/236'C5'[ECO TCS])	0
	All other luminaires	0

From above table it can be seen that all FTL luminaire switched off, they emits no lumen output.

6.2.5.2 Work plane Grid for Students Summary:

Summary of work plane grid for students is as following table:

Table 6.20: Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	55	5.31	558	0.10	0.01	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on work plane grid for students is 55 lx.
- Maximum illuminance (E_{max}) on work plane grid for students is 558 lx.
- Minimum illuminance (E_{min}) on work plane grid for students is 5.31 lx.
- Uniformity on work plane grid for students is 0.10.
- E_{min} / E_{max} = 0.01.

6.2.5.3 Isolines (E, Perpendicular) on Work plane Grid for Students:

Isolines (E, perpendicular) on work plane Grid for students is as follows:

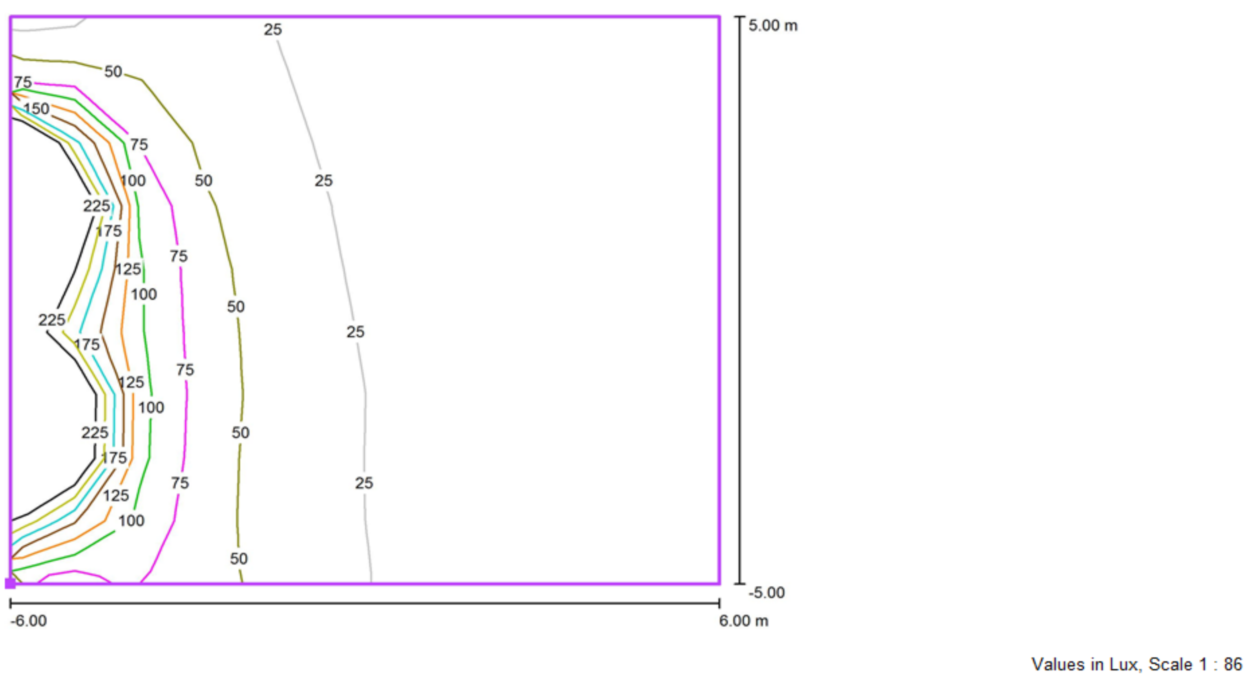


Fig 6.14: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the isolines are concentrated near the windows.
- Very bad illumination in the classroom.
- Insufficient lighting.

6.2.5.4 Value Chart (E, Perpendicular) on Work plane Grid for Students:

Value Chart (E, Perpendicular) on Work plane Grid for students is as follows:

37	44	38	29	23	18	14	12	10	9.27	9.52
96	73	47	34	24	18	14	12	10	8.77	8.72
445	118	60	39	27	20	16	13	10	5.31	8.00
467	138	71	44	30	22	17	14	11	8.94	7.70
174	128	75	47	30	23	17	14	11	9.65	5.53
289	133	77	49	34	24	18	15	12	9.81	8.22
558	150	76	50	34	24	19	15	11	9.91	8.87
275	130	71	47	33	24	18	14	12	10	10
110	97	72	49	33	25	18	15	12	11	11

5.00 m

-5.00

-6.00

6.00 m

Values in Lux, Scale 1 : 86

Fig 6.15: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is badly illuminated.
- Window side portion is not well illuminated.

6.2.5.5 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 6.21: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	5.34	4.88	6.33	0.91	0.77	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 5.34 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 6.33 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 4.88 lx.
- Uniformity on calculation gird for board is 0.91.
- E_{min} / E_{max} = 0.77.

6.2.5.6 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 6.16: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is lower than the recommended average illuminance.
- Uniformity is good.
- Very bad illumination on blackboard.

6.2.5.7 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 6.22: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	/
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	/
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	/

From above UGR Observer Table it can be seen UGR value is very low. It means no glare, low illumination on blackboard.

6.2.5.8 Photometric Result:

Table 6.23: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	55	5.87	1229	0.107
Floor	68	178	2.94	746	0.017
Ceiling	88	22	6.03	68	0.276
Walls (4)	59	35	3.60	419	/

Table 6.24: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	Surface Description	E_{max} (lx)	E_{min} (lx)	E_{av} (lx)	Uniformity (u_o)
1	Floor Surface	746	2.94	178	0.017
2	Ceiling	68	6.03	22	0.276
3	Four Walls	419	3.6	35	-

- Total Luminous Flux: 0 lm
- Total Load: 0 W
- Ground area: 120.00 m²
- LPD: 0 W/m²
- In this condition classroom is considered as lightless.

6.3 Result Overview:

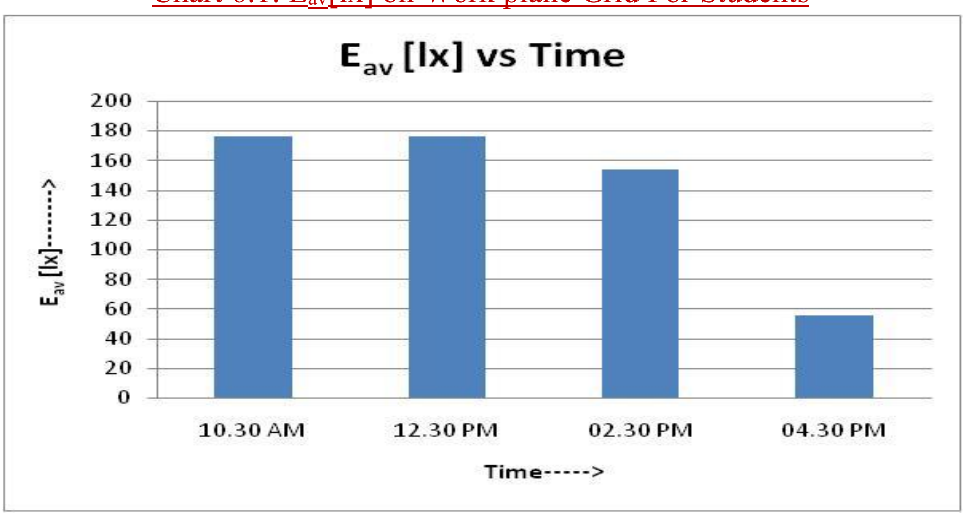
6.3.1 Illuminance on Work plane Grid For Students:

Average Illuminance on work plane Grid For Students for four times are tabulated below:

Table 6.25: Eav[lx] on Work plane Grid For Students

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
E_{av} [lx]	176	176	154	55

Chart 6.1: E_{av}[lx] on Work plane Grid For Students



From above chart it can be summarized that:

- Insufficient average illumination in the classroom.
- As the time goes on average illumination also decreases.

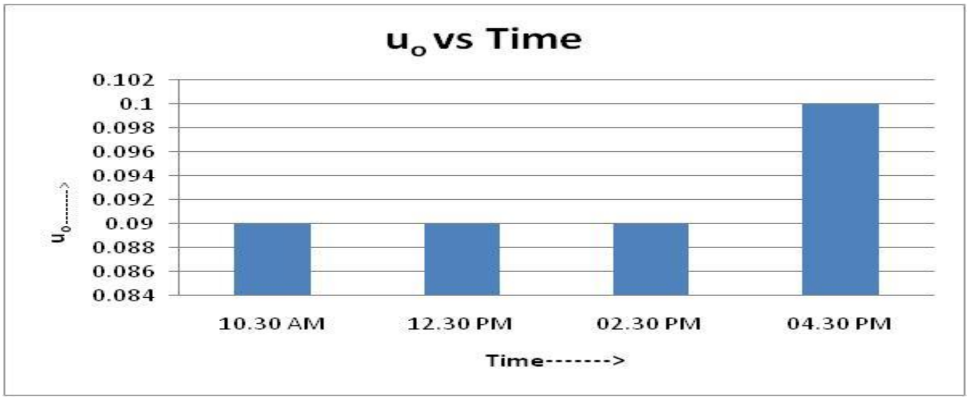
6.3.2 Uniformity on Work plane Grid For Students:

Uniformity(u_0) on work plane Grid For Students for four times are tabulated below:

Table 6.26: Uniformity(u0) on Work plane Grid For Students

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
u_o	0.09	0.09	0.09	0.1

Chart 6.2: Uniformity(u_0) on Work plane Grid For Students



From the above chart it can be summarized that:

- Uniformity in the classroom is bad.

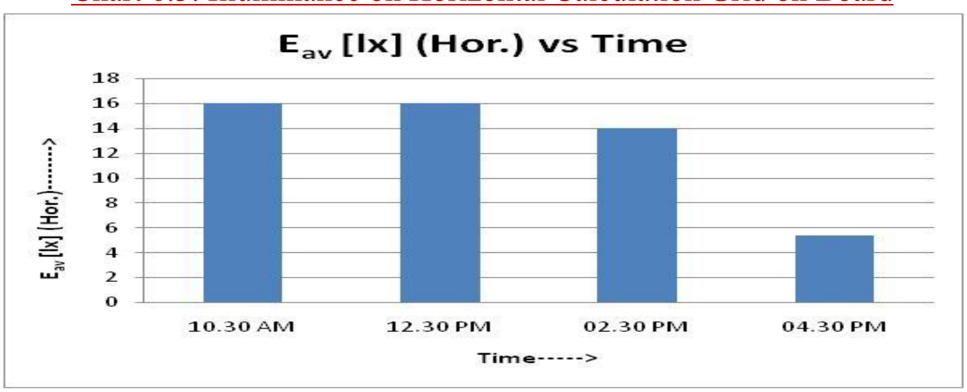
6.3.3 Illuminance on Horizontal Calculation Grid On Board:

Illuminance on Horizontal Calculation Grid on Board for four times are tabulated below:

Table 6.27: Illuminance on Horizontal Calculation Grid on Board

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
E_{av} [lx] (Hor.)	16	16	14	5.34

Chart 6.3: Illuminance on Horizontal Calculation Grid on Board



From above chart it can be summarized that:

- Improper illumination on the blackboard, in one word darkness on blackboard.

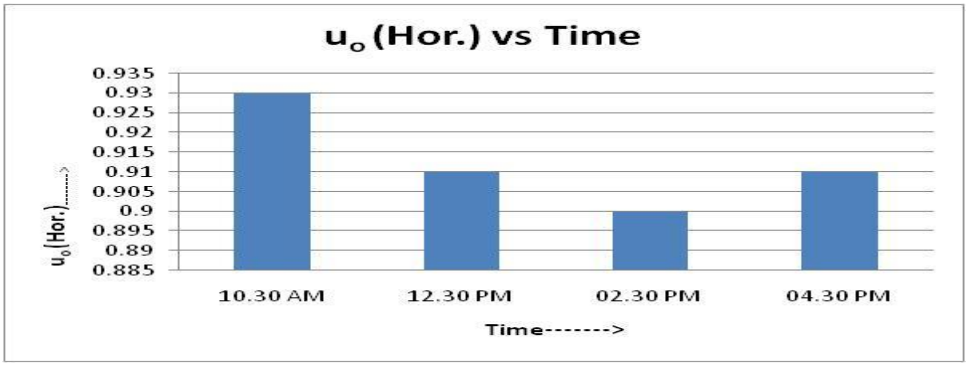
6.3.4 Uniformity on Horizontal Calculation Grid On Board:

Uniformity(u_0) on Horizontal Calculation Grid on Board for four times are tabulated below:

Table 6.28: Uniformity(u0) on Horizontal Calculation Grid on Board

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
u_o (Hor.)	0.93	0.91	0.9	0.91

Chart 6.4: Uniformity(u_0) on Horizontal Calculation Grid on Board



From above table it can be summarized that:

- Horizontal uniformity is good but it is for low value of average and minimum illuminance.

6.3.5 Total wattage of Luminaire:

As the no luminaire is used in the classroom so luminaire total wattage is 0 for the four measurement time.

- Total Wattage: 0X9=0 Watt

6.3.6 LPD:

Total Wattage: 0X9=0 Watt

Total Area of the room: 12X10=120 m^2

LPD: 0/120= 0W/ m^2

6.4 Summary:

Table 6.30: Average Illumination on Work Plane

SL NO	Work Plane Name	Time	Average Illuminance (lux)
1	Work Plane for Students	10.30 AM	176
2	Work Plane for Students	12.30 PM	176
3	Work Plane for Students	02.30 PM	154
4	Work Plane for Students	04.30 PM	55

Table 6.31: Average Illumination (Horz.) on Blackboard

SL NO	Work Plane Name	Time	Average Illuminance (lux)
1	Black Board	10.30 AM	16
2	Black Board	12.30 PM	16
3	Black Board	02.30 PM	14
4	Black Board	04.30 PM	5.34

Table 6.32: LPD of the Classroom

SL NO	Time	LPD (W/m²)
1	10.30 AM	0
2	12.30 PM	0
3	02.30 PM	0
4	04.30 PM	0

- Transmittance of the window is high, 90%.
- Daylight enters in the room is comparatively previous chapter high.
- No Artificial Lighting is used.
- Illuminance on the work plane is not satisfy the recommendation value.
- Very Bad Uniformity.

6.5 Recommendation:

- It is recommended to use Daylight & Artificial Light for proper illumination.
- Use modern LED Batten for energy consumption.
- Use Dimmer for better uniformity & energy consumption.

Chapter-7

Lighting Design By Using Only Artificial LED Luminiare

7.1 Design Consideration:

- In this design only Artificial light are taken for lighting calculation.
- Here control of artificial light implied..
- Dimming strategy has been taken here, because LED batten are used for artificial lighting.

7.2 Details of Luminaire:

In modified lighting design LED batten luminaire are used and details of these luminaire are as follows:

Name of Luminaire:

1. FSC Lighting L28548-40WT-40K.
2. FSC Lighting L28648-25W-40K.

Luminous Flux of the Luminaire:

1. FSC Lighting L28548-40WT-40K.
    - Luminous flux (Lamps): 5057 lm
    - Luminous flux (Luminaire): 5057 lm
2. FSC Lighting L28648-25W-40K.
    - Luminous flux (Lamps): 3333 lm
    - Luminous flux (Luminaire): 3333 lm

Wattage of the Luminaire:

1. FSC Lighting L28548-40WT-40K: 38.3 Watt.
2. FSC Lighting L28648-25W-40K: 24.9 Watt.

Luminaire Classification according to CIE:

1. FSC Lighting L28548-40WT-40K: 88.
2. FSC Lighting L28648-25W-40K: 91.

Luminaire CIE Flux Code:

1. FSC Lighting L28548-40WT-40K: 42 71 89 88 100.
2. FSC Lighting L28648-25W-40K: 42 71 90 91 100.

Luminaire Fittings:

1. FSC Lighting L28548-40WT-40K: 1 x User defined (Correction Factor 1.000).
2. FSC Lighting L28648-25W-40K: 1 x User defined (Correction Factor 1.000).

Luminaire LDC (Polar):

1. FSC Lighting L28548-40WT-40K:

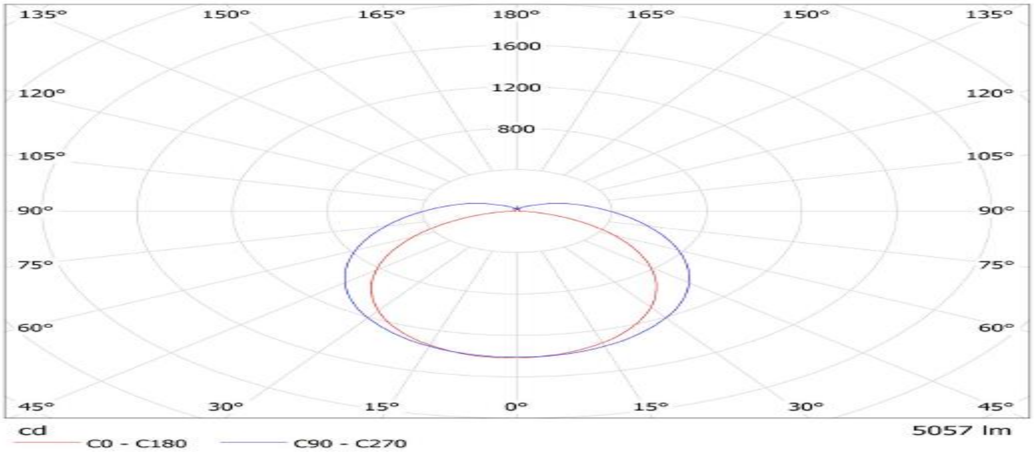


Fig 7.1: LDC (Polar) of the Luminaire FSC Lighting L28548-40WT-40K

2. FSC Lighting L28648-25W-40K:

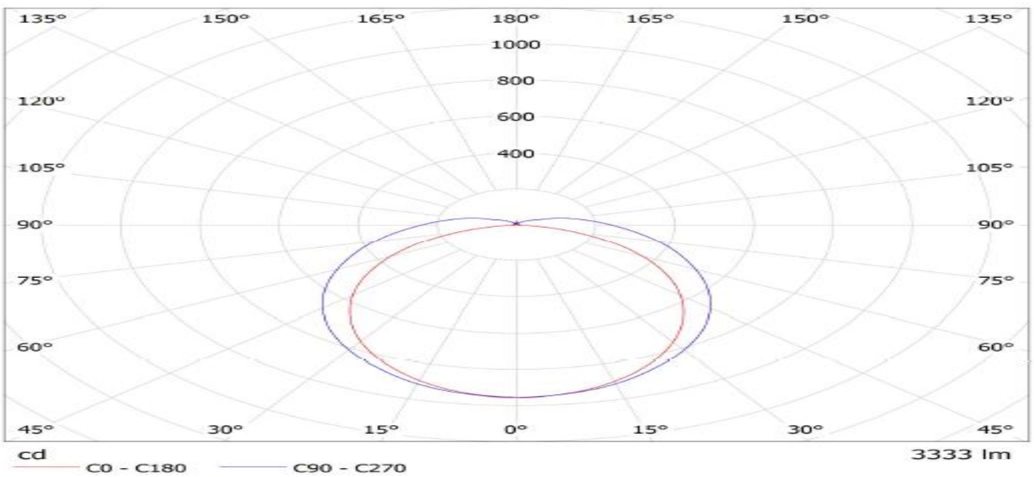


Fig 7.2: LDC (Polar) of the Luminaire FSC Lighting L28648-25W-40K

Luminaire LDC (Linear):

1. FSC Lighting L28548-40WT-40K:

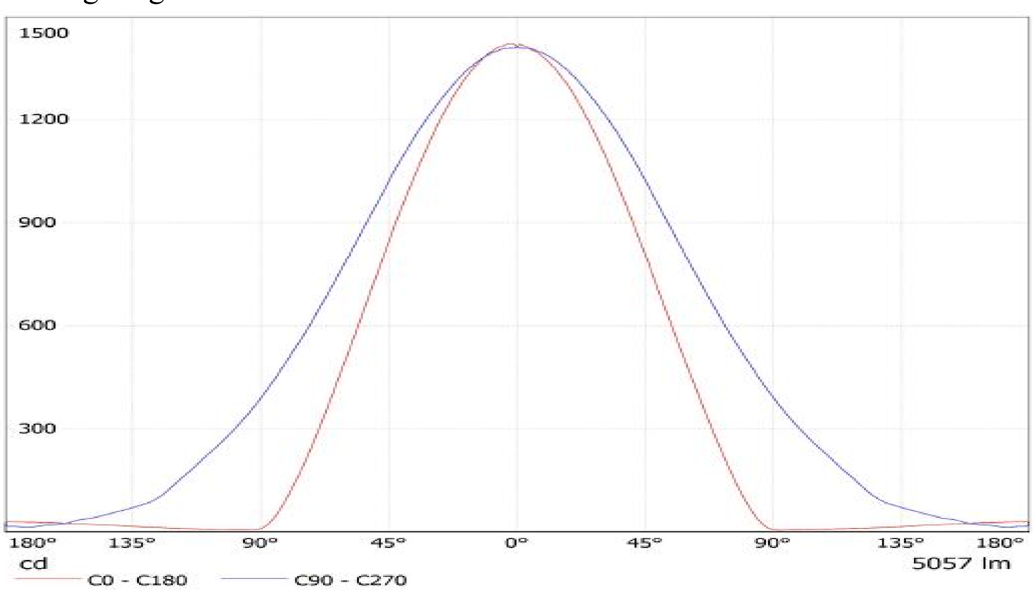


Fig 7.3: LDC (Linear) of the Luminaire FSC Lighting L28548-40WT-40K

2. FSC Lighting L28648-25W-40K:

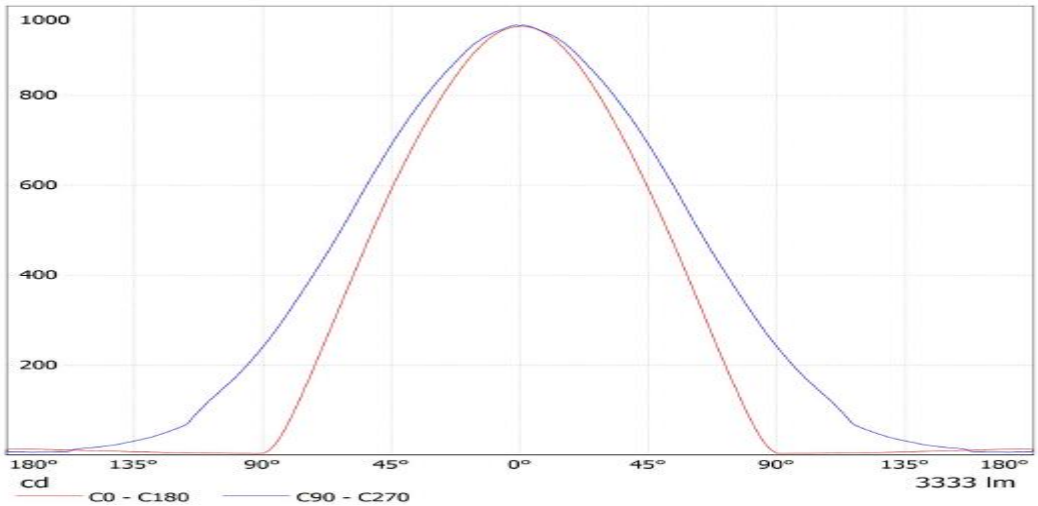


Fig 7.4: LDC (Linear) of the Luminaire FSC Lighting L28648-25W-40K

Luminaire Luminance Diagram:

1. FSC Lighting L28548-40WT-40K:

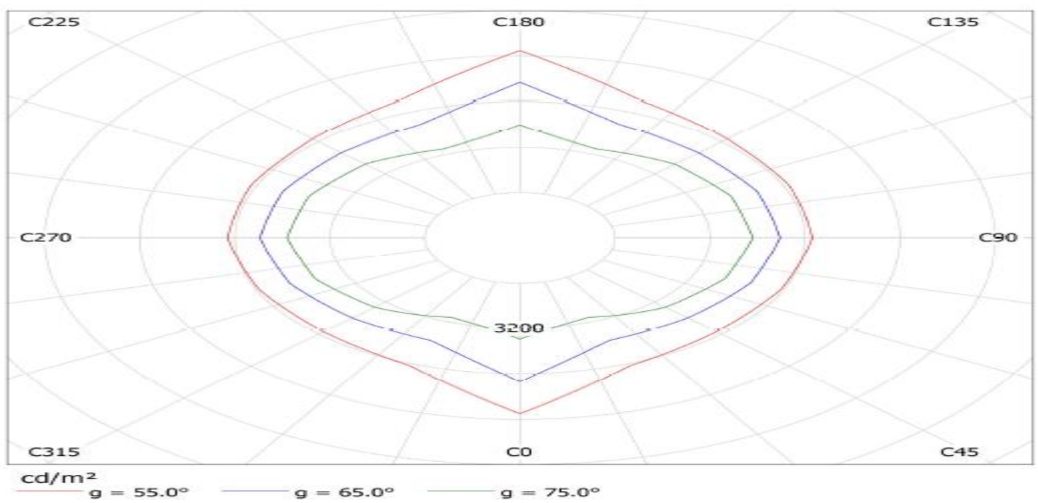


Fig 7.5: Luminance Diagram of the Luminaire FSC Lighting L28548-40WT-40K

2. FSC Lighting L28648-25W-40K:

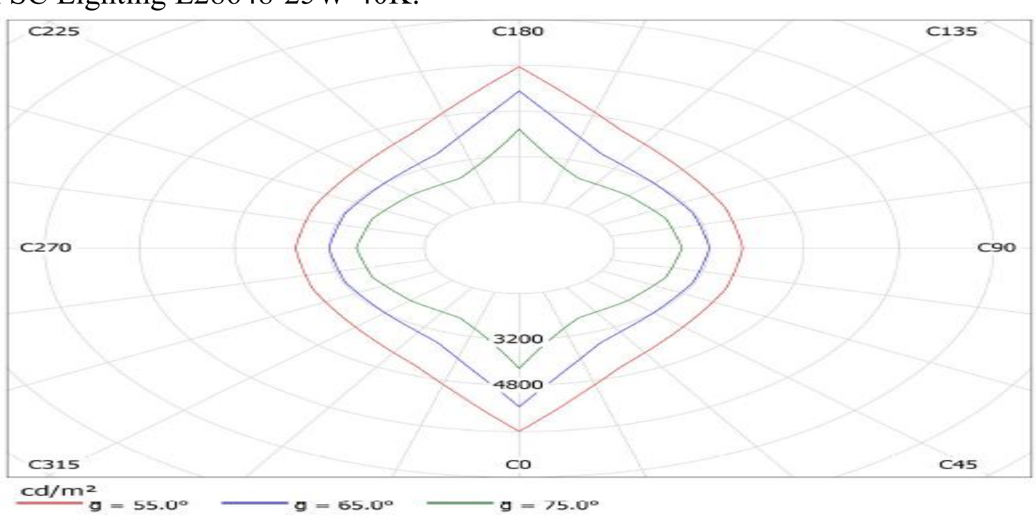


Fig 7.6: Luminance Diagram of the Luminaire FSC Lighting L28648-25W-40K

7.3 Arrangement of Luminaire:

Details of luminaire arrangement is as follows:

7.3.1 No of Luminaire Used in the Classroom:

In the above mentioned classroom total 11 nos of luminaire LED batten type luminaire used for lighting up the classroom.

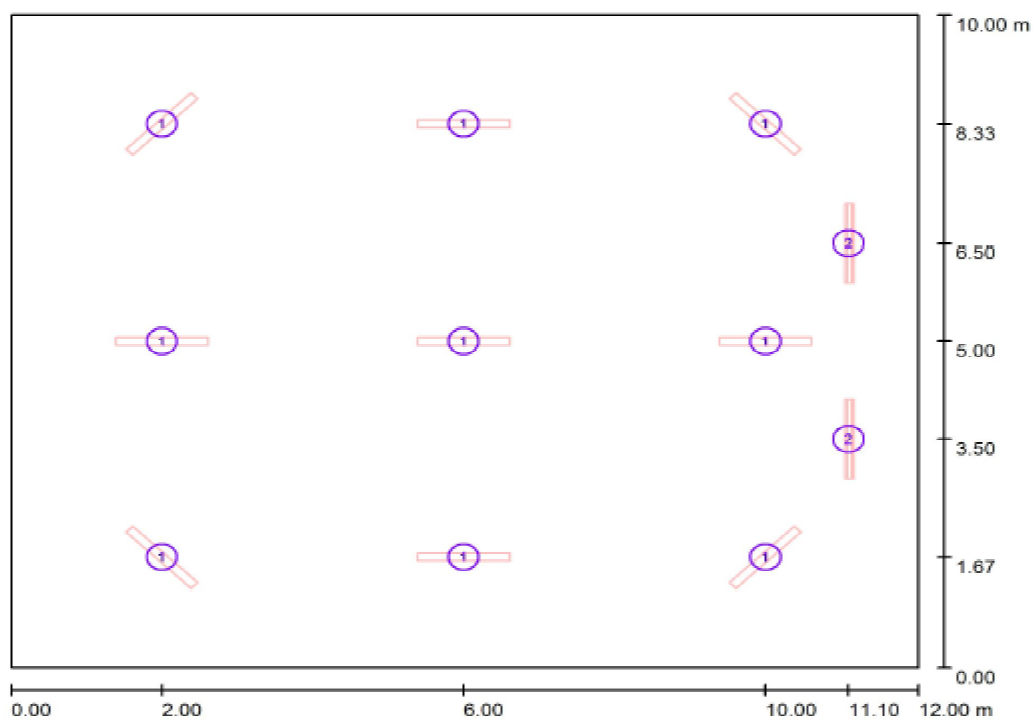
1. FSC Lighting L28548-40WT-40K: 9 nos for illuminate the whole classroom in vertical work plane.
2. FSC Lighting L28648-25W-40K: 2 nos for illuminating the Black board in horizontal plane & Dias for vertical work plane.

7.3.2 Mounting of Luminaire Used in the Classroom:

In the above mentioned classroom luminaire are mounted as follows:

1. FSC Lighting L28548-40WT-40K: Ceiling Surface Mounted.
2. FSC Lighting L28648-25W-40K: 0.5 Meter down from surface.

7.3.3 Luminaire Layout Plan:



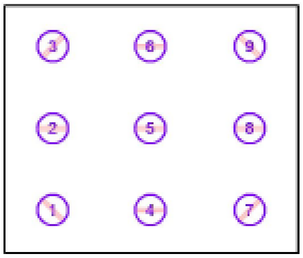
Scale 1 : 86

Luminaire Parts List

No.	Pieces	Designation
1	9	FSC Lighting L28548-40WT-40K
2	2	FSC Lighting L28648-25W-40K

Fig 7.7: Luminaire Layout Plan

1. **FSC Lighting L28548-40WT-40K**:

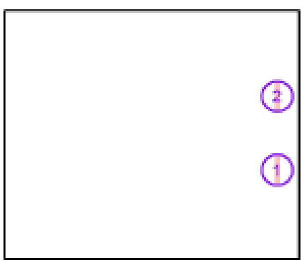


No.	Position [m] X	Y	Z	Rotation [°] X	Y	Z
1	2.000	1.667	3.000	0.0	0.0	-45.0
2	2.000	5.000	3.000	0.0	0.0	0.0
3	2.000	8.333	3.000	0.0	0.0	45.0
4	6.000	1.667	3.000	0.0	0.0	0.0
5	6.000	5.000	3.000	0.0	0.0	0.0
6	6.000	8.333	3.000	0.0	0.0	0.0
7	10.000	1.667	3.000	0.0	0.0	45.0
8	10.000	5.000	3.000	0.0	0.0	0.0
9	10.000	8.333	3.000	0.0	0.0	-45.0

Fig 7.8: Luminaire Position Co-ordinate FSC Lighting L28548-40WT-40K

- Here No:1 & No:9 corner luminaire are rotated by -45^0 to Z axis and No:3 & No:7 corner luminaire are rotated by $+45^0$ to Z axis. This is for better illumination on the working plane.
- All other luminaires except above have no rotation.

2. **FSC Lighting L28648-25W-40K:**



No.	Position [m] X	Y	Z	Rotation [°] X	Y	Z
1	11.100	3.500	2.500	-20.0	0.0	90.0
2	11.100	6.500	2.500	-20.0	0.0	90.0

Fig 7.9: Luminaire Position Co-ordinate FSC Lighting L28648-25W-40K

- Here No:1 & No:2 luminaire are rotated by $+90^0$ to Z axis & -20^0 to X axis.
- This is for better vertical luminance on Dias & Horizontal luminance on Black Board.

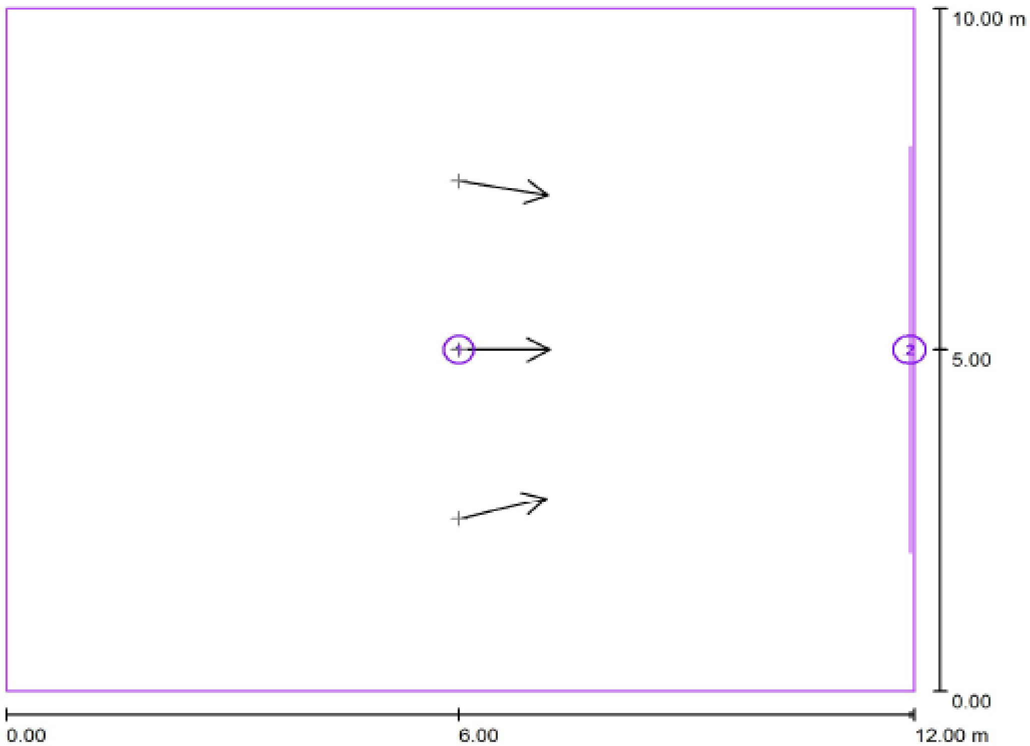
7.4 Lighting Parameters Measurement:

7.4.1 Consideration for Measurement of Lighting Parameters:

For measurement of lighting parameters of the mentioned classroom following consideration is taken:

- Height of the work plane is 970 mm from base ground.

- Because no daylight is considered here so one time measurement has been taken.
- For calculation of lighting parameters on Student Work plane a Grid of 11X9 points in Horizontal Plane is considered, which size is 12 meter X 12 meter and positioned at 6m, 5m & 0.970m.
- For calculation of lighting parameters on Blackboard a Grid of 1X9 points in Vertical Plane is considered, which size is 1 meter X 6 meter and positioned at 11.950m, 5m & 1.3m.



List of the Calculation Grids

No.	Designation	Position [m] X	Y	Z	Size [m] L	W	Rotation [°] X	Y	Z
1	Workplane Grid for students	6.000	5.000	0.970	12.000	10.000	0.0	0.0	0.0
2	Horizontal Calculation Grid on Board	11.950	5.000	1.300	1.000	6.000	0.0	-90.0	0.0

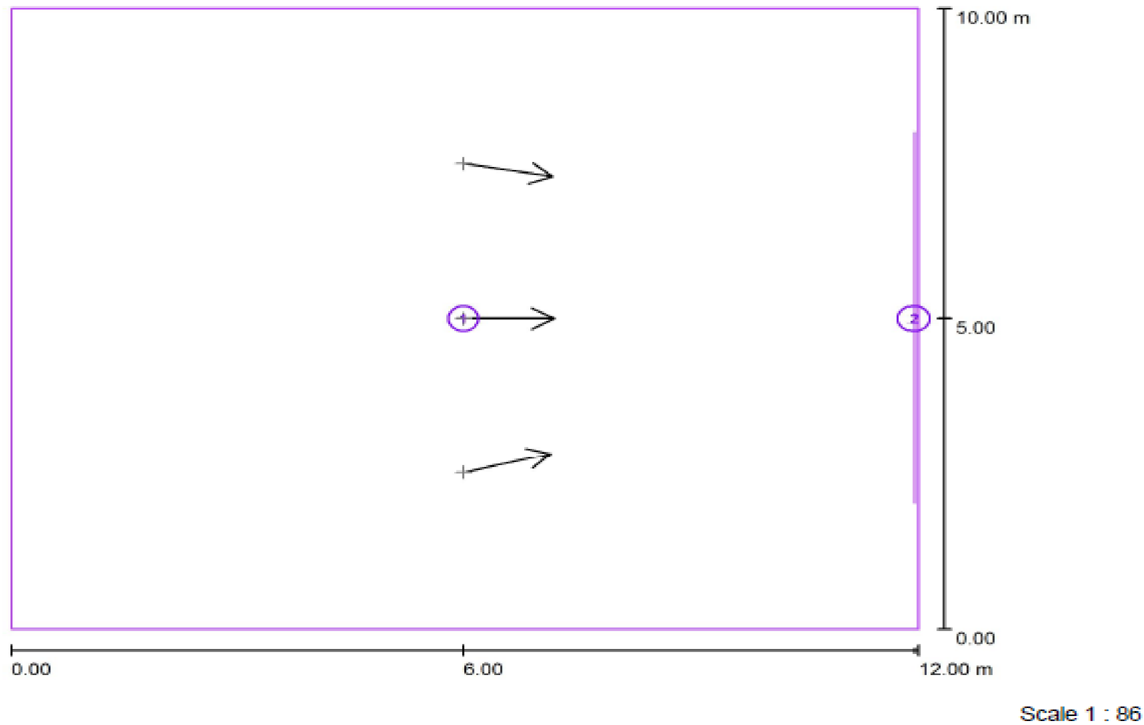
Fig 7.10: Calculation Grid Layout Plan & Position

- For calculation of UGR 3 nos UGR Observer are considered, positioned as following table:

Table 7.1: UGR Observer Position Table

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	16
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	17
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	17



List of the Calculation Grids

No.	Designation	Position [m] X	Y	Z	Size [m] L	W	Rotation [°] X	Y	Z
1	Workplane Grid for students	6.000	5.000	0.845	12.000	10.000	0.0	0.0	0.0
2	Horizontal Calculation Grid on Board	11.950	5.000	1.300	1.000	6.000	0.0	-90.0	0.0

Fig 7.11: UGR Observer Layout Plan

7.4.2 Measurement of Lighting Parameters:

7.4.2.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°.
- Date: 21.03.2022.

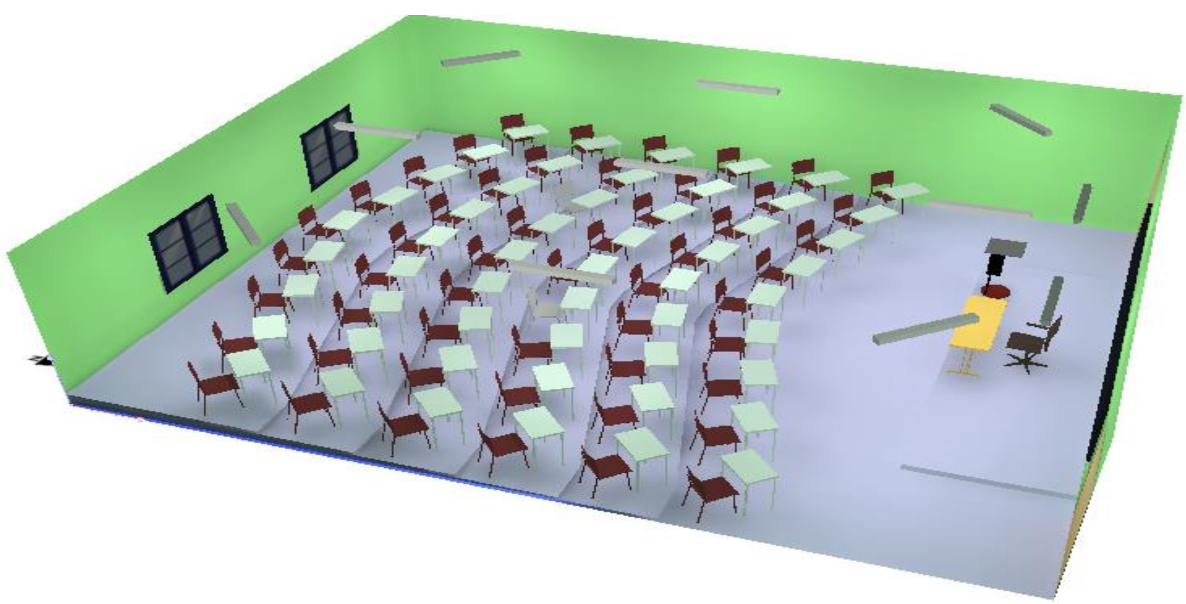


Fig 7.12: Window Orientation of the classroom

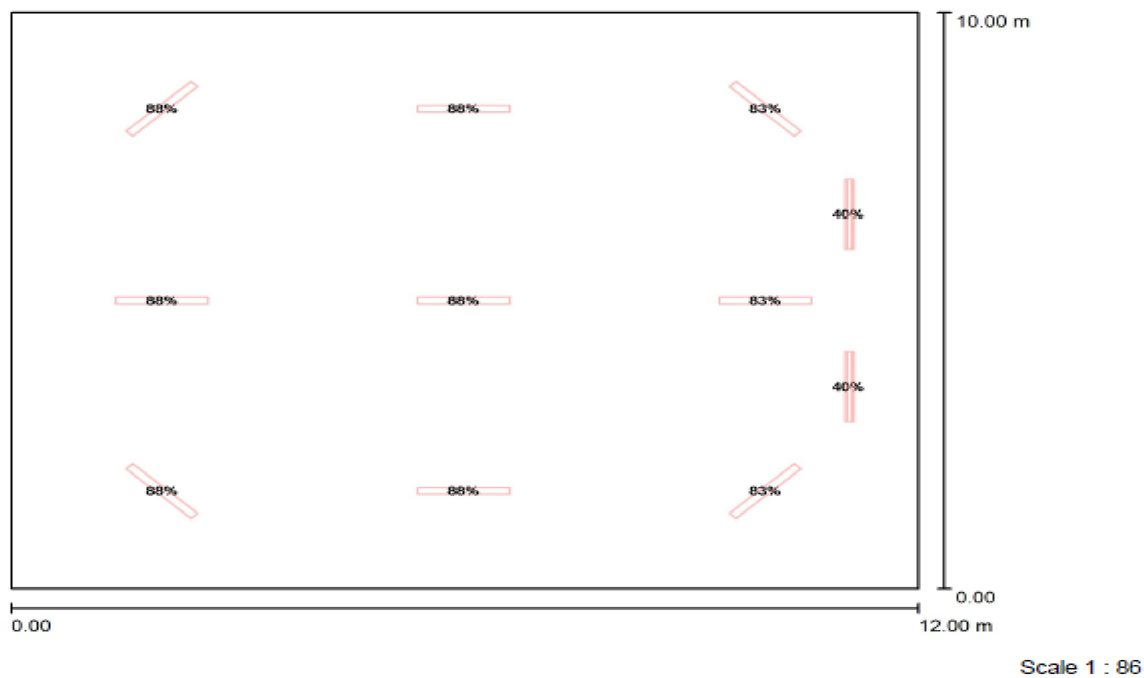


Fig 7.13: Luminaire Dimming Layout Plan

Table 7.2: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	LAST ROW (FSC Lighting L28548-40WT-40K)	88
2	MIDDLE ROW (FSC Lighting L28548-40WT-40K)	88
3	FIRST ROW (FSC Lighting L28548-40WT-40K)	83
4	BLACK BOARD (FSC Lighting L28648-25W-40K)	40

From above table & figure it can be summarized that:

1. Last Row Luminaires are 12% dimmed to their full output.
2. Middle Row Luminaires are 12% dimmed to their full output.
3. First Row Luminaires are 17% dimmed to their full output.
4. Luminaires for Black Board are 60% dimmed to their full output.
5. These type of dimming for better illumination on working plane & energy savings.

7.4.2.2 Work plane Grid for Students Summary:

Summary of work plane grid for students is as following table:

Table 7.3: Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	306	77	452	0.25	0.17	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on work plane grid for students is 306 lx.
- Maximum illuminance (E_{max}) on work plane grid for students is 452 lx.
- Minimum illuminance (E_{min}) on work plane grid for students is 77 lx.
- Uniformity on work plane grid for students is 0.25.
- E_{min} / E_{max} = 0.17.

7.4.2.3 Isolines (E, Perpendicular) on Work plane Grid for Students:

Isolines (E, perpendicular) on work plane Grid for students is as follows:

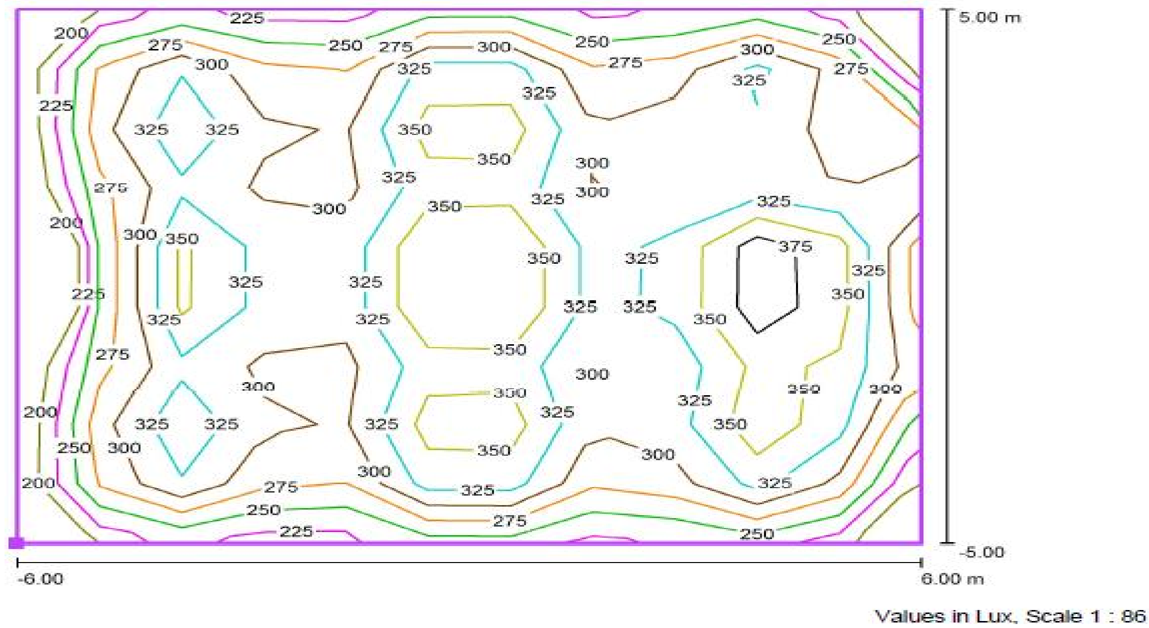


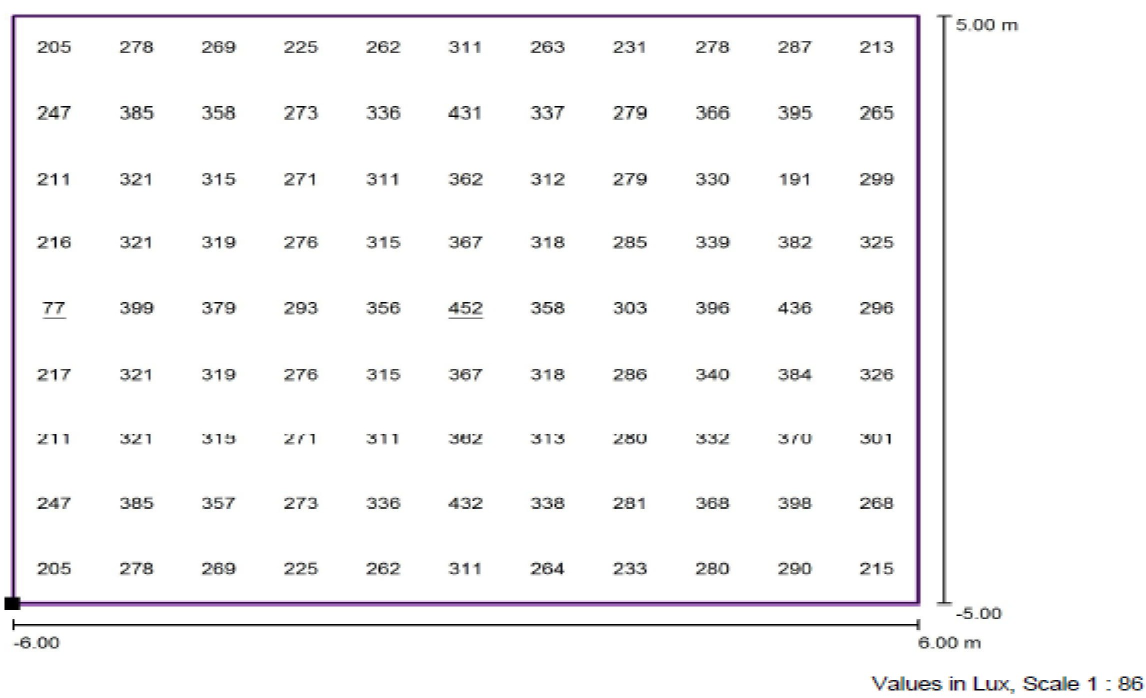
Fig 7.14: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the high value isolines are concentrated on work plane adjacent to the luminaires.
- But 300 lx isoline can cover maximum of the classroom.

7.4.2.4 Value Chart (E, Perpendicular) on Work plane Grid for Students:

Value Chart (E, Perpendicular) on Work plane Grid for students is as follows:



205	278	269	225	262	311	263	231	278	287	213
247	385	358	273	336	431	337	279	366	395	265
211	321	315	271	311	362	312	279	330	191	299
216	321	319	276	315	367	318	285	339	382	325
77	399	379	293	356	452	358	303	396	436	296
217	321	319	276	315	367	318	286	340	384	326
211	321	315	271	311	362	313	280	332	370	301
247	385	357	273	336	432	338	281	368	398	268
205	278	269	225	262	311	264	233	280	290	215

Fig 7.15: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is well illuminated.
- Maximum grid point illuminance value is greater than 300lx .
- Very few grid points illuminance value is less but nearer to 300 lx.

7.4.2.5 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 7.4: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	212	190	235	0.90	0.81	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 212 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 235 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 190 lx.
- Uniformity on calculation gird for board is 0.90.
- E_{min} / E_{max} = 0.81.

7.4.2.6 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 7.16: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is higher than the recommended average illuminance.
- Uniformity is good.

7.4.2.7 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 7.5: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	16
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	17
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	17

From above UGR Observer Table it can be seen UGR value is 16 to 17. It is under the specification recommendation limit. (Ref. 3.1.4)

7.4.2.8 Photometric Result:

Table 7.6: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	306	78	449	0.254
Floor	68	215	11	754	0.050
Ceiling	88	156	106	806	0.678
Walls (4)	59	188	14	340	/

Table 7.7: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	**Surface Description**	**E_{max} (lx)**	**E_{min} (lx)**	**E_{av} (lx)**	**Uniformity (u_o)**
1	Floor Surface	754	11	215	0.05
2	Ceiling	806	106	156	0.678
3	Four Walls	340	14	188	-

Table 7.8: Luminaire Output

No.	Row Index	Dimming %	Pieces	Designation (Correction Factor)	ø (Luminaire) (lm)	P (W)
1	Last Row	12%	3	FSC Lighting L28548-40WT-40K	4450	33.7
2	Middle Row	12%	3	FSC Lighting L28548-40WT-40K	4450	33.7
3	First Row	17%	3	FSC Lighting L28548-40WT-40K	4197	31.8
4	Black Board	60%	2	FSC Lighting L28648-25W-40K	1333	14.9
				Total:	41957	327.4

- Total Luminous Flux: 41957 lm.
- Total Load: 327.4 W.
- Ground area: 120.00 m².
- LPD: 7.23 W/m².

7.5 Result Overview:

7.5.1 UGR Observer:

3 UGR Observer result output is 16 to 17, which is under the recommendation limit (16-25).

7.5.2 Illuminance on Work plane Grid For Students:

Average Illuminance on work plane Grid For Students is 306 lx which is above the recommendation value (300 lx).

7.5.3 Uniformity on Work plane Grid For Students:

Uniformity(u_0) on work plane Grid For Students is 0.25.

7.5.4 Illuminance on Horizontal Calculation Grid On Board:

Illuminance on Horizontal Calculation Grid on Board is 212 lx, which is above the recommendation value (200 lx).

7.5.5 Uniformity on Horizontal Calculation Grid On Board:

Uniformity(u_0) on Horizontal Calculation Grid on Board is 0.9, which is very good uniformity.

7.5.6 Total wattage of Luminaire:

As dimming is used in the classroom so luminaire total wattage is as follows:

- Front Row 3 luminaire with dimming 17%: 38.3 X 3 X (1 - 0.17) = 95.4 Watt
- Middle Row 3 luminaire with dimming 12%: 38.3 X 3 X (1- 0.12) = 101.1 Watt
- Last Row 3 luminaire with dimming 12%: 38.3 X 3 X (1- 0.12) = 101.1 Watt
- 2 Luminaire for Black Board with dimming 60%: 24.9 X 2 X (1 – 0.06) = 29.8 Watt
- Total wattage of 11 nos luminaire: 95.4 + 101.1 + 101.1 + 29.8 = 327.4 Watt

7.5.7 LPD:

Total Wattage: 327.4 Watt

Total Area of the room: 12X10=120 m^2

LPD: 327.4/120= 2.73 W/ m^2

7.6 Summary:

- No Daylight enters in the room.
- Artificial Lighting Controller is used.
- Illuminance on the work plane is satisfy the recommendation value.
- As LED is used so luminaire total wattage is low.
- Energy consumption of the classroom is high.

Table 7.9: Average Illumination on Work Plane

SL NO	Work Plane Name	Time	Average Illuminance (lux)
1	Work Plane for Students	10.30 AM	306
2	Work Plane for Students	12.30 PM	306
3	Work Plane for Students	02.30 PM	306
4	Work Plane for Students	04.30 PM	306

Table 7.10: Average Illumination (Horz.) on Black Board

SL NO	Work Plane Name	Time	Average Illuminance (Horz.) (lux)
1	Black Board	10.30 AM	212
2	Black Board	12.30 PM	212
3	Black Board	02.30 PM	212
4	Black Board	04.30 PM	212

Table 7.11: Unified Glare Rating by Glare Observer

SL NO	Work Plane	Time	UGR (Obs 1, Obs 2 & Obs 3)
1	Work Plane for Students	10.30 AM	16, 17, 17
2	Work Plane for Students	12.30 PM	16, 17, 17
3	Work Plane for Students	02.30 PM	16, 17, 17
4	Work Plane for Students	04.30 PM	16, 17, 17

Table 7.12: LPD of the Classroom

SL NO	Time	LPD (W/m^2)
1	10.30 AM	2.73
2	12.30 PM	2.73
3	02.30 PM	2.73
4	04.30 PM	2.73

7.7 Recommendation:

- It is recommended to use daylight integrated with artificial light for better energy conservation.

Chapter-8

Lighting Design Integrating Daylight With Artificial LED Luminaire

8.1 Design Consideration:

- In this design Daylight Integrating with Artificial light are taken for lighting calculation.
- Here control of artificial light has been implied..
- Dimming strategy has been taken here, because LED batten are used for artificial lighting.
- Four times a day are taken for calculation of lighting parameters, 10.30 AM, 12.30 PM, 02.30 PM & 04.30 PM.

8.2 Details of Luminaire:

In modified lighting design LED batten luminaire are used and details of these luminaire are same as Chapter 7.

8.3 Arrangement of Luminaire:

Details of luminaire arrangement is as same as Chapter 7.

8.4 Lighting Parameters Measurement:

8.4.1 Consideration for Measurement of Lighting Parameters:

For measurement of lighting parameters of the mentioned classroom following consideration is taken:

- Height of the work plane is 970 mm from base ground considered as primary work plane for overall classroom vertical illuminance measurement and also a work plane 720 mm high from base also considered as a secondary work plane for measurement of illuminance on first row of desk in the classroom to crosscheck recommended illumination achieved for the work plane below the primary work plane.
- Because daylight is considered here so four time measurement, at 10.30 AM, 12.30 PM, 02.30 PM & 04.30 PM of daytime has been taken.
- For calculation of lighting parameters on Student Work plane a Grid of 11X9 points in Horizontal Plane is considered as primary work plane, which size is 12 meter X 10 meter and positioned at 6m, 5m & 0.970m. (Fig 8.1)

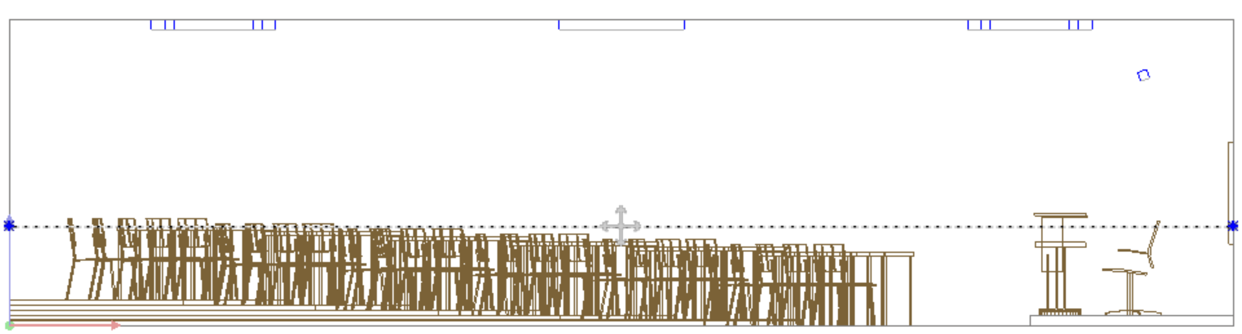


Fig 8.1: Primary Work plane Grid For Students

- For calculation of lighting parameters on Student Work plane for first row desks a Grid of 1X9 points in Horizontal Plane is considered as secondary work plane, which size is 1 meter X 10 meter and positioned at 8m, 5m & 0.720m. (Fig 8.2)

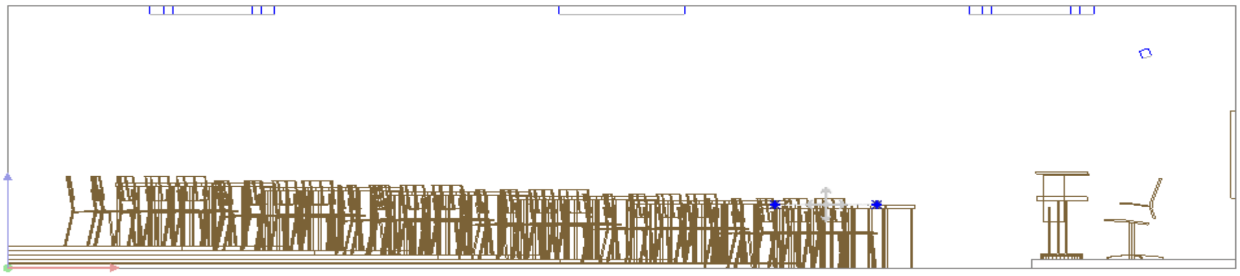


Fig 8.2: Secondary Work plane Grid For Students

- For calculation of lighting parameters on Blackboard a Grid of 1X9 points in Vertical Plane is considered, which size is 1 meter X 6 meter and positioned at 11.950m, 5m & 1.3m. (Fig 8.3)

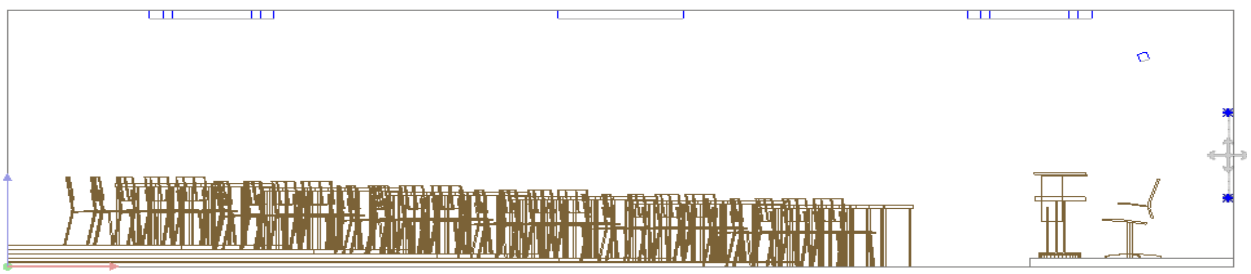
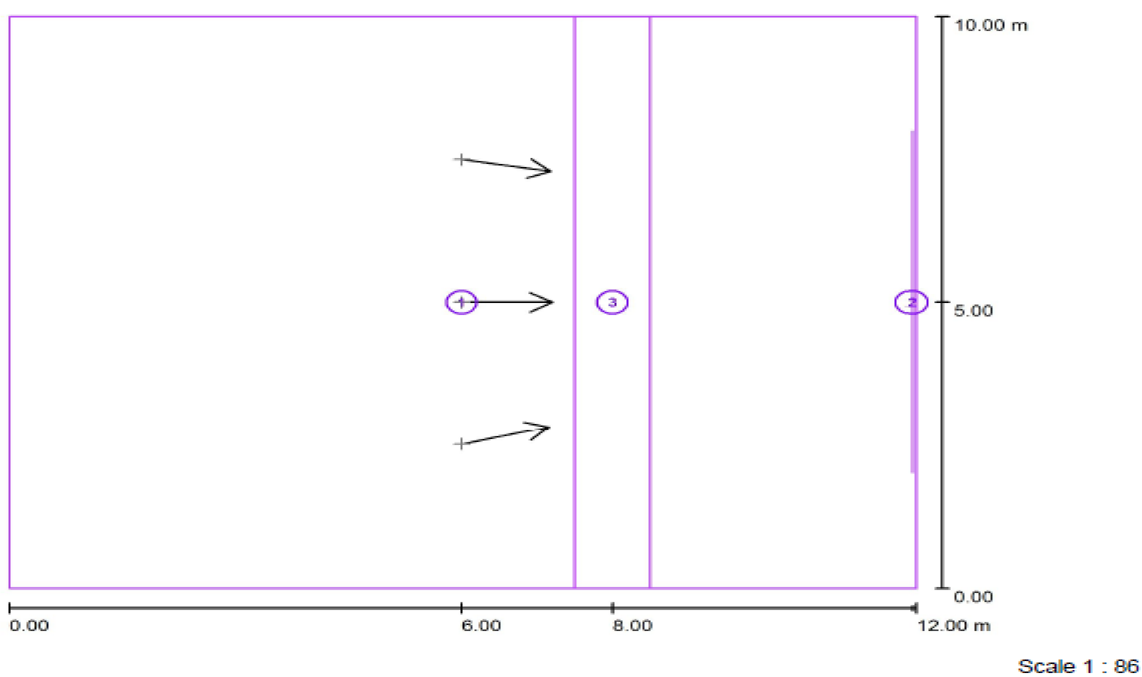


Fig 8.3: Horizontal Calculation Grid on Board



List of the Calculation Grids

No.	Designation	Position [m] X	Position [m] Y	Position [m] Z	Size [m] L	Size [m] W	Rotation [°] X	Rotation [°] Y	Rotation [°] Z
1	Primary Workplane Grid for students	6.000	5.000	0.970	12.000	10.000	0.0	0.0	0.0
2	Horizontal Calculation Grid on Board	11.950	5.000	1.300	1.000	6.000	0.0	-90.0	0.0
3	Secondary Workplane Grid for students	8.000	5.000	0.720	1.000	10.000	0.0	0.0	0.0

Fig 8.4: Calculation Grid Layout Plan & Position

- For calculation of UGR 3 nos UGR Observer are considered, positioned as following table:

Table 8.1: UGR Observer Position Table

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	21
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	21
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	21

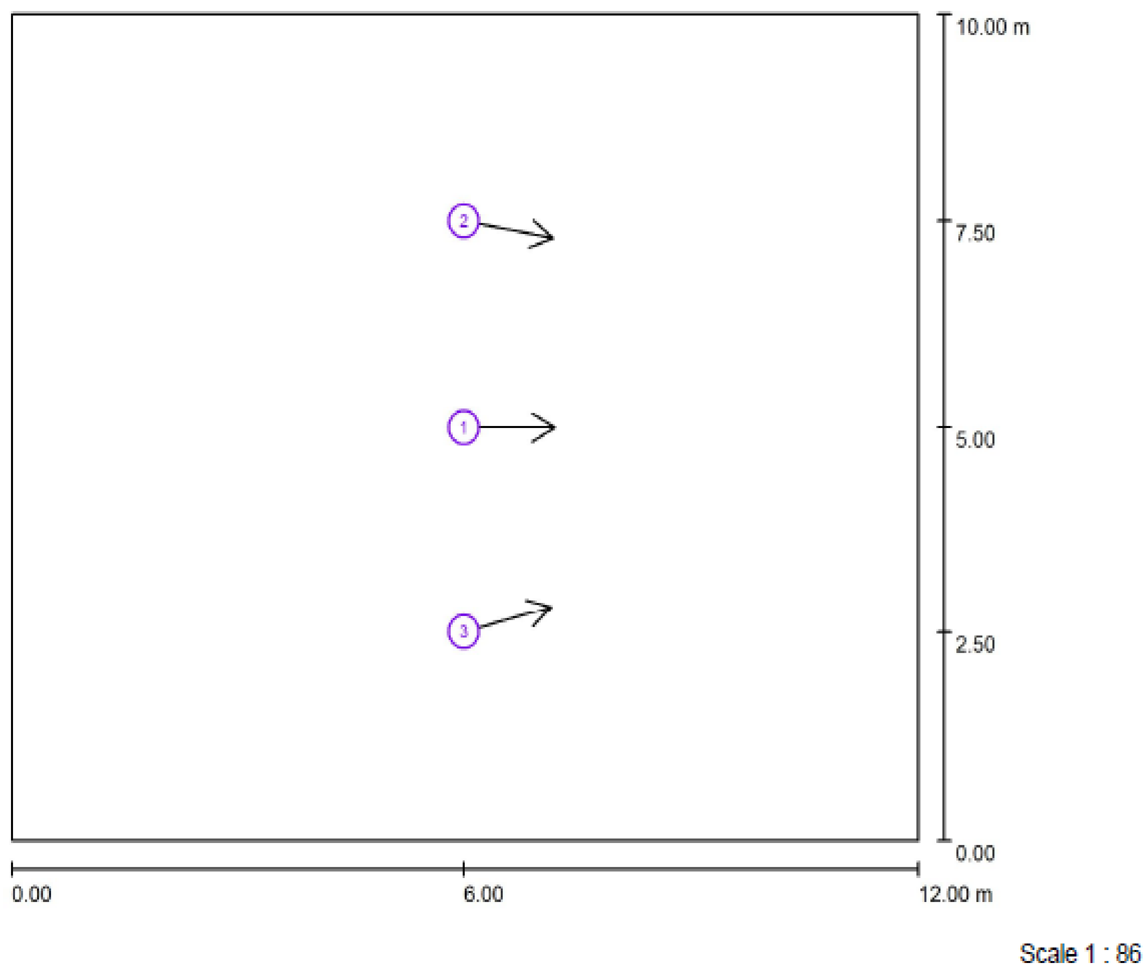


Fig 8.5: UGR Observer Layout Plan

8.4.2 Measurement of Lighting Parameters at 10.30 AM:

8.4.2.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°.
- Date: 21.03.2022, Time:10:30:00 (+5 hours difference to GMT).
- Reference sky type: Clear sky.

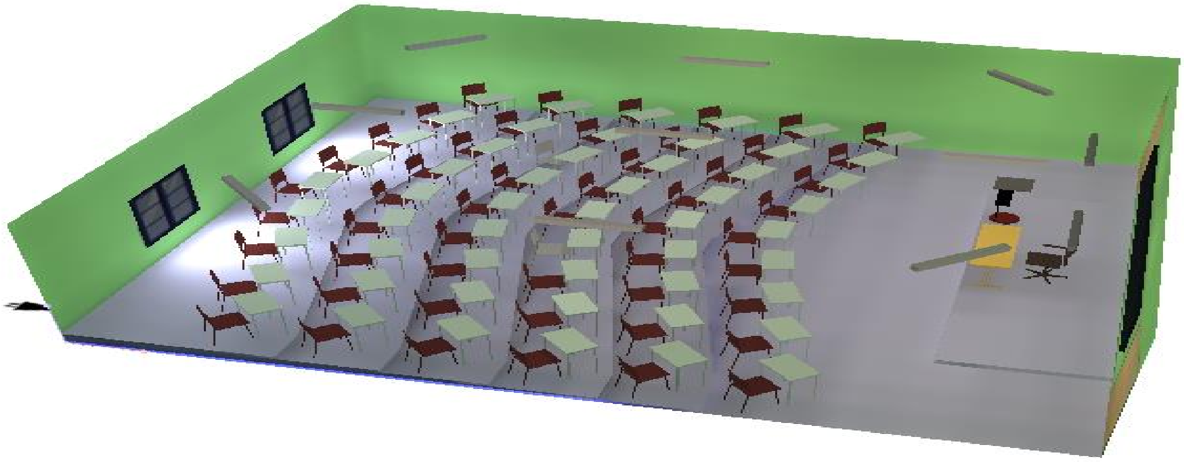


Fig 8.6: Window Orientation of the classroom at 10.30 AM

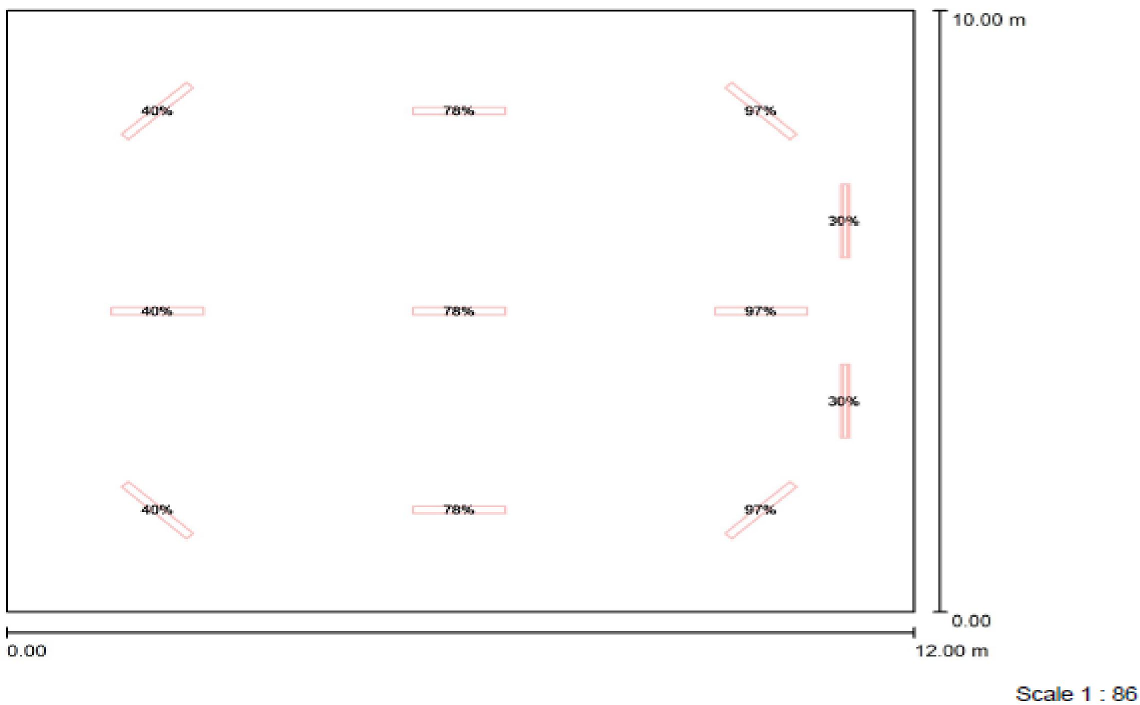


Fig 8.7: Luminaire Dimming Layout Plan

Table 8.2: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	LAST ROW (FSC Lighting L28548-40WT-40K)	40
2	MIDDLE ROW (FSC Lighting L28548-40WT-40K)	78
3	FIRST ROW (FSC Lighting L28548-40WT-40K)	97
4	BLACK BOARD (FSC Lighting L28648-25W-40K)	30

From above table & figure it can be summarized that:

1. Last Row Luminaires are 60% dimmed to their full output.
2. Middle Row Luminaires are 22% dimmed to their full output.
3. First Row Luminaires are 3% dimmed to their full output.
4. Luminaires for Black Board are 70% dimmed to their full output.
5. These type of dimming for better illumination on working plane & energy savings.

8.4.2.2 Primary Work plane Grid for Students Summary:

Summary of primary work plane grid for students is as following table:

Table 8.3: Primary Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}$/E_m	H [m]	Camera
1	perpendicular	424	222	2596	0.52	0.09	/	0.000	/

$E_{h\,m}$/E_m = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on primary work plane grid for students is 424 lx.
- Maximum illuminance (E_{max}) on primary work plane grid for students is 2596 lx.
- Minimum illuminance (E_{min}) on primary work plane grid for students is 222 lx.
- Uniformity on primary work plane grid for students is 0.52.
- E_{min} / E_{max} = 0.09.

8.4.2.3 Isolines (E, Perpendicular) on Primary Work plane Grid for Students:

Isolines (E, perpendicular) on primary work plane Grid for students is as follows:

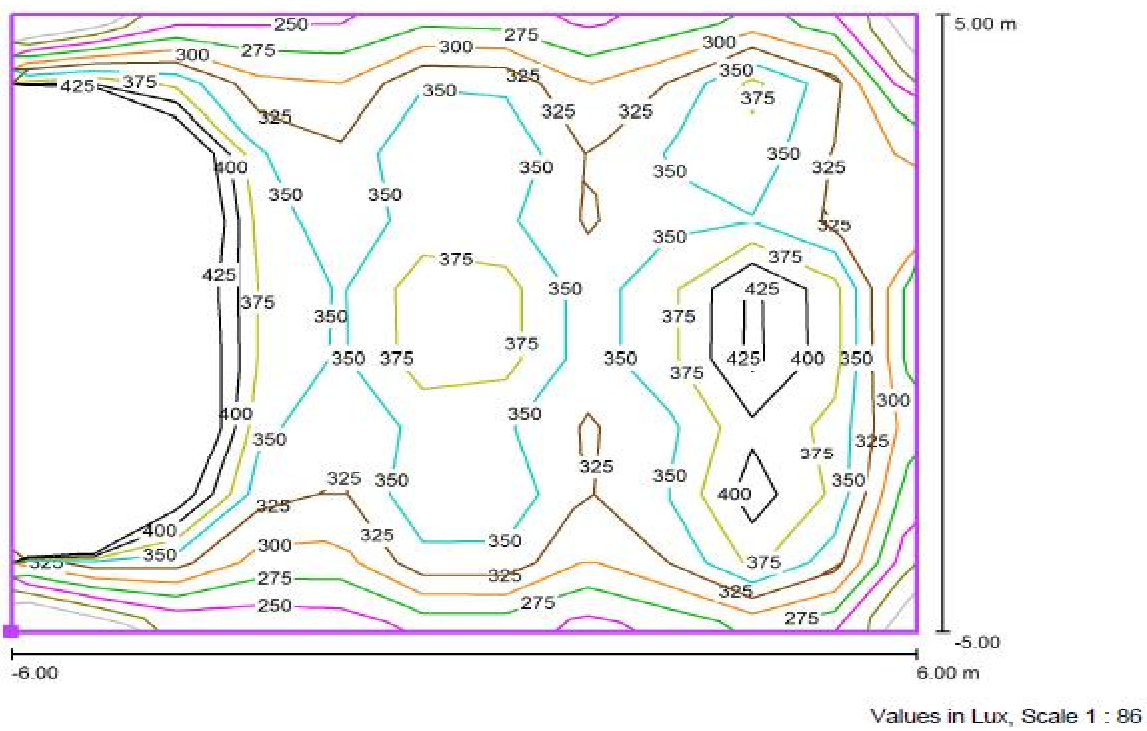


Fig 8.8: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the high value isolines are concentrated on work plane adjacent to the luminaires and windows.
- But 300 lx isoline can cover maximum of the classroom.

8.4.2.4 Value Chart (E, Perpendicular) on Primary Work plane Grid for Students:

Value Chart (E, Perpendicular) on Primary Work plane Grid for students is as follows:

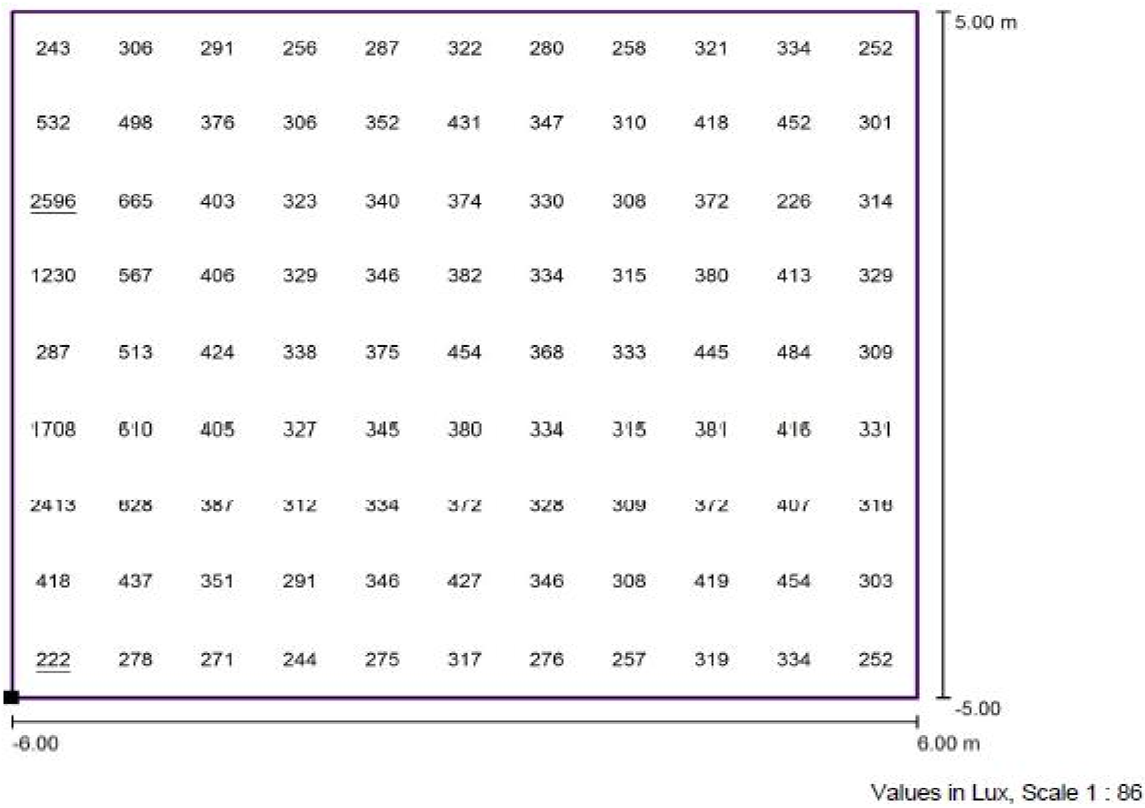


Fig 8.9: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is well illuminated.
- Maximum grid point illuminance value is greater than 300 lx .
- Very few grid points illuminance value is less but nearer to 300 lx.

8.4.2.5 Secondary Work plane Grid for Students Summary:

Summary of secondary work plane grid for students is as following table:

Table 8.4: Secondary Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	300	253	333	0.84	0.76	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on secondary work plane grid for students is 300 lx.
- Maximum illuminance (E_{max}) on secondary work plane grid for students is 333 lx.
- Minimum illuminance (E_{min}) on secondary work plane grid for students is 253 lx.
- Uniformity on secondary work plane grid for students is 0.84.
- E_{min} / E_{max} = 0.76.

8.4.2.6 Value Chart (E, Perpendicular) on Secondary Work plane Grid for Students:

Value Chart (E, Perpendicular) on Secondary Work plane Grid for students is as follows:

Fig 8.10: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- At first row desk recommended average illumination level 300 lx achieved.

8.4.2.7 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 8.5: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	219	206	231	0.94	0.89	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 219 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 231 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 206 lx.
- Uniformity on calculation gird for board is 0.94.
- E_{min} / E_{max} = 0.89.

8.4.2.8 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 8.11: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is higher than the recommended average illuminance.
- Uniformity is good.

8.4.2.9 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 8.6: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Position [m] Y	Position [m] Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	17
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	18
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	18

From above UGR Observer Table it can be seen UGR value is 17 to 18. It is under the specification recommendation limit.

8.4.2.10 Photometric Result:

Table 8.7: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	430	125	5514	0.291
Floor	68	807	30	2889	0.037
Ceiling	88	195	132	902	0.679
Walls (4)	59	241	32	581	/

Table 8.8: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	Surface Description	E_{max} (lx)	E_{min} (lx)	E_{av} (lx)	Uniformity (u_o)
1	Floor Surface	2889	30	807	0.037
2	Ceiling	902	132	195	0.679
3	Four Walls	581	32	241	-

Table 8.9: Luminaire Output

No.	Row Index	Dimming %	Pieces	Designation (Correction Factor)	ø (Luminaire) (lm)	P (W)
1	Last Row	60%	3	FSC Lighting L28548-40WT-40K	2022.8	15.32
2	Middle Row	22%	3	FSC Lighting L28548-40WT-40K	3944.46	29.874
3	First Row	3%	3	FSC Lighting L28548-40WT-40K	4905.29	37.151
4	Black Board	70%	2	FSC Lighting L28648-25W-40K	999.9	7.47
				Total:	34617.45	261.975

- Total Luminous Flux: 34617.45 lm.
- Total Load: 261.975 W.
- Ground area: 120.00 m².
- LPD: 2.18 W/m².

8.4.3 Measurement of Lighting Parameters at 12.30 PM:

8.4.3.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°.
- Date: 21.03.2022, Time:12:30:00 (+5 hours difference to GMT).
- Reference sky type: Clear sky.

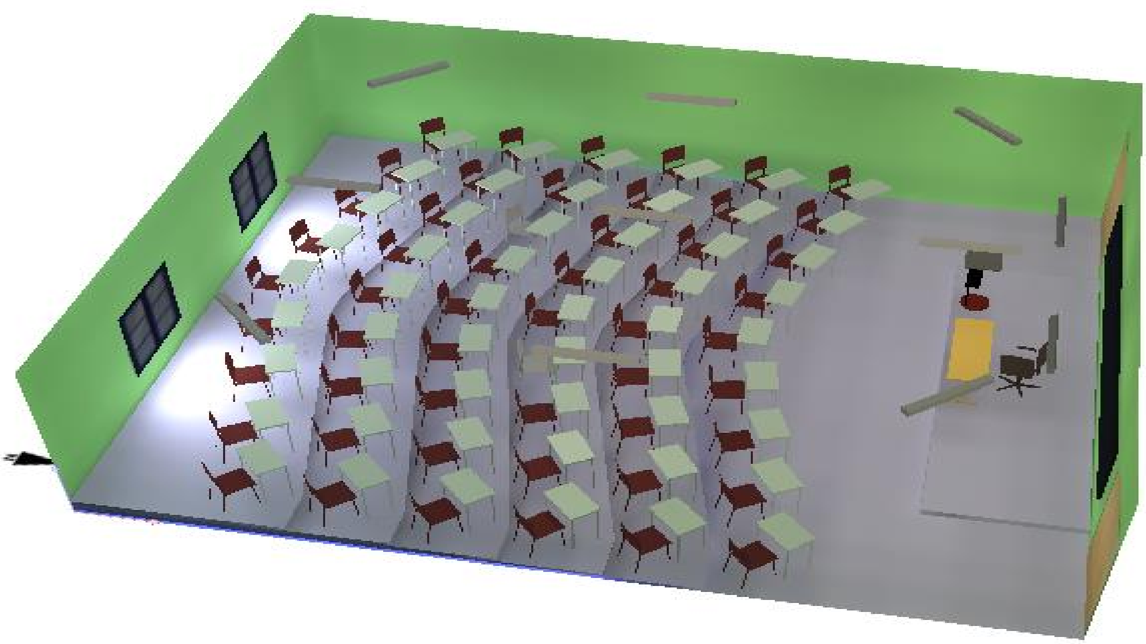


Fig 8.12: Window Orientation of the classroom at 12.30 PM

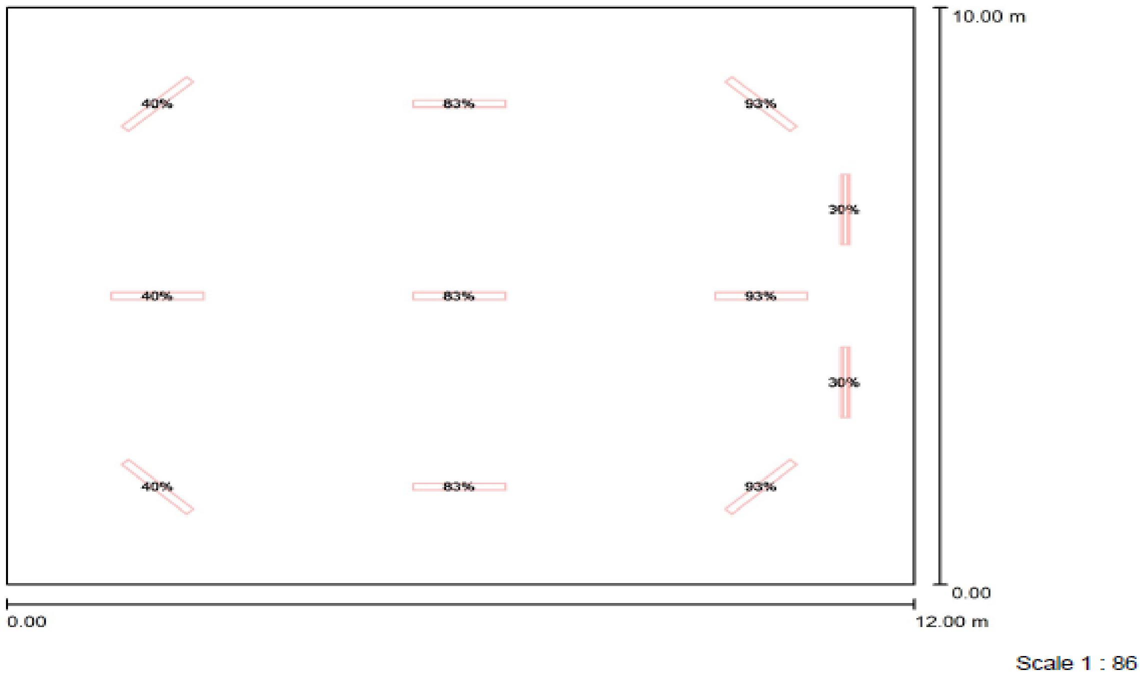


Fig 8.13: Luminaire Dimming Layout Plan

Table 8.10: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	LAST ROW (FSC Lighting L28548-40WT-40K)	40
2	MIDDLE ROW (FSC Lighting L28548-40WT-40K)	83
3	FIRST ROW (FSC Lighting L28548-40WT-40K)	93
4	BLACK BOARD (FSC Lighting L28648-25W-40K)	30

From above table & figure it can be summarized that:

1. Last Row Luminaires are 60% dimmed to their full output.
2. Middle Row Luminaires are 17% dimmed to their full output.
3. First Row Luminaires are 7% dimmed to their full output.
4. Luminaires for Black Board are 70% dimmed to their full output.
5. These type of dimming for better illumination on working plane & energy savings.

8.4.3.2 Primary Work plane Grid for Students Summary:

Summary of primary work plane grid for students is as following table:

Table 8.11: Primary Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	425	218	2599	0.51	0.08	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on primary work plane grid for students is 425 lx.
- Maximum illuminance (E_{max}) on primary work plane grid for students is 2599 lx.
- Minimum illuminance (E_{min}) on primary work plane grid for students is 218 lx.
- Uniformity on primary work plane grid for students is 0.51.
- E_{min} / E_{max} = 0.08.

8.4.3.3 Isolines (E, Perpendicular) on Primary Work plane Grid for Students:

Isolines (E, perpendicular) on primary work plane Grid for students is as follows:

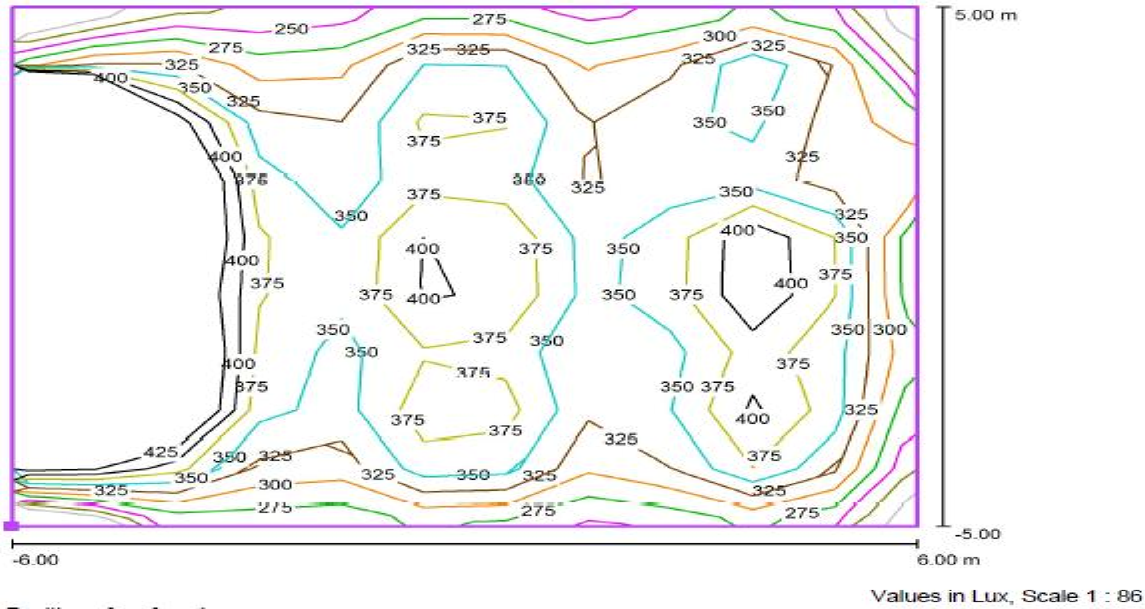


Fig 8.14: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the high value isolines are concentrated on work plane adjacent to the luminaires and windows.
- But 300 lx isoline can cover maximum of the classroom.

8.4.3.4 Value Chart (E, Perpendicular) on Primary Work plane Grid for Students:

Value Chart (E, Perpendicular) on Primary Work plane Grid for students is as follows:

219	274	266	243	283	325	280	254	311	323	243
395	424	347	293	353	442	351	305	406	437	291
2265	606	386	314	341	381	333	305	363	218	306
1872	630	412	330	352	391	339	313	372	403	323
303	525	428	343	386	471	377	331	434	471	302
1092	549	403	334	357	394	343	315	374	407	325
2599	673	408	328	351	388	339	310	388	398	311
610	524	387	314	367	451	359	310	411	443	298
255	320	306	269	295	337	287	261	316	328	249

5.00 m

5.00

-6.00 6.00 m

Values in Lux, Scale 1 : 86

Fig 8.15: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is well illuminated.
- Maximum grid point illuminance value is greater than 300 lx .
- Very few grid points illuminance value is less but nearer to 300 lx.

8.4.3.5 Secondary Work plane Grid for Students Summary:

Summary of secondary work plane grid for students is as following table:

Table 8.12: Secondary Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	300	251	333	0.83	0.75	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on secondary work plane grid for students is 300 lx.
- Maximum illuminance (E_{max}) on secondary work plane grid for students is 333 lx.
- Minimum illuminance (E_{min}) on secondary work plane grid for students is 251 lx.
- Uniformity on secondary work plane grid for students is 0.83.
- E_{min} / E_{max} = 0.75.

8.4.3.6 Value Chart (E, Perpendicular) on Secondary Work plane Grid for Students:

Value Chart (E, Perpendicular) on Secondary Work plane Grid for students is as follows:

Fig 8.16: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- At first row desk recommended average illumination level 300 lx achieved.

8.4.3.7 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 8.13: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	215	202	228	0.94	0.88	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 215 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 228 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 202 lx.
- Uniformity on calculation gird for board is 0.94.
- E_{min} / E_{max} = 0.88.

8.4.3.8 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 8.17: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is higher than the recommended average illuminance.
- Uniformity is good.

8.4.3.9 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 8.14: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	17
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	17
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	17

From above UGR Observer Table it can be seen UGR value is 17. It is under the specification recommendation limit.

8.4.3.10 Photometric Result:

Table 8.15: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	430	123	5441	0.286
Floor	68	809	30	2958	0.037
Ceiling	88	195	131	869	0.673
Walls (4)	59	242	32	560	/

Table 8.16: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	**Surface Description**	**E_{max} (lx)**	**E_{min} (lx)**	**E_{av} (lx)**	**Uniformity (u_o)**
1	Floor Surface	2958	30	809	0.037
2	Ceiling	869	131	195	0.673
3	Four Walls	560	32	242	-

Table 8.17: Luminaire Output

No.	Row Index	Dimming %	Pieces	Designation (Correction Factor)	ø (Luminaire) (lm)	P (W)
1	Last Row	60%	3	FSC Lighting L28548-40WT-40K	2022.8	15.32
2	Middle Row	17%	3	FSC Lighting L28548-40WT-40K	4197.31	31.789
3	First Row	7%	3	FSC Lighting L28548-40WT-40K	4703.01	35.619
4	Black Board	70%	2	FSC Lighting L28648-25W-40K	999.9	7.47
				Total:	34769.16	263.124

- Total Luminous Flux: 34769.16 lm.
- Total Load: 263.124 W.
- Ground area: 120.00 m².
- LPD: 2.19 W/m².

8.4.4 Measurement of Lighting Parameters at 02.30 PM:

8.4.4.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°.
- Date: 21.03.2022, Time:14:30:00 (+5 hours difference to GMT).
- Reference sky type: Clear sky.

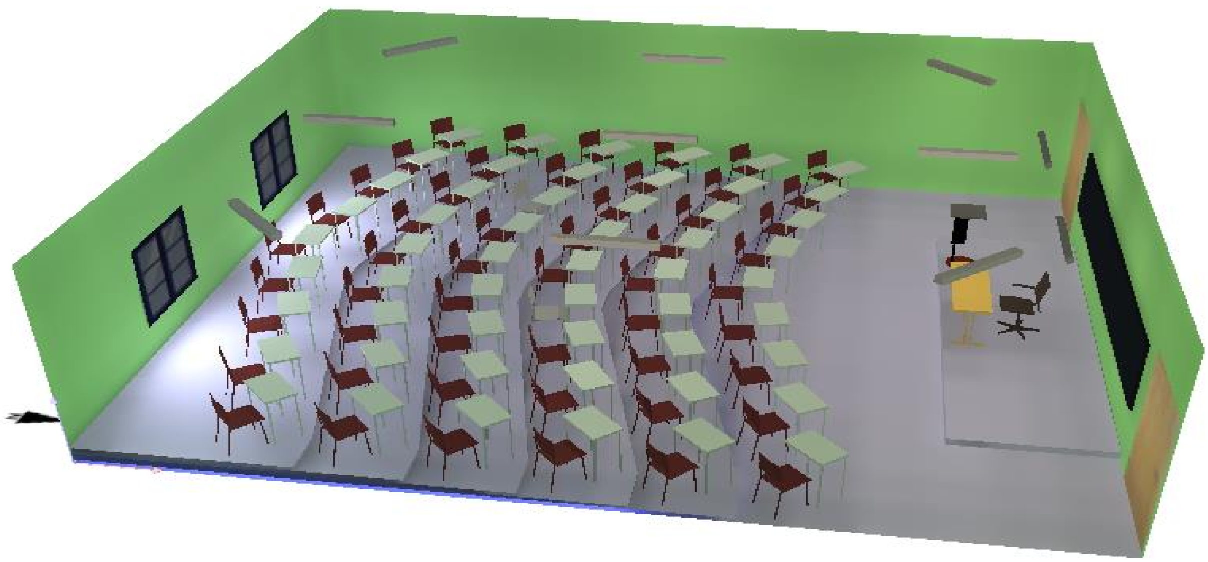


Fig 8.18: Window Orientation of the classroom at 02.30 PM

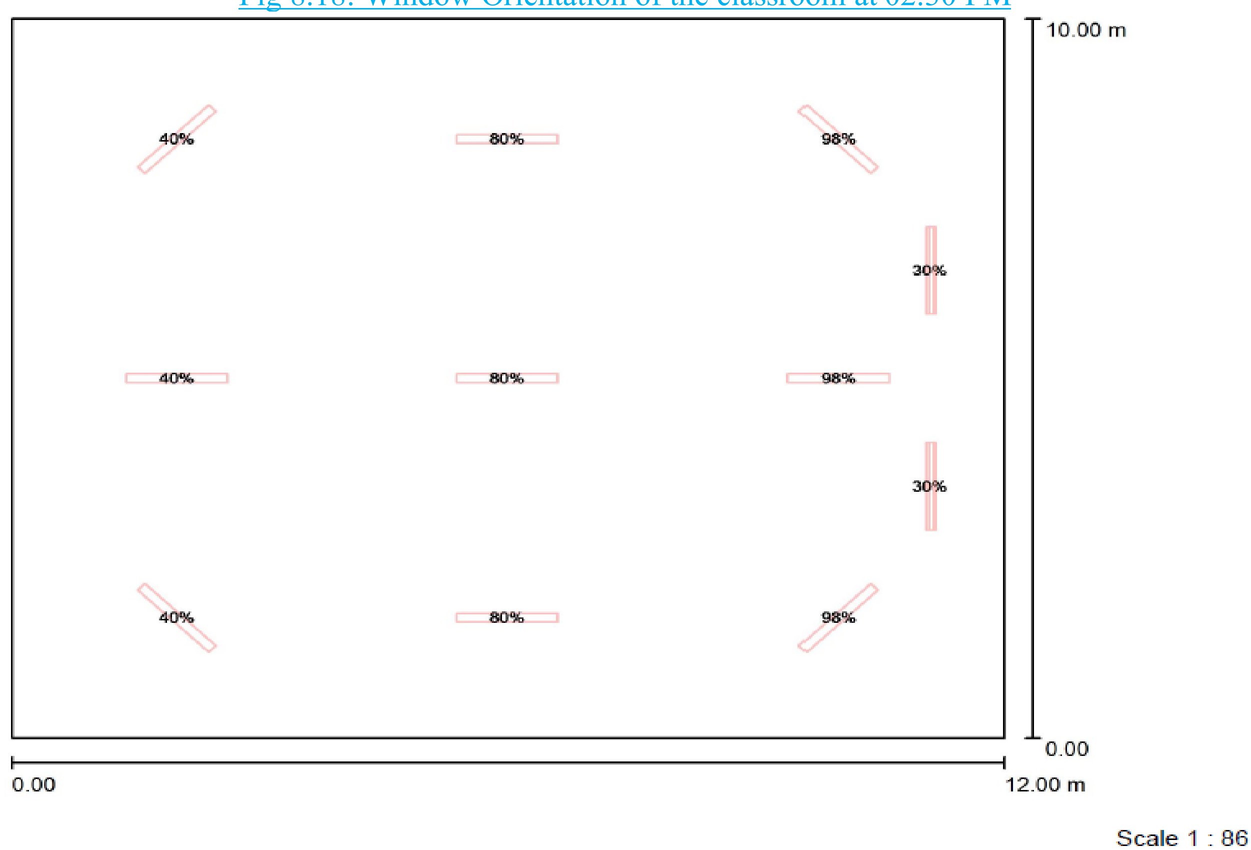


Fig 8.19: Luminaire Dimming Layout Plan

Table 8.18: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	LAST ROW (FSC Lighting L28548-40WT-40K)	40
2	MIDDLE ROW (FSC Lighting L28548-40WT-40K)	80
3	FIRST ROW (FSC Lighting L28548-40WT-40K)	98
4	BLACK BOARD (FSC Lighting L28648-25W-40K)	30

From above table & figure it can be summarized that:

1. Last Row Luminaires are 60% dimmed to their full output.
2. Middle Row Luminaires are 20% dimmed to their full output.
3. First Row Luminaires are 2% dimmed to their full output.
4. Luminaires for Black Board are 70% dimmed to their full output.
5. These type of dimming for better illumination on working plane & energy savings.

8.4.4.2 Primary Work plane Grid for Students Summary:

Summary of primary work plane grid for students is as following table:

Table 8.19: Primary Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h m}/E_m$	H [m]	Camera
1	perpendicular	405	199	2021	0.49	0.10	/	0.000	/

$E_{h m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on primary work plane grid for students is 405 lx.
- Maximum illuminance (E_{max}) on primary work plane grid for students is 2021 lx.
- Minimum illuminance (E_{min}) on primary work plane grid for students is 199 lx.
- Uniformity on primary work plane grid for students is 0.49.
- E_{min} / E_{max} = 0.10.

8.4.4.3 Isolines (E, Perpendicular) on Primary Work plane Grid for Students:

Isolines (E, perpendicular) on primary work plane Grid for students is as follows:

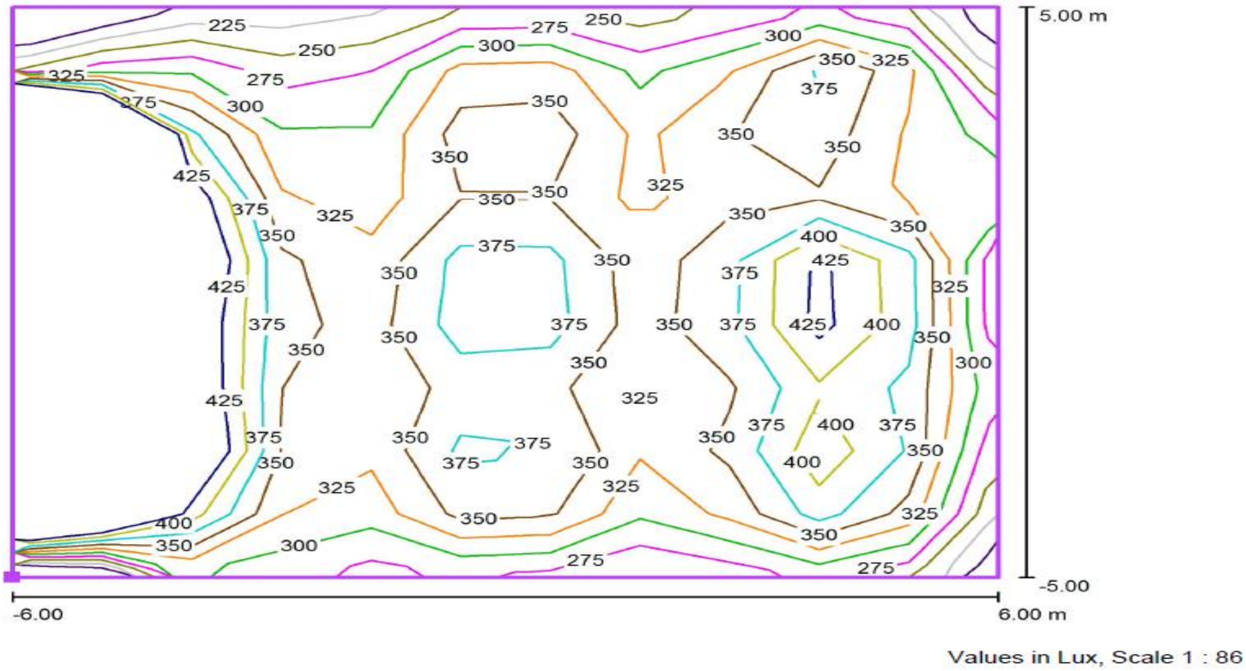


Fig 8.20: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the high value isolines are concentrated on work plane adjacent to the luminaires and windows.
- But 300 lx isoline can cover maximum of the classroom.

8.4.4.4 Value Chart (E, Perpendicular) on Primary Work plane Grid for Students:

Value Chart (E, Perpendicular) on Primary Work plane Grid for students is as follows:

199	252	245	225	268	311	272	253	317	332	247
343	374	314	270	335	424	342	305	416	451	298
1475	493	341	288	321	365	324	304	370	225	312
1792	580	377	306	333	376	330	312	379	413	328
427	543	411	325	369	454	368	332	446	486	310
792	498	382	319	344	382	336	316	383	418	331
2021	594	384	316	340	378	334	312	375	409	317
939	558	387	310	360	441	355	313	424	459	306
311	372	330	277	295	334	286	264	325	339	256

5.00 m

-5.00

-6.00 6.00 m

Values in Lux, Scale 1 : 86

Fig 8.21: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is well illuminated.
- Maximum grid point illuminance value is greater than 300 lx .
- Very few grid points illuminance value is less but nearer to 300 lx.

8.4.4.5 Secondary Work plane Grid for Students Summary:

Summary of secondary work plane grid for students is as following table:

Table 8.20: Secondary Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	300	249	332	0.83	0.75	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on secondary work plane grid for students is 300 lx.
- Maximum illuminance (E_{max}) on secondary work plane grid for students is 332 lx.
- Minimum illuminance (E_{min}) on secondary work plane grid for students is 249 lx.
- Uniformity on secondary work plane grid for students is 0.83.
- E_{min} / E_{max} = 0.75.

8.4.4.6 Value Chart (E, Perpendicular) on Secondary Work plane Grid for Students:

Value Chart (E, Perpendicular) on Secondary Work plane Grid for students is as follows:

Fig 8.22: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- At first row desk recommended average illumination level 300 lx achieved.

8.4.4.7 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 8.21: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	219	206	231	0.94	0.89	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 219 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 231 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 206 lx.
- Uniformity on calculation gird for board is 0.94.
- E_{min} / E_{max} = 0.89.

8.4.4.8 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 8.23: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is higher than the recommended average illuminance.
- Uniformity is good.

8.4.4.9 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 8.22: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	17
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	18
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	18

From above UGR Observer Table it can be seen UGR value is 17 to 18. It is under the specification recommendation limit.

8.4.4.10 Photometric Result:

Table 8.23: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	408	122	4283	0.300
Floor	68	783	29	2961	0.038
Ceiling	88	187	127	911	0.679
Walls (4)	59	240	30	764	/

Table 8.24: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	Surface Description	E_{max} (lx)	E_{min} (lx)	E_{av} (lx)	Uniformity (u_o)
1	Floor Surface	2961	29	783	0.038
2	Ceiling	911	127	187	0.679
3	Four Walls	764	30	240	-

Table 8.25: Luminaire Output

No.	Row Index	Dimming %	Pieces	Designation (Correction Factor)	ø (Luminaire) (lm)	P (W)
1	Last Row	40%	3	FSC Lighting L28548-40WT-40K	3034.2	22.98
2	Middle Row	20%	3	FSC Lighting L28548-40WT-40K	4045.6	30.64
3	First Row	2%	3	FSC Lighting L28548-40WT-40K	4955.86	37.534
4	Black Board	70%	2	FSC Lighting L28648-25W-40K	999.9	7.47
				Total:	38106.78	288.402

- Total Luminous Flux: 38106.78 lm.
- Total Load: 288.402 W.
- Ground area: 120.00 m².
- LPD: 2.40 W/m².

8.4.5 Measurement of Lighting Parameters at 04.30 PM:

8.4.5.1 Planning Data:

- Location: Calcutta, Longitude: 88.40°, Latitude: 22.50°, North deviation: 90.0°.
- Date: 21.03.2022, Time:16:30:00 (+5 hours difference to GMT).
- Reference sky type: Clear sky.

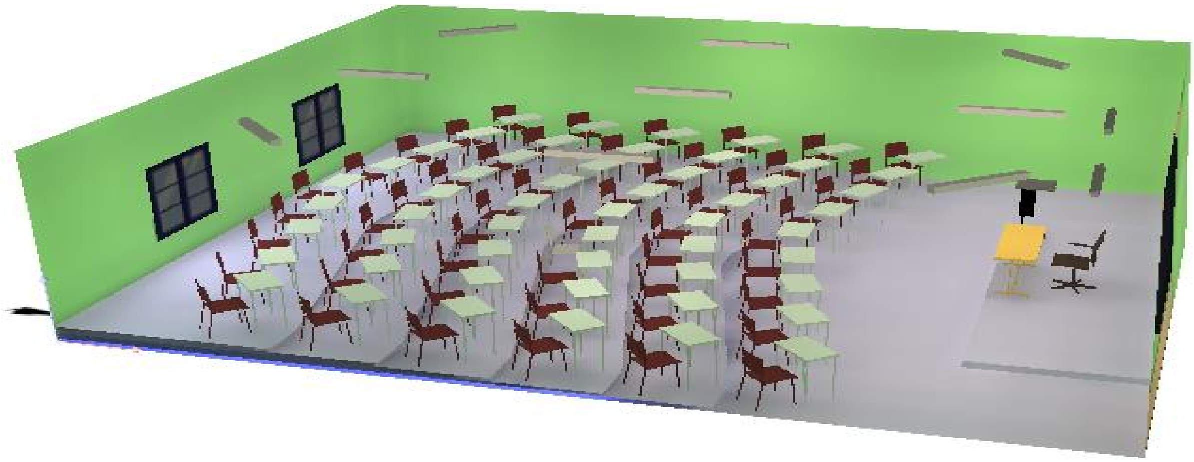


Fig 8.24: Window Orientation of the classroom at 04.30 PM

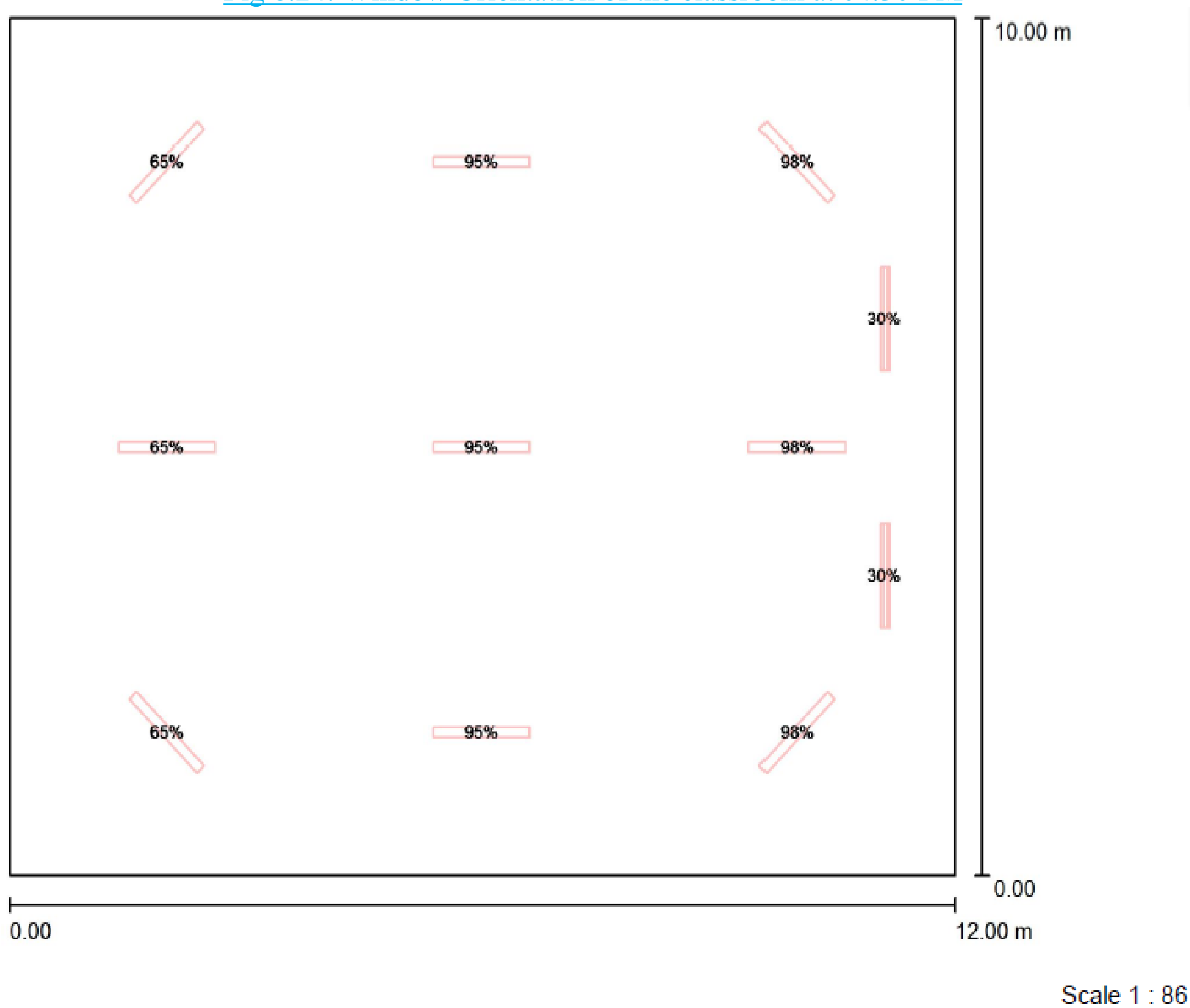


Fig 8.25: Luminaire Dimming Layout Plan

Table 8.26: Luminaire Dimming Value

No.	Control group (Luminaire)	Dimming values (Total) [%]
1	LAST ROW (FSC Lighting L28548-40WT-40K)	65
2	MIDDLE ROW (FSC Lighting L28548-40WT-40K)	95
3	FIRST ROW (FSC Lighting L28548-40WT-40K)	98
4	BLACK BOARD (FSC Lighting L28648-25W-40K)	30

From above table & figure it can be summarized that:

1. Last Row Luminaires are 35% dimmed to their full output.
2. Middle Row Luminaires are 5% dimmed to their full output.
3. First Row Luminaires are 2% dimmed to their full output.
4. Luminaires for Black Board are 70% dimmed to their full output.
5. These type of dimming for better illumination on working plane & energy savings.

8.4.5.2 Primary Work plane Grid for Students Summary:

Summary of primary work plane grid for students is as following table:

Table 8.27: Primary Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	354	200	726	0.57	0.28	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on primary work plane grid for students is 354 lx.
- Maximum illuminance (E_{max}) on primary work plane grid for students is 726 lx.
- Minimum illuminance (E_{min}) on primary work plane grid for students is 200 lx.
- Uniformity on primary work plane grid for students is 0.57.
- E_{min} / E_{max} = 0.28.

8.4.5.3 Isolines (E, Perpendicular) on Primary Work plane Grid for Students:

Isolines (E, perpendicular) on primary work plane Grid for students is as follows:

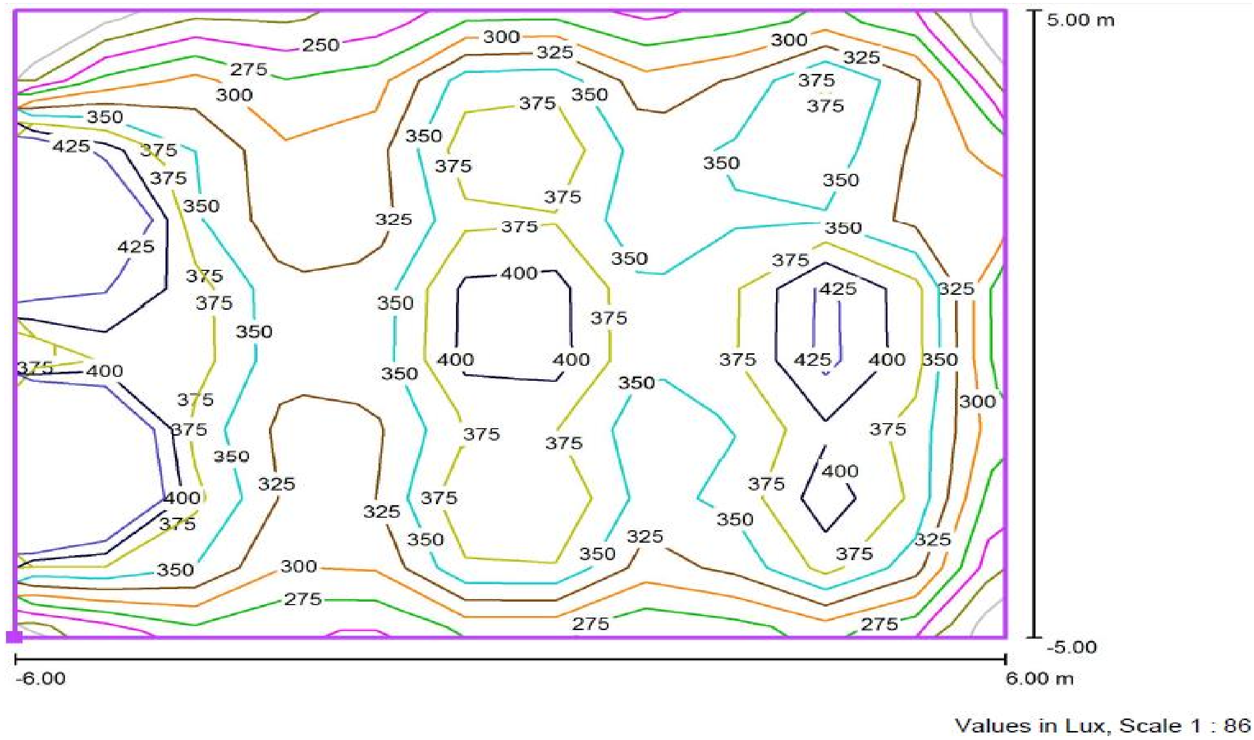


Fig 8.26: Isolines (E, Perpendicular)

From above figure it can be seen that:

- Most of the high value isolines are concentrated on work plane adjacent to the luminaires and windows.
- But 300 lx isoline can cover maximum of the classroom.

8.4.5.4 Value Chart (E, Perpendicular) on Primary Work plane Grid for Students:

Value Chart (E, Perpendicular) on Primary Work plane Grid for students is as follows:

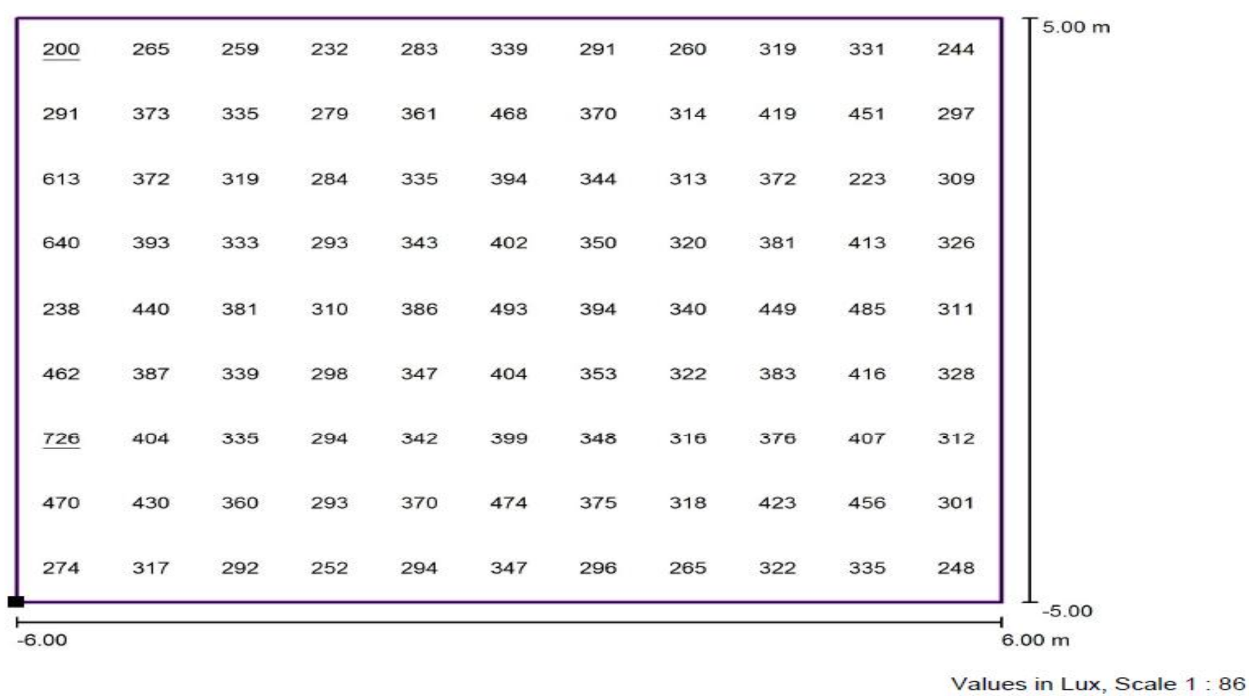


Fig 8.27: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- Class room is well illuminated.
- Maximum grid point illuminance value is greater than 300lx .
- Very few grid points illuminance value is less but nearer to 300 lx.

8.4.5.5 Secondary Work plane Grid for Students Summary:

Summary of secondary work plane grid for students is as following table:

Table 8.28: Secondary Work plane Grid for Students Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	perpendicular	309	260	341	0.84	0.76	/	0.000	/

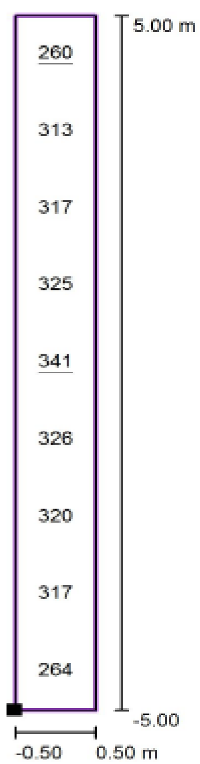
$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average illuminance (E_{av}) on secondary work plane grid for students is 309 lx.
- Maximum illuminance (E_{max}) on secondary work plane grid for students is 341 lx.
- Minimum illuminance (E_{min}) on secondary work plane grid for students is 260 lx.
- Uniformity on secondary work plane grid for students is 0.84.
- E_{min} / E_{max} = 0.76.

8.4.5.6 Value Chart (E, Perpendicular) on Secondary Work plane Grid for Students:

Value Chart (E, Perpendicular) on Secondary Work plane Grid for students is as follows:



Values in Lux, Scale 1 : 81

Fig 8.28: Value Chart (E, Perpendicular)

From above figure it can be summarized that:

- At first row desk recommended average illumination level 300 lx achieved.

8.4.5.7 Horizontal Calculation Grid On Board Summary:

Summary of Horizontal Calculation Grid On Board is as following table:

Table 8.29: Horizontal Calculation Grid On Board Summary

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\ m}/E_m$	H [m]	Camera
1	horizontal	215	203	228	0.94	0.89	/	0.000	/

$E_{h\ m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

From above table it can be summarized that:

- Average horizontal illuminance (E_{av}) on calculation gird for board is 215 lx.
- Maximum horizontal illuminance (E_{max}) on calculation gird for board is 228 lx.
- Minimum horizontal illuminance (E_{min}) on calculation gird for board is 203 lx.
- Uniformity on calculation gird for board is 0.94.
- E_{min} / E_{max} = 0.89.

8.4.5.8 Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board:

Value Chart (E, Horizontal) on Horizontal Calculation Grid On Board is as follows:

Fig 8.29: Value Chart (E, Horizontal)

From above value chart it can be summarized that:

- Blackboard horizontal average illuminance is higher than the recommended average illuminance.
- Uniformity is good.

8.4.5.9 Measurement of UGR:

3 Nos UGR Observer result overview is as following table:

Table 8.30: UGR Observer Result Overview

UGR Calculation Points List

No.	Designation	Position [m] X	Y	Z	Viewing direction [°]	Value
1	UGR Calculation Point 1	6.000	5.000	1.200	0.0	17
2	UGR Calculation Point 1	6.000	7.500	1.200	-10.0	18
3	UGR Calculation Point 1	6.000	2.500	1.200	15.0	18

From above UGR Observer Table it can be seen UGR value is 17 to 18. It is under the specification recommendation limit.

8.4.5.10 Photometric Result:

Table 8.31: Details of Output on Different Plane

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	355	111	1362	0.312
Floor	68	367	16	1353	0.045
Ceiling	88	173	117	900	0.674
Walls (4)	59	216	22	554	/

Table 8.32: Lighting Parameters on Floor, Ceiling & Walls

Lighting Parameters on Floor, Ceiling & Walls					
SL no	**Surface Description**	**E_{max} (lx)**	**E_{min} (lx)**	**E_{av} (lx)**	**Uniformity (u_o)**
1	Floor Surface	1353	16	367	0.045
2	Ceiling	900	117	173	0.674
3	Four Walls	554	22	216	-

Table 8.33: Luminaire Output

No.	Row Index	Dimming %	Pieces	Designation (Correction Factor)	ø (Luminaire) (lm)	P (W)
1	Last Row	35%	3	FSC Lighting L28548-40WT-40K	3287.05	24.895
2	Middle Row	5%	3	FSC Lighting L28548-40WT-40K	4804.15	36.385
3	First Row	2%	3	FSC Lighting L28548-40WT-40K	4955.86	37.534
4	Black Board	70%	2	FSC Lighting L28648-25W-40K	999.9	7.47
				Total:	41140.98	311.382

- Total Luminous Flux: 41140.98 lm.
- Total Load: 311.382 W.
- Ground area: 120.00 m².
- LPD: 2.59 W/m².

8.5 Result Overview:

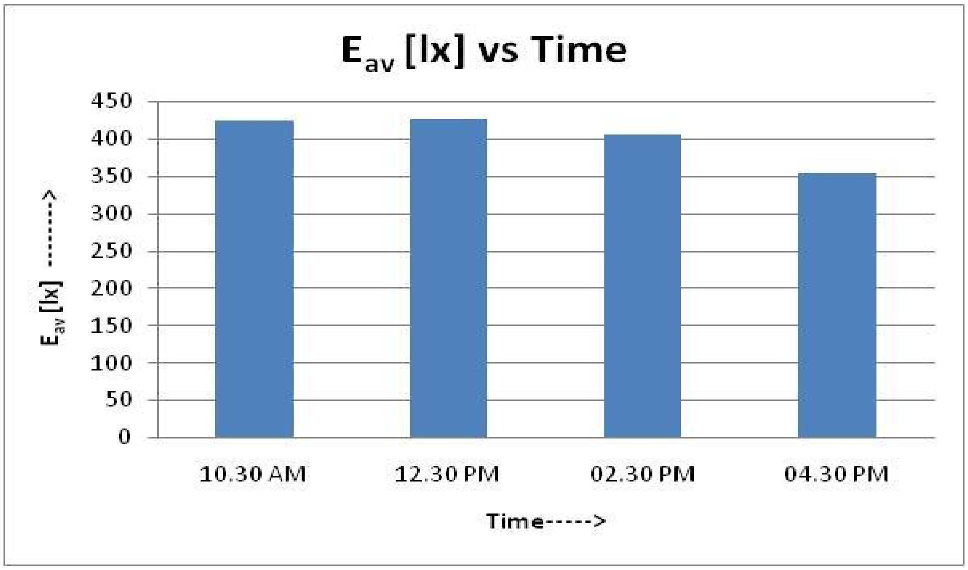
8.5.1 Illuminance on Primary Work plane Grid For Students:

Average Illuminance on primary work plane Grid For Students for four times are tabulated below:

Table 8.34: E_{av}[lx] on Primary Work plane Grid For Students

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
E_{av} [lx]	424	425	405	354

Chart 8.1: E_{av}[lx] on Primary Work plane Grid For Students



From above chart it can be summarized that:

- Sufficient average illumination in the classroom.
- As the time goes on average illumination also decreases.

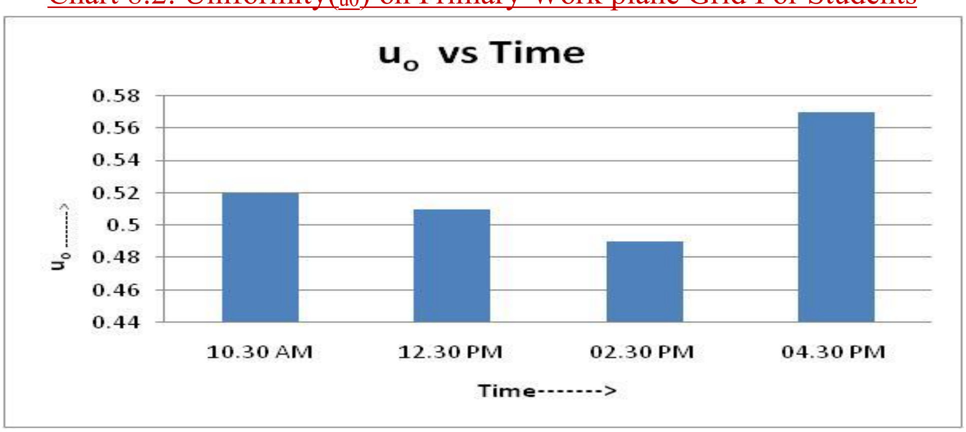
8.5.2 Uniformity on Primary Work plane Grid For Students:

Uniformity(u_0) on primary work plane Grid For Students for four times are tabulated below:

Table 8.35: Uniformity(u_0) on Primary Work plane Grid For Students

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
u_o	0.52	0.51	0.49	0.57

Chart 8.2: Uniformity(u_0) on Primary Work plane Grid For Students



From the above chart it can be summarized that:

- Uniformity in the classroom in considerable.

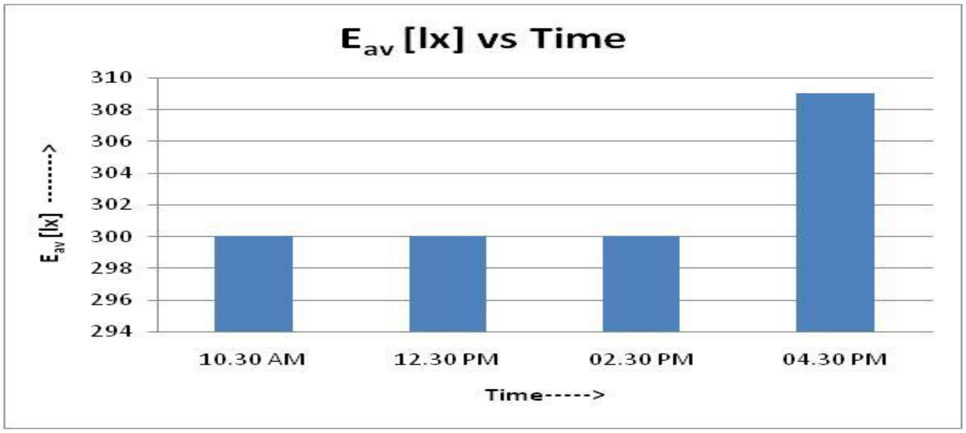
8.5.3 Illuminance on Secondary Work Plane Grid For Students:

Average Illuminance on secondary work plane Grid for Students for four times are tabulated below:

Table 8.36: E_{av}[lx] on Secondary Work plane Grid For Students

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
E_{av} [lx]	300	300	300	309

Chart 8.3: E_{av}[lx] on Secondary Work plane Grid For Students



From above chart it can be summarized that:

- Sufficient average illumination on the first row desks.

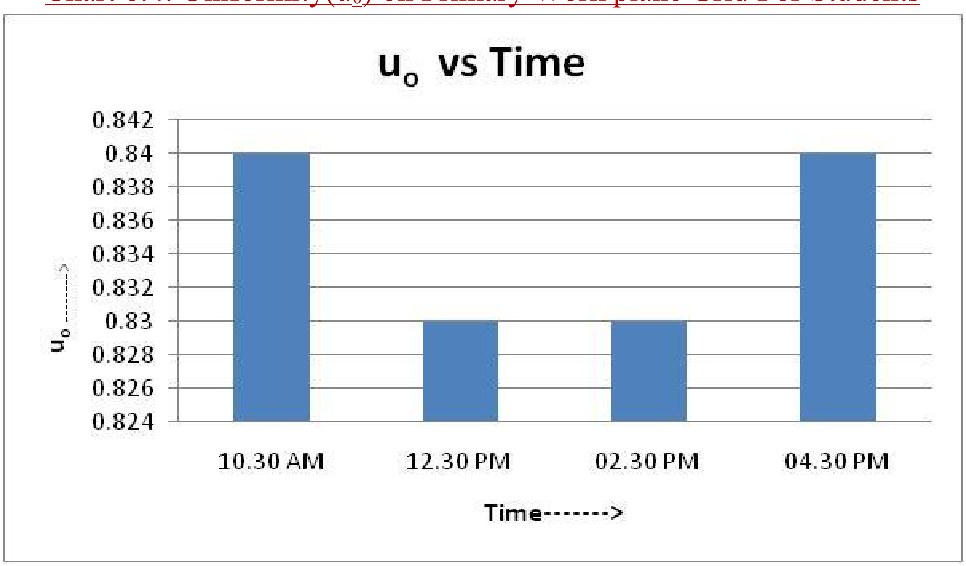
8.5.4 Uniformity on Secondary Work plane Grid For Students:

Uniformity(u_0) on secondary work plane Grid For Students for four times are tabulated below:

Table 8.37: Uniformity(u_0) on Primary Work plane Grid For Students

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
u_o	0.84	0.83	0.83	0.84

Chart 8.4: Uniformity(u_0) on Primary Work plane Grid For Students



From the above chart it can be summarized that:

- Uniformity on the front row desks are very good.

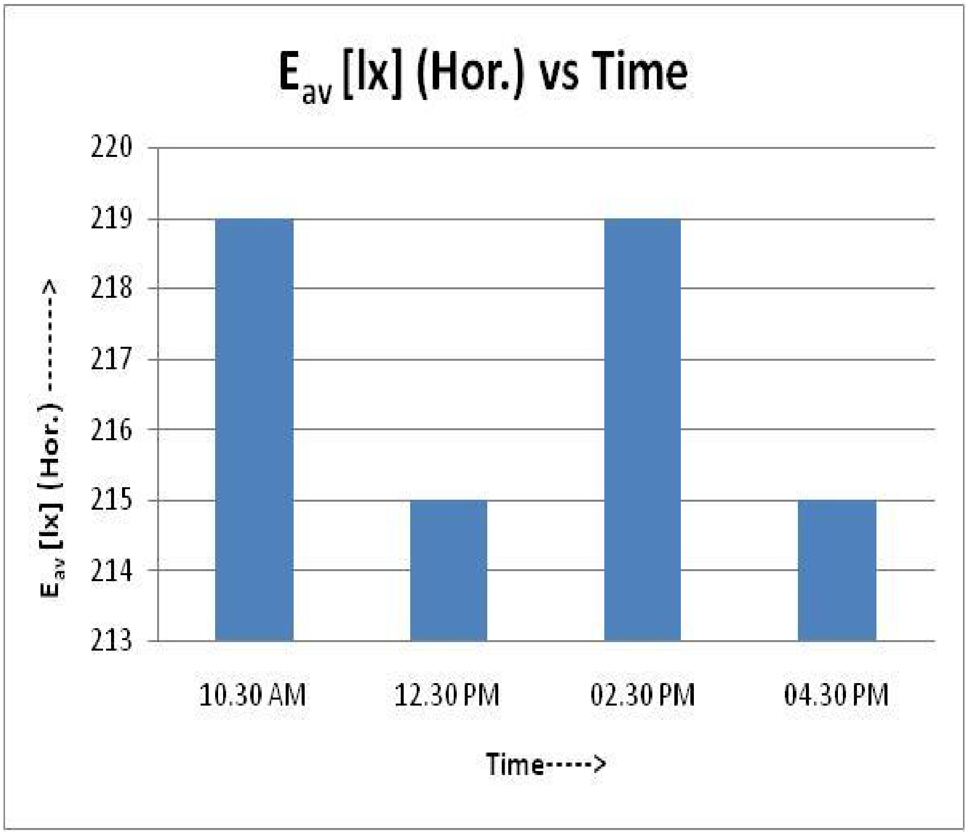
8.5.5 Illuminance on Horizontal Calculation Grid On Board:

Illuminance on Horizontal Calculation Grid on Board for four times are tabulated below:

Table 8.38: Illuminance on Horizontal Calculation Grid on Board

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
E_{av} [lx] (Hor.)	219	215	219	215

Chart 8.5: Illuminance on Horizontal Calculation Grid on Board



From above chart it can be summarized that:

- Proper illumination on the blackboard.

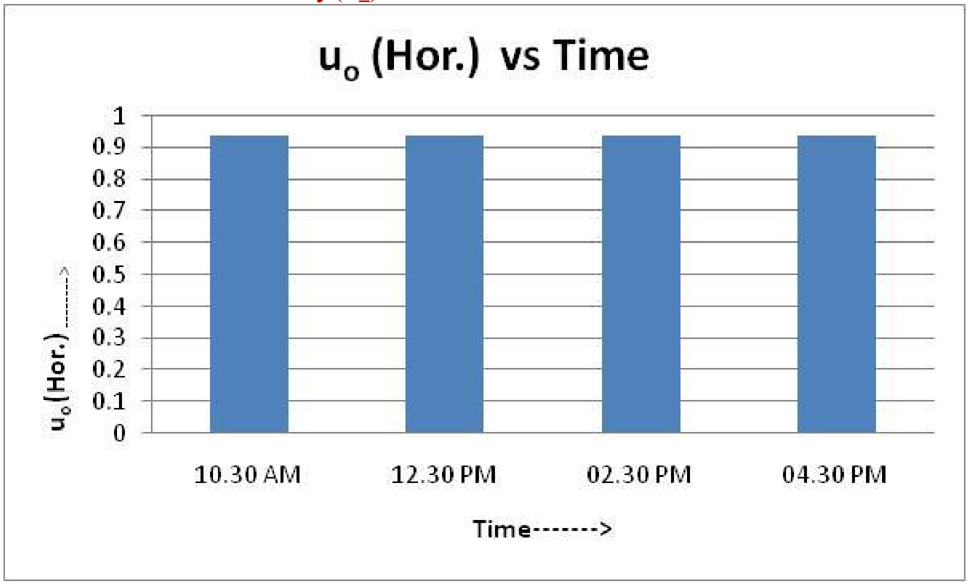
8.5.6 Uniformity on Horizontal Calculation Grid On Board:

Uniformity(u_0) on Horizontal Calculation Grid on Board for four times are tabulated below:

Table 8.39: Uniformity(u_0) on Horizontal Calculation Grid on Board

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
u_o (Hor.)	0.94	0.94	0.94	0.94

Chart 8.6: Uniformity(u_0) on Horizontal Calculation Grid on Board



From above table it can be summarized that:

- Horizontal uniformity is good.

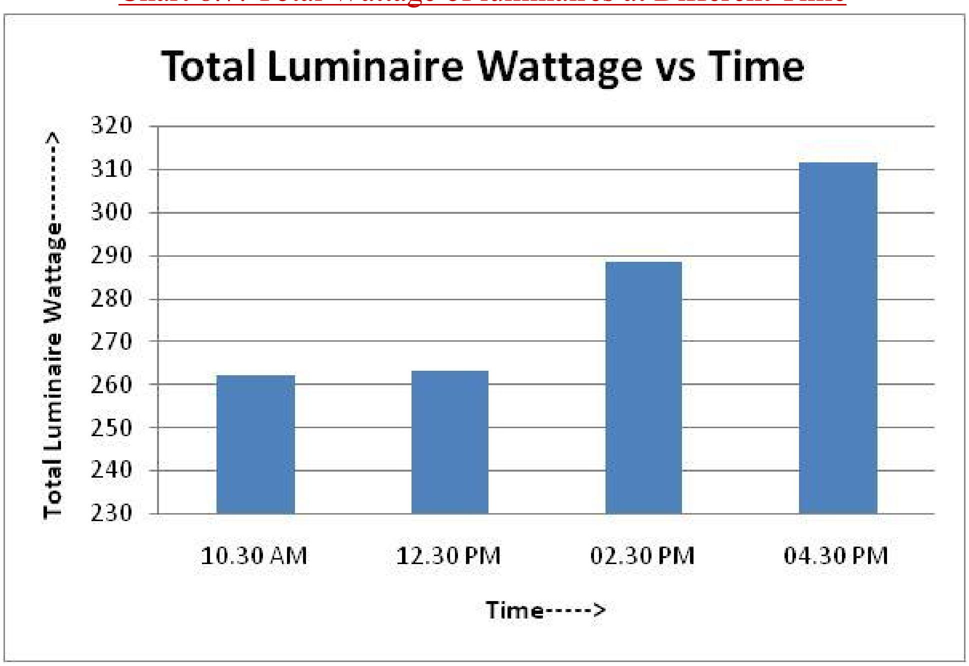
8.5.7 Total wattage of Luminaire:

As the dimmable luminaire is used in the classroom so luminaire total wattage is as the following table:

Table 8.40: Total Wattage of the luminaire

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
Total Luminaire Wattage	261.975	263.124	288.402	311.382

Chart 8.7: Total Wattage of luminaires at Different Time



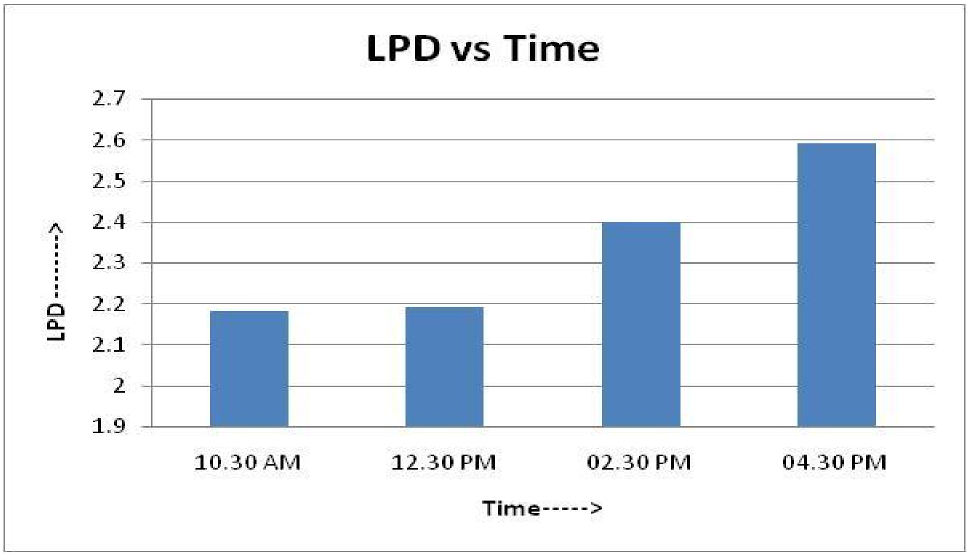
8.5.8 LPD:

As the dimmable luminaire is used in the classroom so luminaire LPD is as the following table:

Table 8.41: LPD of the luminaire

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
LPD	2.18	2.19	2.40	2.59

Chart 8.8: LPD of luminaires at Different Time



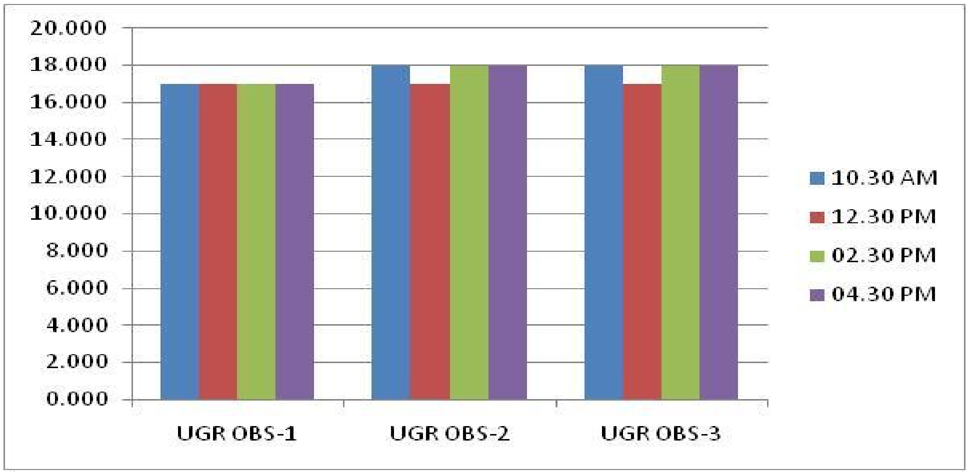
8.5.9 UGR Observer:

3 UGR Observer at four different times are tabulated below:

Table 8.42: UGR Observer Result

	10.30 AM	12.30 PM	02.30 PM	04.30 PM
UGR OBS-1	17	17	17	17
UGR OBS-2	18	17	18	18
UGR OBS-3	18	17	18	18

Chart 8.9: UGR Observer Result



- Glare is under the recommended value
- Sufficient lighting on blackboard.

8.6 Summary:

Table 8.43: Average Illumination on Primary Work Plane

SL NO	Work Plane	Time	Average Illuminance (lux)
1	Primary Work Plane for Students	10.30 AM	424
2	Primary Work Plane for Students	12.30 PM	425
3	Primary Work Plane for Students	02.30 PM	405
4	Primary Work Plane for Students	04.30 PM	354

Table 8.44: Average Illumination on Secondary Work Plane

SL NO	Work Plane	Time	Average Illuminance (lux)
1	Secondary Work Plane for Students	10.30 AM	300
2	Secondary Work Plane for Students	12.30 PM	300
3	Secondary Work Plane for Students	02.30 PM	300
4	Secondary Work Plane for Students	04.30 PM	309

Table 8.45: Average Illumination (Horz.) on Black Board

SL NO	Work Plane Name	Time	Average Illuminance (Horz.) (lux)
1	Black Board	10.30 AM	219
2	Black Board	12.30 PM	215
3	Black Board	02.30 PM	219
4	Black Board	04.30 PM	215

Table 8.46: Unified Glare Rating by Glare Observer

SL NO	Work Plane	Time	UGR (Obs. 1, Obs. 2 & Obs. 3)
1	Work Plane for Students	10.30 AM	17, 18, 18
2	Work Plane for Students	12.30 PM	17, 17, 17
3	Work Plane for Students	02.30 PM	17, 18, 18
4	Work Plane for Students	04.30 PM	17, 18, 18

Table 8.47: LPD of the Classroom

SL NO	Time	LPD (W/m^2)
1	10.30 AM	2.18
2	12.30 PM	2.19
3	02.30 PM	2.40
4	04.30 PM	2.59

From the above design it can be summarized that:

- Average Illumination on primary work plane grid for students can be achieved to above 300 lx.
- Maximum Grid point vertical illuminance value very nearer or above 300 lx.
- Average Illumination on first row desk also achieved 300 lx, so it can be said in also lower work plane recommended illumination achieved.
- Uniformity on work plane grid for students is above 0.5.
- Average Horizontal Illuminance on blackboard is above 200 lx.
- Horizontal uniformity on blackboard is above 0.9.
- 3 nos Glare observer UGR value is in between 17 to 18.

Chapter-9

Result Analysis

9.1 Result Analysis:

The details of result analysis of different measured parameters of above four designs for four times of a day are as follows:

NOTE: DL means Daylight & AL means Artificial Light.

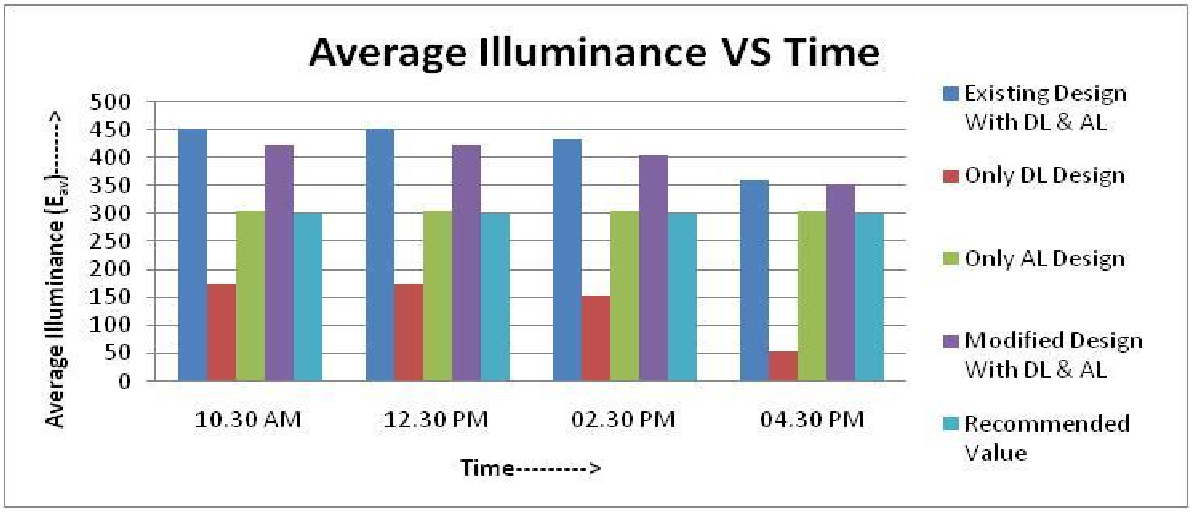
9.1.1 Average Illumination (E_{av}) on work plane Grid for Students:

The details of result analysis of Average Illumination (E_{av}) of above four designs for four times of a day are as following table & chart:

Table 9.1: Average Illumination (E_{av}) on Work plane for 4 design for 4 daytime

Average Illuminance (lx) VS Time				
	10.30 AM	12.30 PM	02.30 PM	04.30 PM
Existing Design With DL & AL	453	452	435	362
Only DL Design	176	176	154	55
Only AL Design	306	306	306	306
Modified Design With DL & AL	424	425	405	354
Recommended Value	300	300	300	300

Chart 9.1: Average Illumination (E_{av}) on Work plane for 4 design for 4 daytime



- **Observation:**
    1. Average Illumination on work plane grid for students lowered by some lux from Existing Design with Daylight & Artificial Light in Modified Design with Daylight & Artificial Light in all four measurement Time.
    2. In modified Design Average Illuminance is higher than recommended value of average illuminance for classroom lighting (300 lx) as per guidance of IS 3646 (Part 1): 1992 (Code of Practice for Interior Illumination) .
    3. The lighting was designed keeping two objects in mind, namely, to make the task easy to see and to create a good visual environment.

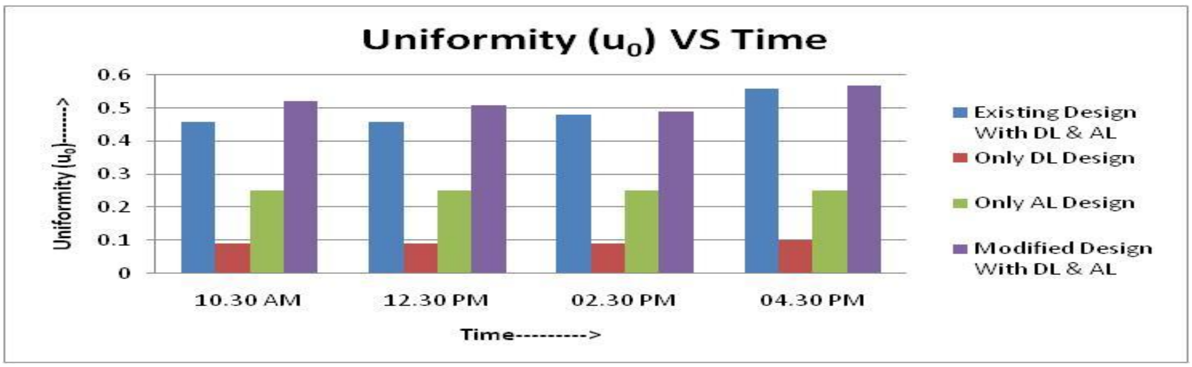
9.1.2 Uniformity (u_0) on work plane Grid for Students:

The details of result analysis of Uniformity (u_0) of above four design for four times a day are as following table & chart:

Table 9.2: Uniformity (u_0) on Work plane for 4 design for 4 daytime

Uniformity (u_0) VS Time				
	10.30 AM	12.30 PM	02.30 PM	04.30 PM
Existing Design With DL & AL	0.46	0.46	0.48	0.56
Only DL Design	0.09	0.09	0.09	0.1
Only AL Design	0.25	0.25	0.25	0.25
Modified Design With DL & AL	0.52	0.51	0.49	0.57

Chart 9.2: Uniformity (u_0) on Work plane for 4 design for 4 daytime



- **Observation:**
  1. Uniformity on work plane grid for students is better in modified design than existing design.

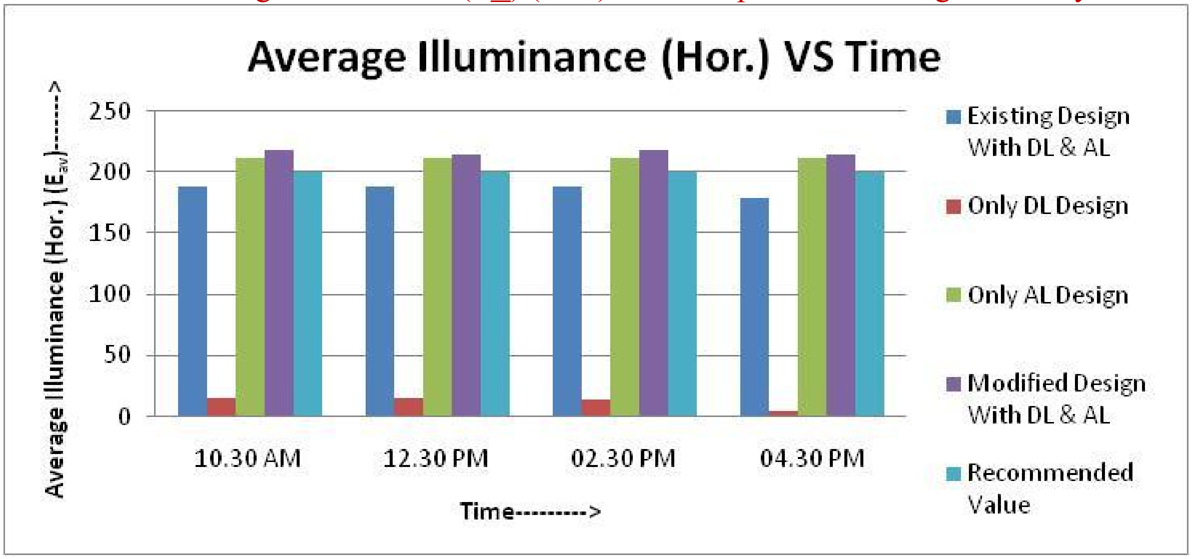
9.1.3 Average Illumination (E_{av}) (Hor.) on Calculation Grid for Blackboard:

The details of result analysis of Average Illumination (E_{av}) (Hor.) of above four design for four times a day are as following table & chart:

Table 9.3: Average Illumination (E_{av}) (Hor.) on Work plane for 4 design for 4 daytime

Average Illuminance (Hor.) (lx) VS Time				
	10.30 AM	12.30 PM	02.30 PM	04.30 PM
Existing Design With DL & AL	189	189	188	179
Only DL Design	16	16	14	5.34
Only AL Design	212	212	212	212
Modified Design With DL & AL	219	215	219	215
Recommended Value	200	200	200	200

Chart 9.3: Average Illumination (E_{av}) (Hor.) on Work plane for 4 design for 4 daytime



- **Observation:**
    1. Average Horizontal Illuminance on calculation grid on black board is higher than the recommendation value on horizontal plane (200 lx) as per IESNA Lighting Handbook-10th Edition for Modified Design than Existing Design.
    2. Average Horizontal Illuminance on calculation grid on blackboard is optimized for modified design.

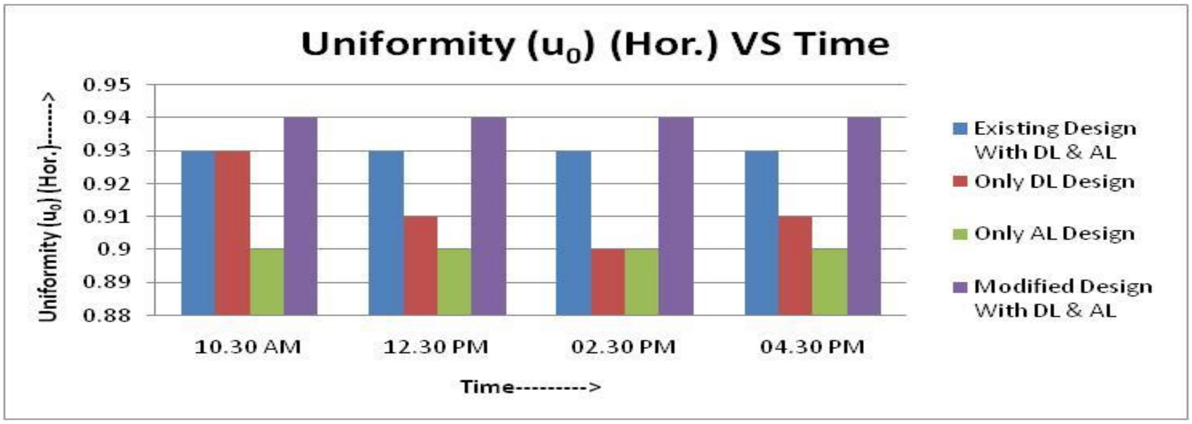
9.1.4 Uniformity (u_0) (Hor.) on work plane Grid for Students:

The details of result analysis of Uniformity (u_0) of above four design for four times a day are as following table & chart:

Table 9.4: Uniformity (u_0) (Hor.) on Work plane for 4 design for 4 daytime

Uniformity (u_0) (Hor.) VS Time				
	10.30 AM	12.30 PM	02.30 PM	04.30 PM
Existing Design With DL & AL	0.93	0.93	0.93	0.93
Only DL Design	0.93	0.91	0.9	0.91
Only AL Design	0.9	0.9	0.9	0.9
Modified Design With DL & AL	0.94	0.94	0.94	0.94

Chart 9.4: Uniformity (u_0) (Hor.) on Work plane for 4 design for 4 daytime



- **Observation:**
    1. Uniformity on horizontal plane is better in modified design than the existing design.

9.1.5 3 Nos Glare Observer:

The details of result analysis of 3 nos Glare Observer of above four design for four times a day are as following table & chart:

Table 9.5: UGR by Glare Observer-1 for 4 design for 4 daytime

UGR VS Time (Obsever-1)				
	10.30 AM	12.30 PM	02.30 PM	04.30 PM
Existing Design With DL & AL	21	21	21	21
Only AL Design	16	16	16	16
Modified Design With DL & AL	17	17	17	17

Table 9.6: UGR by Glare Observer-2 for 4 design for 4 daytime

UGR VS Time (Obsever-2)				
	10.30 AM	12.30 PM	02.30 PM	04.30 PM
Existing Design With DL & AL	21	21	21	22
Only AL Design	17	17	17	17
Modified Design With DL & AL	18	17	18	18

Table 9.7: UGR by Glare Observer-3 for 4 design for 4 daytime

UGR VS Time (Obsever-3)				
	10.30 AM	12.30 PM	02.30 PM	04.30 PM
Existing Design With DL & AL	21	21	21	21
Only AL Design	17	17	17	17
Modified Design With DL & AL	18	17	18	18

Chart 9.5: UGR by Glare Observer-1 for 4 design for 4 daytime

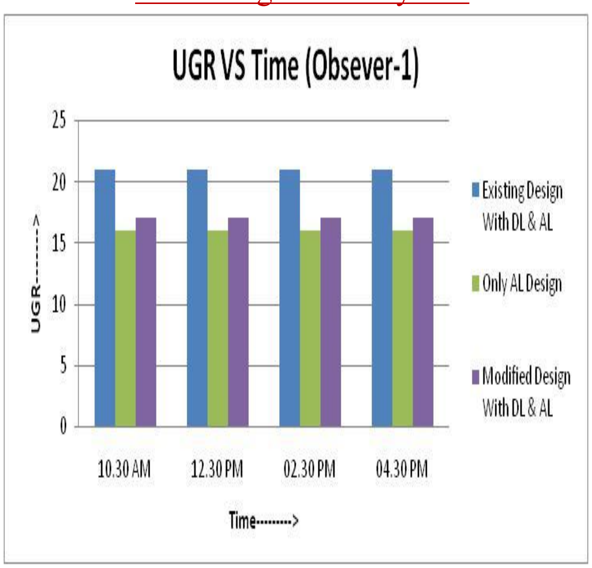


Chart 9.6: UGR by Glare Observer-2 for 4 design for 4 daytime

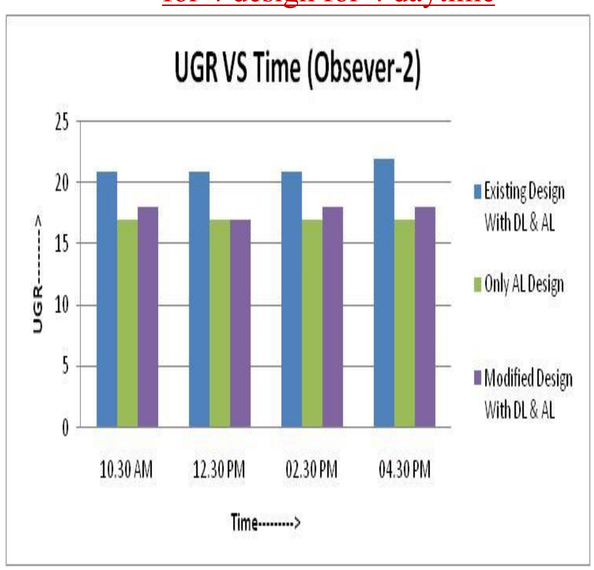
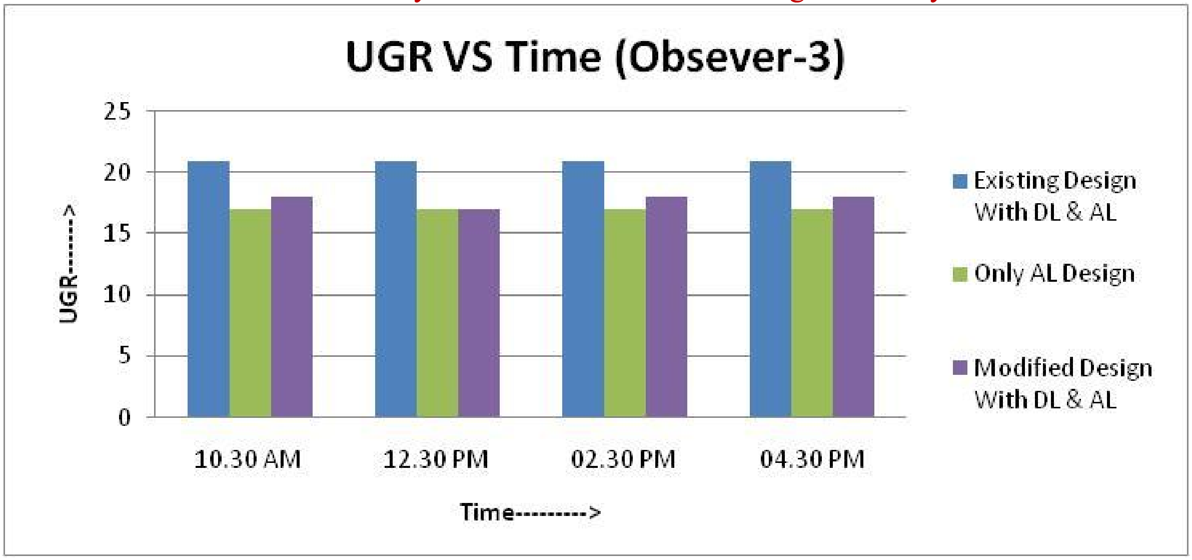


Chart 9.7: UGR by Glare Observer-3 for 4 design for 4 daytime



- **Observation:**
    1. UGR by 3 Observer is under recommended value (16-25) as per BSEN 12464-1:2021.

9.1.6 Energy Consumption Analysis:

For above Four design details of energy consumption analysis during a day are discussed below:

9.1.6.1 Existing Lighting Design with the combination of Daylight & FTL:

In existing lighting design daylight is integrated with FTL to illuminate the classroom and FTL are not dimmable so power requirement is fixed for the whole daytime.

Power requirement in each FTL luminaire: 84.7 Watt

No of Luminaire used: 9 Nos

Total power requirement: 84.7 X 9 = 762.3 Watt

If we think daily 6 hours class then total energy consumed: 762.3 X 6 / 1000 = 4.58 kW-hr.

9.1.6.2 Lighting Design with only by Daylight:

In this design only daylight is used to illuminate the classroom, no artificial light are used so power requirement is 0.

So Energy consumed for 6 hours class: 0 kW-hr

9.1.6.3 Lighting Design with only by Artificial LED Luminaire:

In this design only LED dimmable luminaire is used for illuminate the classroom for whole day, no daylight is used, so power requirement is fixed for a day.

Total Power requirement in classroom: 327.4 Watt

Total Energy consumed for a 6 hours class: 327.4 X 6 / 1000 = 1.97 kW-hr

9.1.6.4 Lighting Design by Integrating Daylight & Artificial LED Luminaire:

In this design LED luminaire is used with the integration of daylight to illuminate the room. Also LED luminaires are dimmable, so at four measurement time four different amount of power is required to illuminate the classroom. So average value of four measurement is taken for calculation.

At 10.30 AM Power Requirement is 261.975 Watt,
At 12.30 PM Power Requirement is 263.124 Watt
At 02.30 PM Power Requirement is 288.402 Watt
At 04.30 PM Power Requirement is 311.382 Watt
Average Power Requirement is (261.975+263.124+288.402+311.382)/4 =281.221 Watt
Total Energy consumed for 6 hours class: 281.221 x 6 /1000 = 1.69 kW-hr

- **Observation:**

1. So by modification from FTL to LED and using dimming, it can save about (4.58-1.69) 2.89 kW-hr per day.

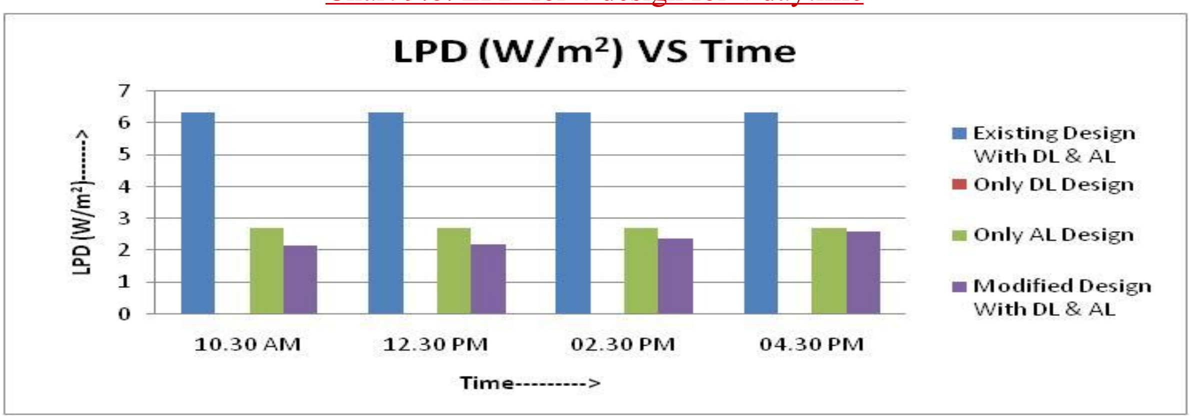
9.1.7 LPD Analysis:

The details of result analysis of LPD of above four design for four times a day are as following table & chart:

Table 9.8: LPD for 4 design for 4 daytime

LPD (W/m^2) VS Time				
	10.30 AM	12.30 PM	02.30 PM	04.30 PM
Existing Design With DL & AL	6.35	6.35	6.35	6.35
Only DL Design	0	0	0	0
Only AL Design	2.73	2.73	2.73	2.73
Modified Design With DL & AL	2.18	2.19	2.40	2.59

Chart 9.8: LPD for 4 design for 4 daytime



- **Observation:**

1. LPD has been reduced significantly in modified design from existing design.
2. In modified design LPD value is under the recommendation value (12.9 W/m^2) as per ECBC 2017.

9.1.8 Secondary Work plane Grid for Students Illumination & Uniformity:

In Modified Design with Artificial LED Luminaire integrated with Daylight average illumination is about 300 lx and uniformity is about 0.8 for all daytime. So it can be concluded that:

- In modified design on every level work plane recommended average illuminance can be achieved.

CHAPTER-10
CONCLUSION

10.1 Conclusion:

Lighting design provides a major scope to achieve energy efficiency at the design stage, by incorporation of modern energy efficient lamps, luminaires and gears, effective controls, and careful design apart from good operational practices. Lighting is not just a high priority when considering classroom design; it is also a high return, low-risk investment. By installing new lighting technologies, classroom can reduce the amount of electricity consumed and energy costs associated with lighting. Various light control systems are introduced in current markets because the installed lighting systems are outdated and energy inefficient. It has been found that for energy efficient lighting design and usage of energy efficient light source is very important. Thus, LED in suitable luminaires are used in the project. The lighting design has been made considering the various requirements at the classroom as follows:

- Replacement with energy efficient lamps for energy saving and operating cost saving.
- Reduce the excess light level to the required level with good uniformity and minimizing glare.
- Good lighting system is created for Healthy environment for the classroom students and teachers.
- Reduction in energy consumption per year.
- Use of low maintenance lamps with longer life which will improve average illuminance.

A comparison of different lighting installation scheme in classroom was designed in terms of average Illuminance, LPD and energy consumption. From the bar charts, appropriate value for average illuminance and LPD were recommended area wise. The per day energy savings is prepared, to justify the proposal for new energy efficient lighting design using LEDs.

10.2 Future Scope:

Lighting system designed here is controlled by via manual buttons & switches. Modern technology growing day by day may be further utilized for lighting control. In smart lighting, android Smartphone or PC with Bluetooth and Wi-Fi for controlling purpose are developed. Smart lighting is one of the easiest ways to save energy where every light point is connected to an intelligent system that delivers high-quality, reliable illumination and sometimes even extraordinary value beyond illumination to the users. In future, smart lighting will be the key part of Internet of Things (IoT) that brings in the collaborative streaming of real-time data and artificial intelligence but the most striking feature is - it enables consumers to make better decisions thereby saving money. IoT is the concept of combining computers and networks to monitor and control devices to generate, exchange and consume data with minimal human intervention. General Lighting as well as some special lighting system may be controlled by visual light control system instead of radio-frequency controller. The LED can also be dimmed accurately by integrating daylight sensors with the artificial lighting in parts of the classroom place where daylight is available leading to further saving in energy. Also lighting load can be connected to the solar energy obtained from solar panel on the terrace. Regions where long daylight is present, this can be very effective way of energy saving. Also, by using the next technology is OLEDs (Organic LED) where it uses organic semiconductors to generate light, saving of energy can be obtained.

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