PERFORMANCE OF DIFFERENT TYPE OF LAMPS IN MESOPIC PHOTOMETRY SYSTEM

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

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Abstract:

Mesopic vision is the intermediate region between light adaptive vision i.e. photopic vision & dark adaptive vision i.e. scotopic vision. According to the recommendation of International Commission on Illumination (CIE), mesopic luminance level lies between 0.005 cd/m^{2}and 5 cd/m^2. Different types of the exterior lighting systems (e.g. outdoor lighting, road lighting etc.) are in mesopic region. Significant works has been done about road lighting but in case of outdoor lighting researches are yet to done in photometric field and application areas.

In case of outdoor lighting different types of lamps are used now a day's such as, High Pressure Sodium Vapor (HPSV), Metal Halide (MH) lamp, White Light Emitting Diode (WLED). Performance of these lamps under mesopic photometry in outdoor lighting environment has been studied. As mesopic luminance can't be measured directly at the grid points using luminance meter, at first measure photopic luminance of the field have been measured and then converted to its equivalent mesopic luminance using CIE 191:2010 table.

In this work performance of HPSV &MH lamps with or without surrounding light source (SLS) in different light condition have been studied from the simulated outdoor environment in the laboratory. Cool white fluorescent lamp (CWFTL) and warm white fluorescent lamp (WWFTL) have been used as SLS.

From this work it has made out that for efficient energy management HPSV lamp is not recommended but MH, WWSLS, CWSLS are recommended as in case of HPSV mesopic luminance is less than that of photopic luminance.

From this thesis it has analyzed that HPSV lamp is not recommended in case of road as performance of HPSV lamp with or without any SLS is not up to the mark for road lighting requirement.

Chapter 1:
Introduction

The International Commission on Illumination (CIE) has recommended a mesopic photometry system based on peripheral visual performance of tasks within the range of 0.005 cd/m^2 to 5 cd/m^2 and a combination of photopic vision and scotopic vision. Different night-time outdoor and traffic lighting scenarios are in the mesopic range.

Humans see differently at different light levels. This is because under high light levels typical during the day (photopic vision), the eye uses cones to process light. Under very low light levels, corresponding to moonless nights without electric lighting (scotopic vision), the eye uses rods to process light [1-6]. At many night-time levels, a combination of both cones and rods supports vision. Photopic vision facilitates excellent color discrimination ability, whereas colors are not discriminable under scotopic vision. Mesopic vision falls between these two extremes. In most night-time environments, there is enough ambient light at night to prevent true scotopic vision [7-13].

Mesopic photometry aims to measure light in a way which correlates with the mesopic vision. In mesopic photometry, adaptation luminance is needed to derive the Mesopic luminance for the measurement field. Adaptation luminance is the average luminance (or brightness) of those objects and surfaces in the immediate vicinity of an observer estimating the visual range.

Lamp performance in mesopic photometry system varies from different lamp combination and their individual cases also. Main objective of the thesis is to measure the performance for different lamps in outdoor lighting scenario under mesopic luminance range for all relevant S/P ratio (i.e. Scotopic/Photopic ratio) of lamps.

The main focus of this thesis is to analyse suitable lamp or combination of lamps which is to be considered for road lighting or outdoor lighting applications.

So, here the photopic luminance has been measured under different combination lamp conditions. Then after the determination of Scotopic/Photopic Ratio (S/P ratios), Co-related colour temperature (CCT) & Spectral Power Distribution (SPD) of the lamps, Mesopic Luminances are calculated and mesopic plots are simulated using MATLAB software. After that from the obtained results photopic, mesopic & adaptation luminance of different lamps are compared under different surrounding luminance conditions.

1.1. Literature Survey

- M Eloholmaa, MSc, M ViikariaMSc, L HalonenaDrSc, H Walkeyb PhD, T Goodmanc BSc, J Alferdinck **"Mesopic models from brightness matching to visual performance in night-time driving: a review"** Lighting Res. Technol. 37,2 (2005) pp. 155_ 175[14]

In this paper majority of spectral luminous efficiency functions obtained to date in the mesopic range have been acquired by heterochromatic brightness matching. However, the most recent studies in the mesopic field have adopted a task performance-based approach. This paper summarizes the major mesopic models proposed so far, presenting in detail the experimental conditions of these studies. The authors represent a research consortium which has adopted the task performance-based approach for night-time driving in which mesopic visual performance has been divided into three subtasks. Data for each sub-task will be generated by using a set of common parameter values and 120 observers. The approach and methods used by the consortium are presented.

- N. Bisketzis G. Polymeropoulos F. V. Topalis "**A Mesopic Vision Approach for a Better Design of Road Lighting"** Word Scientific and Engineering Society Transactions on Circuits and Systems, Vol. 3, Issue 5, pp. 1380-1385, July 2004.[15]

This paper approaches the design of road lighting from the point of view of mesopic vision. Up to date all lighting calculations are performed for photopic visual conditions. Although this is true for interior lighting, it is not always the case for road lighting. Usually, the luminance level on roads of low or medium traffic, fall below the lower limits of photopic vision. In that case, the vision becomes mesopic. Recent researches have proved that in mesopic visual conditions the sensitivity of the human eye moves to lower wavelengths. Therefore, some types of lamps which are widely used for road illumination (e.g. high-pressure sodium) are not as efficient as they use to be in the photopic vision. It seems that the efficiency of lighting installations could be improved by using lamps with light spectrum richer in shorter wavelengths (e.g. metal halide). This paper shows that the road lighting quality parameters may be improved if the high-pressure sodium lamps are replaced by metal halide lamps in identical lighting installations, given that the visual performance of the eye is considered under mesopic vision. The calculations shown in this paper prove that metal halide lamps are more efficient than is usually believed and, moreover, energy savings could be achieved.

- The Optical Society of Japan ,Jae Chul Shin, Hirohisa Yaguchi1 and Satoshi Shioiri1 "**Change of Color Appearance in Photopic, Mesopic and Scotopic Vision"** Hirohisa YAGUCHI1 and Satoshi SHIOIRI1 Graduate School of Science and Technology, Chiba University, 2004,Optical society of Japan[16]

Mesopic vision describes a range of light levels where vision is mediated by both cones and rods. The appearance of color in mesopic vision differs drastically from that in photopic vision, where only cones mediate visual information. We used a haploscopic color matching technique to investigate the color appearance under various illuminance levels, ranging from photopic to scotopic via mesopic levels. The observers did color matching between a test color chip under various illuminance levels and a matching color stimulus presented on the Cathode-Ray Tube (CRT) display under the photopic illuminance condition. The results showed that not only chroma and lightness but hue of most color chips changed with illuminance. The manner of the hue changed depended on the color of the test chip, while matching points approached a neutral gray with decrease in illuminance level for all test chips. Chroma reduced continuously with decrease of the illuminance level until 0.1 lx for reddish and yellowish color chips or until 1 lx for greenish and bluish ones. Beyond those illuminance levels, chroma was approximately constant. Lightness decreased with decreasing illuminance level for all test chips except bluish color chips, for which lightness did not decrease much in general and even increased in some cases as predicted by the Purkinje shift. The experimental results obtained in the present study provide critical features that should be considered in predicting the appearance of color at low light levels.

- MeriViikari,AleksanteriEkrias,MarjukkaEloholma,LiisaHalonen,Lighting Laboratory, Helsinki, University of Technology, Finland **"Modeling spectral sensitivity at low light levels based on mesopic visual performance"[17]**

The spectral sensitivity of the eye at low light levels, i.e., mesopic conditions, is determined by the rod and cone photoreceptors of the retina operating together in varying degree as adaptation luminance shifts between the scotopic and photopic. Thus mesopic spectral sensitivity is different from photopic, where only cones contribute to vision. There are definite needs for a practical system of mesopic photometry to be used in assessing light at low light levels, especially in road and other outdoor lighting applications. However, neither of the recently proposed systems of mesopic photometry, the MOVE-model or the X-model, is found satisfactory by common consent of the lighting community. The most active debate has considered the upper luminance limit of the mesopic region, which is regarded to be too high for the MOVE-model and too low for the X-model. The present paper proposes a new modified MOVE-model whose upper luminance limit is adjusted to meet the actual road and street lighting luminance values measured in different weather conditions. The paper compares the MOVE-model, X-model, and the proposed modified MOVE-model with three independent visual performance data sets provided by different European universities. Based on the comparison, recommendations are given for future actions towards internationally accepted practice for mesopic photometry.

- Jiří Habel, Petr Žák, Jan Zálešák**, "Determination of luminous flux in conditions of mesopic vision"[18]**

The article presents results of applying the newly proposed system for mesopic photometry based on visual performance in practical conditions in the area of public lighting. For a group of nine lamps with different spectral composition was made the analysis of the luminous flux changes that occur due to the changes in the spectral sensitivity of the human eye in mesopic conditions.

- M ShpakMSc, P Ka¨rha¨ PhDband E IkonenPhD, **"Mathematical limitations of the CIEmesopic photometry system"**Lighting Res. Technol. 2017; Vol. 49: 111–121[19]

The International Commission on Illumination (CIE) has published a recommended system for mesopic photometry based on visual performance. The system provides means for determining mesopic photometric values based on measuring the spectral composition and intensity of light. The system uses an iterative calculation method. They investigated the conditions under which this system is applicable and identify potential problems with the iterative method. We show that the system works well for the vast majority of lighting applications. However, it hasnon-convergence and discontinuity issues for sources with very high and very low values of scotopic-photopic ratio. A set of parameterized formulae is presented that approximates the mesopic model and provides a continuous, closed-form solution for the adaptation level in all lighting conditions.

- Helsinki University of Technology, Lighting laboratory; Espoo 2005; Editors: Eloholma Marjukka, "**Development Of Visual Performance Based Mesopic Photometry"[13]**

This work started by investigating the applicability of the photopic function to predict visual task performance at mesopic light levels. Visual acuity and pedestrian visibility experiments were carried out in varied lighting and viewing conditions. The results indicated the inadequacy of photopic photometry to characterize the response of peripheral vision at low mesopic light levels. They also indicated that mesopic spectral sensitivity is visual task dependent. Based on these findings, and on an extensive review of mesopic research work, it was evident that there was a demand for visual performance based mesopic photometry. In order to establish a basis for mesopic photometry, a European research consortium with multi-disciplinary expertise was formed. Following this, a framework for the development of performance based mesopic photometry was developed. With this framework the international lighting community and EC Fifth Framework Programme were convinced to identify the urgent need for mesopic photometry. The work continues by introducing a multi-technique approach developed and adopted in a European research work MOVE. In the work of MOVE, a large data-base of mesopic visual task performance was generated by investigating the visual performance of night-time driving using three visual sub-tasks. The data was used in modeling mesopic spectral sensitivity. The MOVE work resulted in two distinct mesopic models; a practical (i.e. linear) model and a more complex chromatic model. The practical model is applicable for the visual task of night-time driving in situations where the background and target both have fairly broad spectral power distributions. The chromatic model gives a better prediction of performance for tasks which colorfulness (chromatic saturation) is high. The MOVE practical model was applied in road lighting dimensioning via road luminance measurements. Road lighting installations using HPS and MH lamps were measured with a CCD luminance photometer. Analysis of the applicability of the MOVE model is conducted on the basis of luminance measurements, calculations and on comparison to a recently proposed X-model by Rea et al. The work concludes by describing how the new performance-based mesopic models of MOVE are integrated into the CIE (Commission Internationale de l'Eclairage) work in order to contribute to the establishment of a standard for mesopic photometry. Finally, the impacts of standardization of mesopic photometry on lighting dimensioning and products are discussed.

- T Uchida ME, Y Ohno PhD **"Simplified field measurement methods for the CIE mesopic photometry system"** Lighting Res. Technol. 2017; Vol. 49: 774–787[20]

For implementation of the mesopic photometry system in CIE 191:2010 to outdoor lighting, two simplified methods to measure the mesopic luminance are proposed. One of the methods, named the Adaptation Spectral Power Distribution) method, assumes that the spectral power distributions (SPDs) of reflected light at test points on the road surface are the same as that of the adaptation field. Another method, named the Source SPD method, assumes that the reflected light SPDs are equal to the SPD of the light source. Error simulations with a real road surface spectral reflectance dataset show that the error distributes over an 8% range due to the variation of the road surface spectral reflectance in the worst case. Although the bias due to the road surface spectral reflectance causes a large error with the Source SPD method, a proposed correction can reduce the error sufficiently. Error simulations also show that the Source SPD method is not so sensitive for lighting scenes that include multiple light source types. It has been shown that the SPD methods can measure the mesopic quantities without scotopic/photopic luminance meters having both $V(\lambda)$ and $V'(\lambda)$ detectors when both the adaptation field and test points consist of road surfaces.

1.2. Problem Definition:

In case of exterior lighting different types of lamps are used such as Metal Halide (MH), High Pressure Sodium Vapor (HPSV), white light emitting diode (WLED) etc. In different cases luminance of these places are in mesopic zone. In some case luminance of grid point is in photopic region (>5 cd/m^2). In that case we consider this grid as photopic luminance and do not convert it to mesopic by CIE 191 table. In this work performance of HPSV & MH lamps with or without surrounding light source (SLS) in different light condition have been studied from the simulated outdoor environment in the laboratory. Cool white fluorescent lamp (CWFTL) and warm white fluorescent lamp (WWFTL) have been used as SLS.

1.3. Objective:

The main objectives of this thesis are as follows:

- Photometric behavior of different lamps under mesopic zone.
- To compare L_{mes} of main light & surrounding light sources(SLS) taken together in glow condition and
- To compare addition of L_{mes} of main light in glow condition & L_{mes} of SLS in glow condition.

1.4. Methodology:

- ❖ Measurement of photopic luminance from grid point.
- ❖ Measurement of S/P ratios of different lamp.

- Calculation of photopic luminance to mesopic luminance by CIE 191:2010using MATLAB software.
- Comparison of the status of mesopic luminance in different lighting condition.

1.5. Outline of dissertation:

- Chapter 1 provides the introduction of thesis, its objective and methodology.
- Chapter 2 discussed about theory of photopic, scotopic and mesopic vision, their application along with the theory of different types of lamp.
- Chapter 3 discussed about instruments, lamp details and their specification. Set up of the instrument and their specifications are also discussed here.
- Chapter 4 Measurement of photopic luminance of different lamp with or without SLS.
- Chapter 5 deals with calculation of mesopic luminance from photopic luminance by CIE: 191.
- Chapter 6 deals with analysis of results by MATLAB programming, executing its 3D plot, iso-luminance diagrams and comparing average luminance values.
- Chapter 7 is about conclusion and future scope

Chapter 2:
Mesopic photometry
&
Lamps

Wavelength of visible light lies between 380 to 780 nm. Buthuman eye is not equally sensitive to all wavelength of visible light. Photometry attempts to account for this by weighing the measured power at each wavelength with a factor that represent how sensitive the eye is at that wavelength.

2.1. Type of Vision

The standardized model of eye's response to light as a function of wavelength is given by the luminosity function. Eye has different response as a function of wavelength such as-

I. Photopic vision: Luminance is More than 5 cd/m^2
II. Scotopic vision: Luminance is less than 0.005 cd/m^2
III. Mesopic vision: Luminance is between 0.005 & 5 cd/m^2

Photometry is typically based on eye's photopic response. So photometric measurement may not accurately indicate the perceived brightness of source in dim lighting condition where colors are not discernible, such as under just moonlight or starlight.

2.1.1 Photopic Vision:

It is well lighting condition in vision of eye. Its luminance level is between 5 to $10^8 cd/m^2$. Photopic vision provides for color perception, which is primarily cone mediated and perceptions are chromatic. In other words color vision is present in light level of daylight. Maximum efficacy of photopic vision is 683lumen/watt at a wavelength of 555 nm i.e. green light as shown in Fig. 2.1.

Sensitivity of human vision in photometry region varies with different visible wavelength. For example, in 500nm i.e. in blue green region only 50% of total light at 555 nm reaches retina to create image. Adaptation is faster under photopic vision. The Illuminating Engineering society of North America (IESNA) currently uses photopic measurement criteria evaluating street light. IESNA is currently reviewing photopic vs scotopic & photopic vs mesopic measurement issue.

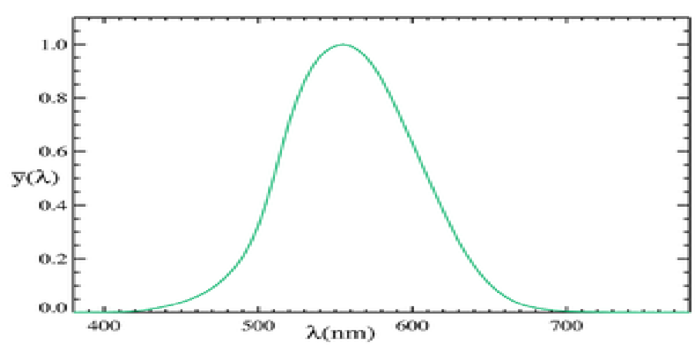


Fig2.1 Spectral Luminous Efficiency Function for Photopic Vision

2.1.1.1. Properties of photopic vision:

The properties of photopic vision are as follows:

- ✓ Known as light adaptive vision
- ✓ Cones cells are responsible here.
- ✓ Higher sensitivity in brighter light.
- ✓ Peak sensitivity towards at 555 nm.
- ✓ Basis for modern photometry.

2.1.2. Scotopic Vision:

Greek word 'scotos' means 'darkness' and 'opia' means 'a condition of sight'. So scotopic vision is the vision of eye under low light condition. This vision is produced exclusively through rod cells.Rod cells are most sensitive around 498 nm as shown in Fig.2.2. In scotopic vision luminance level is between 0.000001 cd/m^2 to 0.005 cd /m^2[1].

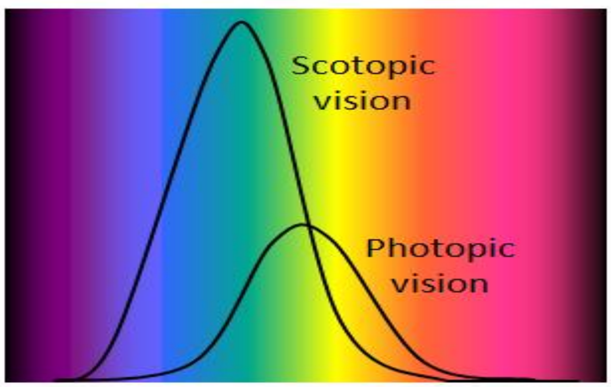
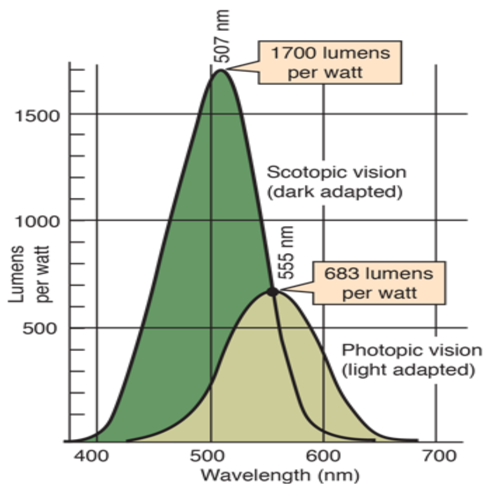


Fig 2.2 Spectral Luminous Efficiency Function for Scotopic & photopic Vision

Relative wavelength sensitivity of a normal human observer is determined by rhodopsin photo pigment. This pigment is not noticeable under photopic or mesopic conditions. The principle that wavelength sensitivity does not change during scotopic vision led to the ability to detect two functional cone classes in individual. In presence of two cone classes their relative sensitivity will change the behavioral wavelength sensitivity. Therefore in experiment two cone classes by measuring wavelength sensitivity on two different backgrounds and nothing a change in observer's relative background sensitivity.

The behavior of rhodopsin photo pigment explains why the human eye cannot resolve lights with different SPD under low light. The reaction of this single photo pigment will give the same quanta for 400 nm light and 700 nm light. Therefore this photo pigment only maps the rate of absorption and does not encode information about the relative spectral composition of light. Scotopic lumen is a scientific way to measure the light is seen. It measures the quality of perceived light. This perception which occurs in our eye is reason for one light look brighter than another, even though they both have same lumens. The phenomenon occurs become the human eye see light several ways of the same time. The technical measuring however measure sight in one dimension only. They do not allow for perceived value of light that human eyes see. This perceived value of light sources has different scotopic ratios.



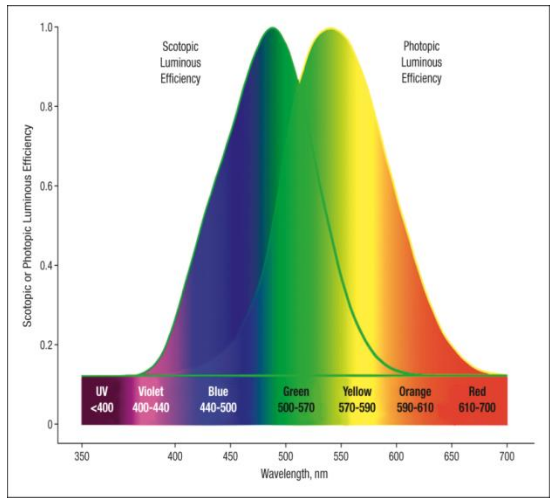


Fig.2.3: Spectral Luminous Efficiency Function for Photopic & Scotopic Vision

Scotopic lumen of a light source is measured multiplying its lumens with scotopic to photopic ratios. Maximum scotopic efficacy is 1700 lm/watt at 507 nm as shown in Fig. 2.3. While the ratio between photopic and scotopic efficacies is only around 2.5 counted at peak sensitivity the ratio increases strongly below 500 nm. In Fig 2.3 green zone represent scotopic vision of light. Its sensitivity is shifted however to peak at 507nm, and decreases in proportionally the same manner as the photopic curve. This results in the scotopic curve reaching a relative value of zero sooner in the visible spectrum than the daylight curve.

The scotopic efficacy curve is assigned a value of unity at 507 nm, and is represented by the symbol V_λ. To determine spectral luminous efficacy V_λ must be multiplied with 1700lm/watt. This value was adjusted from 1754 to allow both curves to obtain the same value of 683 lumens/W at 555 nm. So, a source with our dark adapted vision at 507 nm produces 1700lumens for every Watt radiated, and any other wavelength produces a fraction of that value based on the efficacy curve [1].

2.1.2.1. Properties of scotopic vision:

The properties of scotopic vision are as follows:

- ✓ It is known as dark adaptive or night vision
- ✓ Rod cells are responsible here.
- ✓ Higher sensitivity and speed in different spectral range.
- ✓ Peak sensitivity towards blue ('500nm').

2.1.3. Mesopic Photometry:

Mesopic vision region lies between of photopic vision and scotopic vision in low but not quite dark lighting situations. Mesopic light levels range from luminances of approximately 0.005 to 5 cd m^{-2}. Most night-time outdoor and traffic lighting scenarios are in the mesopic range. This term refers to a range of human vision with both rods and cones active. There is no hard line transition at either end, but for most intent.

Unlike the photopic and scotopic spectral luminous efficiency functions, it is not possible to describe mesopic spectral luminous efficiency with a single function since the interaction between cones and rods differs with light levels. Mesopic vision has many complexities and there have been several models established for mesopic photometry. The earlier models were based on brightness matching, where subjects are asked to match the brightness of a test light with the one in the reference field. However, additivity – in which spectral radiant quantity can be weighted with an appropriate spectral luminous efficiency function and summed linearly across the all wavelengths to quantify corresponding luminous quantity – is not preserved in brightness matching. This is also supported by the fact that target detection and recognition while driving a car are more important than matching the brightness of adjacent surfaces on the road. A recommended system for mesopic photometry based on visual performance was introduced by CIE in 2010. In this system, the upper limit for mesopic luminance is 5 cd/m^2 and the lower limit is 0.005 cd/m^2. Adaptation luminance includes not only the luminance of the foveal field but also that of the peripheral visual field, since both rods and cones contribute to mesopic vision. In some cases it is assumed that adaptation luminance is the average luminance of the whole visual field, but this must be considered a coarse assumption. [21]

The basis of all lighting technology and practice lies in photometry, the measurement of visible light. Photometry provides a method with which to assess light in terms of human visual spectral sensitivity. It mainly lies in two regions photopic and scotopic. The mesopic luminance region covers a range of luminance between the scotopic and photopic regions. Mesopic lighting applications include road and street lighting (as shown in Fig 2.4), outdoor arealighting and other night-time traffic environments. In the mesopic region the spectral sensitivity of the human visual system is not constant and changes with light level. This is due to the changing contribution of the rods and cones on the retina. Thus, not only one mesopic spectral sensitivity function is needed but instead several functions are needed, together with a defined procedure for using these functions in a photometric measurement system.

Fig 2.4 Public lighting designed for mesopic light levels at a bicycle path in Rotterdam (left) and Conventional public lighting (right at background)

Research has also shown that at medium-to-high (photopic) light levels it is easier to discern small details under a light source that has more blue in the spectrum (cooler in appearance). This effect may be helpful for people doing inspection, surgery, sewing, and other detail-oriented visual tasks.

It turns out, however, that these effects aren't due to the rods after all, but to a different kind of light-sensitive cell on the retina, called intrinsically photosensitive retinal ganglion cells (ipRGCs), which have a peak sensitivity in the blue part of the spectrum, not far from the rods' peak sensitivity.

Finally, in several experiments at mesopic light levels, researchers have compared foveal vision and peripheral vision under HPS and MH luminaries at mesopic levels. They found that the color of the light source didn't affect direct vision, the ability to see details when looking directly at the object. However, in a simulated roadway application (no vehicles to run over the subjects!) where they tested peripheral vision, they found that the subjects had faster reaction times under MH than under HPS, all other conditions being equal. Unlike the effects found at medium and high light levels, this is a rod effect; the rods, most responsible for our peripheral vision, are more sensitive to the "cooler" wavelengths of the MH lamp as shown in Fig 2.5.

Fig. 2.5 Object under three types of vision (Purkinje Effect)

Fig 2.5 shows the Purkinje effect where we can directly perceive this blending of photopic and scotopic vision. Cones are more sensitive in red light than that of rods. As the light levels dim red colors appear darken more quickly than other colors. This is due to gradual shift from the photopic to scotopic luminous efficiency functions the rods begin to predominate.

In the words of Duco Schreuder,

‘’There is not one single luminescence value where photopic vision and scotopic vision meet. To the contrary, there is a wide zone of transition between them. Because it is between photopic and scotopic vision, it is usually called the zone of mesopic vision. The reason that the zone of mesopic vision exists is because the activities of neither cones nor rods is simply switched 'on' or 'off'. There are reasons to believe that the cones and the rods both operate in all luminescence conditions’’ [4].

In fig 2.5 we see an image in different vision.

- The top most image is in photopic region where the image is perfectly visible in one’s eye. Here all colors of image are clearly noticeable.
- The lower most image is in scotopic region where the image is not perfectly visible in one’s eye. Here no color of image is found. Only existence of object is shown here.
- The middle image is in mesopic region where image is visible but colors are not perfectly noticeable.

2.1.3.1. History of Mesopic Photometry:

Firstly, spectral luminous efficiency function for photopic vision V(λ) was introduced, then came the spectral luminous efficiency function for scotopic vision V'(λ), but there still existed a condition which is neither photopic nor scotopic. So, to fulfill the visual requirements and visual satisfaction under this condition, mesopic photometry was introduced.

Till the mid-1990s most of the research in this segment was based on brightness matching criterion between the target object and the surface adjacent to it. Seven of the nine initial models of mesopic photometry are based on this criterion. Later with the realization that, detection and recognition of the object is much more relevant than brightness matching, came the criterions based on visual task performance experiments. The first two mesopic models based on task performance show that under off-axis reaction time is dependent on the light spectrum whereas for on-axis the reaction time is independent of the spectrum of light. After that from a few more experiments it was clearly revealed that there exists a strong spectral effect in detection of off-axis target. The most remarkable finding of CIE mesopic system is the formation of a table where values of mesopic luminance corresponding to particular photopic luminance for all relevant S/P ratios are present. Though this table has an enormous importance, there is no clear instructions present to use it for practical application. Research is still going on in this domain to determine the most appropriate criterion of defining mesopic photometry.

The International Commission on Illumination (CIE) has published a recommendation for a performance based mesopic photometry system CIE 191:2010[CIE 191]. The system provides a bridge between scotopic and photopic photometry. It has been developed with an emphasis on the visual performance in road and street lighting applications. According to the CIE 191 system, mesopic luminous efficiency $V_{mes}(\lambda)$ is a linear combination of the photopic V(λ) and scotopic V'(λ) luminous efficiency functions.

Recent research suggest that when the value of background brightness between photopic and scotopic, the visual perception of human can be defined as mesopic vision. Under this condition both Rod and Cones can play part effect to visual perception. The concept was proposed by Plamer in 1966.

After this Lkeda and Sagawa set up more mesopic vision models to calculate the mesopic vision equivalent brightness. The EU research project “Mesopic Optimization and Visual Efficiency” was based on vast amount of data using a visual performance approach, it can be used to calculate the spectral luminous function under mesopic condition.

International Commission on Illumination (CIE) established a technical committee (TCI-58) to study the mesopic vision based on visual performance since 2000.The research report CIE:2010 published by TCI-58, established the measurement and analysis methods of mesopic vision for the background brightness between 0.005cd/m^2 to 5cd/m^2.

2.1.3.2. Combination of Scotopic, Photopic & Mesopic Photometry:

There is usually a complexity between physics with biology. The physics side of things –the radiant power of a light source is simply enough define and not at all wave behaved. But the biological side of things –the evoking of a visual sensation –is very hard to define and not at all well behaved. One of the most obvious things about the visual system that changes is its sensitivity to light.

The smaller the amount of light involved, the more the more sensitive the visual system becomes. The difference between day time vision (high light level) and night time vision (low light level) are obvious to us all. This change in sensitivity is so great that it proved to be useful and necessary to have two definitions of light: One light for higher level which is called photopic and another light for lower level which is called scotopic. And so there are photopic lumens and scotopic lumens. Photopic comes from one of the Greek word for light and scotopic comes from the Greek word for darkness.

Photopic Lumens * S/P Ratio=Scotopic Lumens.

Between the photopic and scotopic conditions, the eye's sensitivity changes rapidly depending on the illuminance level. This is the mesopic region, which can be characterized using the CIE system for mesopic photometry characteristics (level and spectral distribution) of the lighting used, shifting towards the blue as the light level decreases, is given by:λ. Under this system, the relevant spectral luminous efficiency function is described below. [22]
In CIE 191:2010, $V_{mes}(\lambda)$ is defined by the equations,

$$M(m)V_{mes}(\lambda) = mV(\lambda) + (1 - m)V'(\lambda) \text{ ----------------------------- (1)}$$

$$\text{And} L_{mes} = \frac{683}{V_{mes}(\lambda_0)} \int V_{mes}(\lambda) L_e(\lambda) d\lambda \text{-------------------------------- (2)}$$

Where: M (m) is a normalization function such that $V_{mes}(\lambda)$ attains a maximum value of 1
$V_{mes}(\lambda_0)$ is the value of $V_{mes}(\lambda)$ at 555 nm
$L_e(\lambda)$Is the spectral radiance in W.m^{-2}.sr^{-1}.nm^{-1}
m ($0 \leq m \leq 1$) is adaptation coefficient.

The adaptation coefficient 'm' depends on the visual adaptation conditions of observer and its value can be evaluated by an iterative approach as follows:

$$L_{mes,n} = \frac{m_{n-1} L_p + (1 - m_{(n-1)}) L_S V'(\lambda_0)}{m_{(n-1)} + (1 - m_{(n-1)}) V'(\lambda_0)} \text{----------------------------- (3)}$$

$$m_n = a + b\log_{10}(L_{mes,n})$$ -------------------------------------- (4)

Where: L_p is the photopic luminance

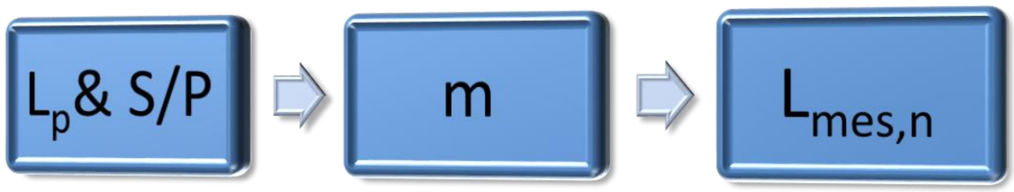
L_s is the scotopic luminance

$V'(\lambda_0)$ Is the value of scotopic spectral luminous efficiency function at $(\lambda_0) = 555\ nm$ i.e. 683/1699.

a=0.7670

b=0.3334 and

n is the iteration step.



Here the adaptation coefficient, m, is determined by the luminance and spectral characteristics of the visual adaptation field and M (m) is a normalizing function such that $V_{mes}(\lambda)$ has a maximum value of unity. For adaptation luminances of 5 cd m-2 or above, the value of m is one, whereas for adaptation luminances of 0.005 cd m-2 or below, m is zero. The spectral characteristics of the adaptation field are expressed in terms of the S/P ratio, which is the ratio of the luminous quantity evaluated according to the CIE scotopic spectral luminous efficiency function, V'(λ), to the quantity evaluated according to the CIE photopic spectral luminous efficiency function, V(λ).[22]

2.1.3.3 Mesopic Vision in Eye:

Standard eye response is visible in two figures below in both linear and logarithmic scale as shown in Fig. 2.6.

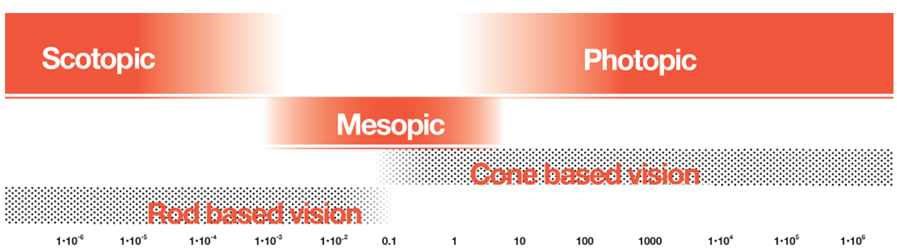


Fig 2.6 Response in Mesopic Vision

Here the basic characteristics of sensitivity of human eye are discussed. This is useful when converting light intensities from luminous units like lumen that take into account eye perception into radiometric units like watts that only into account physical aspects.

A light source radiating 1 W of green light will appear much brighter than another source radiating the same amount of power of red light because the eye is more sensitive in the green region. The human eye is sensible to light wave which wavelength is roughly between 400 nm (violet) and 700 nm (red). Wavelengths shorter than 400 nm (ultraviolet, UV) or longer than 700 nm (infrared, IR) are not visible.

The eye behaves differently in high or low light conditions: in daylight, for brightness levels above 5 cd/m^2 the vision is mainly done by the center of the retina, In that case it can be seen colors and the maximum sensitivity is at 555 nm (in the green region). This type of vision is called photopic vision. In low light conditions, for brightness levels below 50 $\mu cd/m^2$, the vision is mainly done by the peripheral region of the retina which is color-blind, while the center region is not sensitive enough to see any color. This type of vision is called scotopic vision. Maximum sensitivity is at 507 nm (in the blue-green region) and red light is almost invisible.

The vision in-between photopic and scotopic vision is called mesopic. The nice thing about scotopic vision and its reduced sensitivity to red light is that you can use a red flashlight to illuminate an object (to read a map, for example) without disturbing your night vision. It takes several minutes to get vision used to the darkness; if a white flashlight is used instead, the eyes will switch back to photopic vision and there will be a wait of few minutes again. Red light can directly be picked up by the center of the retina without affecting night vision as shown in Fig 2.6a. For this reason, astronomers often use red flashlights.

This standard eye sensitivity is also called standard luminosity function $V(\lambda)$ and is used, for photopic vision, to define a conversion between the radiated energy (in Watts) and the luminous flux (in Lumen). The standard luminosity function $V'(\lambda)$ refers to scotopic vision, but it shouldn't be used to convert to and from photometric units. A tabulated form of the two standard luminosity functions $V(\lambda)$ and $V'(\lambda)$ are represented hereafter.

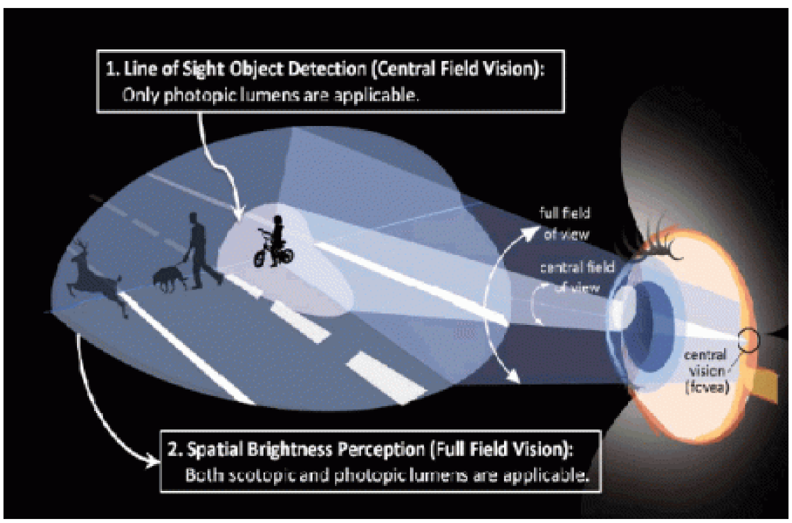


Fig. 2.6a Foveal & Full Field vision

2.2. Description of Lamps:

In case of outdoor lighting different types of lamps are used now a day's such as, High Pressure Sodium Vapor (HPSV), Metal Halide (MH) lamp, White Light Emitting Diode (WLED). Performance of these lamps under mesopic photometry in outdoor lighting environment has been studied.

2.2.1 High Pressure Sodium Vapor (HPSV):

Sodium vapor lamp was first produced commercially by Philips in 1932 in Holland. It is a gas discharge lamp that uses sodium in an excited state to produce light at a characteristics wavelength of 589 nm [6]. The lamp works by creating an electric arc through vaporized sodium metal. Other materials and gases are used to start the lamp or control its color.
There are two variables present in Sodium vapor lamp exists:

A. **High pressure (HPS)**
B. **Low pressure (LPS).**

HPS is a member of high intensity discharge lamp family developed and introduced in 1968 as energy efficient sources for exterior, security and industrial application. These are particularly prevalent in street lighting applications. Now a day's HPS lamps are also suitable for many interior applications, particularly where color rendering is not a crucial concern, due to their long life and high efficiency. These lamps are sometime used as plant glow light.

2.2.1.1 Basic Operation:

In HPS lamp there exist a compact arc tube which contains a mixture of xenon, sodium and mercury. Xenon at low pressure used as a 'starter gases in HPS lamp. As it is a noble gas so it does not take part in any chemical reaction of lamp. Thermal conductivity and ionization potential of xenon gas is lowest among all the noble gases. For low thermal conductivity thermal losses of lamp minimizes. In another case if ionization potential is low breakdown voltage of the gas is low which allows the lamp easily started. So xenon gas facilitates striking arc when voltage is applied across the electrodes. At that time heat is generated by the arc which vaporizes the mercury and sodium (at about 240 degree centigrade temperature). The mercury vapor raises the gas pressure and operating voltage and sodium vapor produces light when pressure within the arc tube is sufficient. About 29% of energy is used for producing light in this lamp [7].

The most common way to start the lamp is with a pulse start. There is an igniter built into the ballast which sends a pulse of high voltage energy through the arc tube. This pulse starts an arc through the xenon gas. The lamp turns sky blue as the xenon lights. The arc then heats up the mercury and mercury vapor then emits the light from the lamp as bluish color. Heat of the lamp increased gradually. At last Sodium is vaporized. This sodium vapor strikes arc over 240 degree centigrade. Sodium is mixed with other impurities to create more white light. Mercury helps add a blue spectrum light to the pure yellow of sodium.

2.2.1.2 Components:

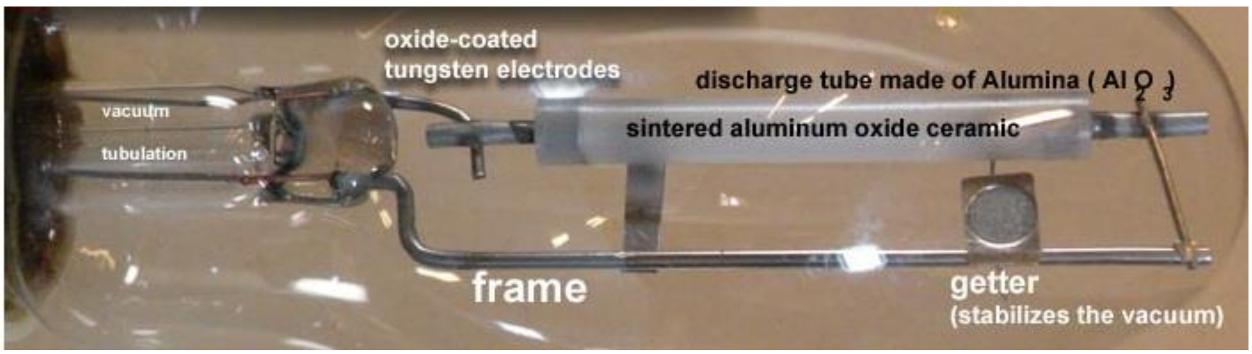


Fig 2.7 Components of a High Pressure Sodium Vapor Lamp

In the fig 2.7 the different components of a high pressure sodium vapor lamp, which are described below:

- ✓ **Arc tube:** Ceramic arc tube populated with mercury-sodium vapor in high pressure and Xenon gas. These substances of tube provides proper environment for producing light. Discharge tube is made of Alumina (Al2O3) i.e. sintered aluminum oxide ceramic.

- ✓ **Electrodes:** Electrodes of HPSV is made of oxide coated tungsten. These carry high voltage and high frequency pulse to strike the arc and vaporize mercury and sodium.

- ✓ **Base:** Base of the lamp provides the electrical connection.

- ✓ **Outer frame:** Outer bulb shields the arc tube from drafts and changes in temperature, prevents oxidation of internal part and filtered UV radiation, which is generated by mercury vapor.

2.2.1.3 Steps of operation:

Metallic sodium and mercury are in coolest position initially. These substances provide sodium and mercury vapor to draw an arc. Temperature of amalgam is determined to a great extent by lamp power.

Lamp power increased→Temperature of amalgam increased→ Mercury and sodium vapor pressure become higher→ Terminal voltage is higher.

As the temperature rises, the constant current and increasing voltage consumes increasing energy until the operating level of power is reached.

2.2.1.4 Ballast:

HPS lamp does not contain starting electrodes. Instead a starting circuit within the ballast is added. It generates a high voltage pulse to the operating electrode. Ballast is usually inductive rather than resistive to minimize resistance losses. In HPS lamp ballast are required to generate arc current flow and deliver proper voltage to arc.

2.2.1.5Application:

This lamp can easily be used in many fixture type and moist weather. As HPSV lamp has high effeciency so it can be considered in case of flood lighting applications, road lighting, industrial lighting.In case of road lighting HPS lamp provide higher contrast than that of other lamp. Acording to the performance of eye in fogy weather HPSV is better than that of other lamps.

2.2.2. Metal Halide lamp:

To improve color there was an intention to use metal instead of mercury in arc discharge light sources since 1930. But problem was low vapor pressure at normal arc tube temperature that prevents gas discharge lamp developed in 1960. This lamp is similar to mercury vapor lamp. This lamp produces light by electric arc through a gaseous mixture of vaporized mercury and metal halide.

This discovery in 1960 by Dr. Reiling that such metal could be introduced into the arc stream via there iodide salts, which have vapor pressure of several millimeter at arc tube temperature of 1000k, metal halide lamps feasible. Sodium iodide salt iodide salt is most common metal halide compound when lamp is cold, the metal iodide reside on bulb wall. MH lamp offers a white light solution at a reasonable light efficacy and a good to very good optical performance. These lamps are good solution for professional and recreational sports lighting in stadium such as Olympic Games, World Championship and Premier League soccer etc. Metal halide lamps are now available of color temperature of 3000K to 20000K. Color temperature is now varying from lamp to lamp. Because of lamp's color characteristics tends to change during lamp's life. Color temperature of this lamp can also be varies by electrical characteristics of lamp and electrical system and by manufacturing variances of bulb. Latest Metal Halide technology "Pulse Start" has improved color rendering & more control Kelvin variance.

2.2.2.1 Components:

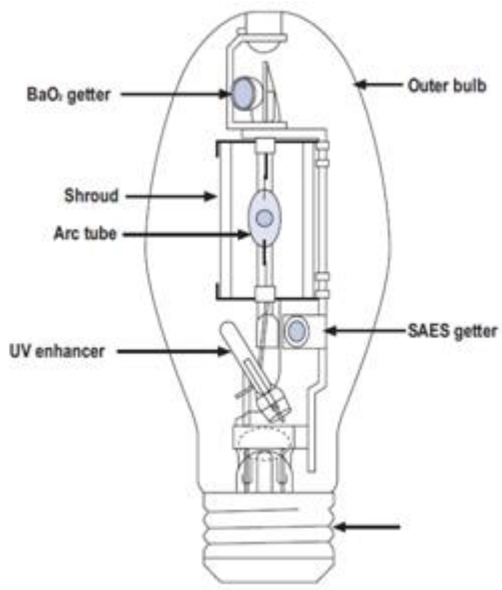


Fig 2.8 Components of a Metal Halide Lamp

Metal halide lamp mainly consist of –

I. Arc tube
II. Outer bulb
III. Base

Arc tube consists of fused quartz. Here two tungsten electrode, doped with thorium are sealed into each end and AC voltage is applied to them Light is actually created between the arc of two electrode. The lamp contains mercury vapor and iodide & bromides of different metal which makes halides at different condition. Borosilicate glass is used in case of outer envelope (bulb) due to its ability to insulate as well as block UV-B radiation coming from the arc. The bulb also prevents user from touching fouling the fuse quartz discharge tube with oil from the skin. The mercury vapor arc in metal halide lamp produces UV light. Borosilicate glass, also known as Pyrex insulates the lamp. Insulating the lamp is extremely important to keep the color constant. Some halides have lower vaporization point and will begin to drop out of the discharge if the lamp gets colder.

2.2.2.2 Basic Operation:

Similar to high-pressure mercury lamps or high-pressure sodium lamps, metal halide lamps also belong to the group of discharge lamps. In discharge lamps, light is generated by a gas discharge of particles created between two hermetically sealed electrodes in an arc tube. After ignition, the particles in the arc are partially ionized, making them electrically conductive, and "plasma" is created. In high intensity discharge lamps, the arc tube is usually enclosed in an evacuated outer bulb which isolates the hot arc tube thermally from the surroundings, similar to the principle of a thermos flask. But there are also some discharge lamps without outer bulbs, as well as lamps with gas-filled outer bulbs. In contrast to low-pressure discharge, there is high pressure and a high temperature in a discharge tube.

In an arc tube, gas discharge works through excitation of the luminous additives (metal halide salts) and the mercury is excited by the current flow. Visible radiation characteristic for the respective elements is emitted. The mixture of the visible radiation of the different elements results in the designed color temperature and color rendering for a particular lamp. In the operating state, the mercury evaporates completely. The other elements involved are present in saturated format the given temperatures, i.e. they only evaporate in part; the rest is in liquid form at the coolest point in the arc tube. The fraction of the filling that has evaporated depends on the temperature of the coolest point on the arc tube wall and also varies for the different filling components. Changes to the temperature of the arc tube wall can change the composition of the metal halides in the discharge, thus also changing the color properties of the lamp [11].

2.2.2.3 Steps of operation:

- When lamp is off mercury and halides are condensed on fused quartz tube. But when lamp is turned on current passed through the starting electrode and jumps the short distance to main electrode.
- After the small arc tube heats up and mercury vaporized, electric arc fight to work through the resistance of gas, but over time more molecule of gas become ionized. So it becomes easier to pass through electric current. As a result arc becomes wider and hotter and solid mercury turns into vapor. Soon the arc is able to travel through mercury vapor to reach the other main electrode on the opposite side of discharge tube. Now resistance of the path is less and current stop flowing through the starting electrode.
- After mercury vapor arc strikes and heats, the halides become vaporized and dissociates. The metal atoms diffuse away from the arc to cooler areas and recombine with halogen before they damage any part of silica or electrodes. Lamp is now fully warm up and produced its white light.

Basic requirement of MH LAMP inside arc tube:

- Excitation level of metal atoms must be lower than average of the excitation level of mercury.
- The energy level configuration of the metal must be robust to encourage a high percentage of visible radiation.
- At bulb wall operating temperature of iodide metal is stable.
- The iodide vapor pressure must be relatively high enough.

2.2.2.4 Ballast:

Gas discharge lamps have a negative resistance property; meaning that when the current through the bulb increases, voltage across it become decreases. If bulb is powered from a constant voltage source, the current will increase until the bulb destroys itself. Many fixtures use inductive ballast, also known as magnetic ballast, similar to those used with fluorescent lamps. This consists of an iron-core inductor. The inductor presents impedance to AC current. If the current through the lamp increases, the inductor reduces the voltage to keep the current limited.

Electronic ballasts are lighter and more compact. They consist of an electronic oscillator which generates a high frequency current to drive the lamp. Because they have lower resistive losses than inductive ballast, they are more energy efficient. However, high-frequency operation does not increase lamp efficiency as for fluorescent lamps [9].

2.2.2.5 Application

METAL HALIDE LAMP TYPES	APPLICATION[10]
MEDIUM WATTAGE	1.Recreational Sports Lighting 2. Area Lighting(Squares and park) 3. Illumination buildings & Monument.
HIGH WATTAGE	1.Recreational & Professional sports 2.Professional Area lighting. 3.Flood Lighting
METAL HALIDE OF SPECIAL COLOURS	1.Park & Squares 2.Bridge & Statues 3.Building & Landmark 4.Event Lighting

Chapter 3: Experimental Set-up

Mesopic vision is the intermediate region between light adaptive vision i.e. photopic vision & dark adaptive vision i.e. scotopic vision. According to the recommendation of International Commission on Illumination (CIE), mesopic luminance level lies between 0.005 cd/$m^2$and 5 cd/m^2. Different types of the exterior lighting systems (e.g. outdoor lighting, road lighting etc.) are in mesopic region. However lighting measurement in these areas are performed in photopic photometry system due to non-availability of mesopic instruments. Therefore for accurate result it is necessary to find out correct mesopic quantities from the measured photopic quantities using CIE standards.

In case of outdoor lighting different types of lamps are used now a day's such as, High Pressure Sodium Vapor (HPSV), Metal Halide (MH) lamp, White Light Emitting Diode (WLED). In this work performance of HPSV & MH lamps with or without surrounding light source (SLS) in different light conditions have been studied from the simulated outdoor environment in the laboratory. Cool white fluorescent lamp (CWFTL) and warm white fluorescent lamp (WWFTL) have been used as SLS. As mesopic luminance can't be measured directly at the grid points using luminance meter, at first measure photopic luminance of the field have been measured and then converted to its equivalent mesopic luminance using CIE 191:2010tables. The steps of the experiments are as follows:

- ✓ Photopic luminance measurement is taken by luminance meter from the grid points. At first luminance of each grid is taken for only main lamp (first HPSV and then MH lamp).
- ✓ Next time same measurement is done by glowing one SLS (first CWSLS and then WWSLS lamp). The luminaire used in all combination was same, only the lamps were changed.
- ✓ After measuring individual luminance combination of different lamp is taken into account. In this case different combination of one type of main lamp and one type of SLS lamp was glowing together and luminance of different grid points is measured.
- ✓ Then photopic luminance was converted to mesopic luminance by CIE: 191:2010tables.

3.1. Instrument details & specification:

❖ Scotopic/Photopic Meter

Scotopic/Photopic Ratio for a particular source was measured using Scotopic/Photopic Meter of "SOLAR Light", Sl. No. 3101 as shown in figure 3.1. This meter has two sensors equipped with CIE V(λ) and V'(λ) sensitivity functions respectively. It evaluates and shows scotopic and photopic illuminance as seen by the sensor. The S/P ratio of a source can be obtained by dividing the measured scotopic illuminance with photopic illuminance.

Range: Photopic Detector (PMA 2130):0 to 150000lux

Scotopic Detector (PMA 2131): 0 to 150000lux

Fig 3.1: Scotopic/Photopic Meter

- **Spectroradiometer**

Fig3.2 shows “JETI” make Specbos 1200Spectroradiometer, which is used to measure the SPD of the light sources.

Range: Spectral range-380-780nm.
Calculated wavelength step- 1nm.
Digital electronic resolution- 16Bit ADC (15Bit used).
Viewing angle-1.80.
Measuring distance/diameter- 20cm- 6mm; 100cm- 31mm.
Measuring values- Spectral radiance, Total luminance/total radiance, Total Illuminance / total irradiance, Chromaticity coordinates x,y,u',v', CCT, Color Purity, CRI.
Measuring range luminance- 2…7x104cd/m2.
Measuring range illuminance- 20…5x105lux.
Luminance accuracy- ±2 %(@100cd/m2 and illuminant (A)
Luminance reproducibility- ±1%.
Chromaticity accuracy- ±0.001 x,y(@ illuminant (A).
Color reproducibility- ±0.0005x, y.
CCT reproducibility- ±20K (@illuminant (A).
Wavelength accuracy- ±0.5nm.

Fig 3.2: Spectroradiometer

- **Luminance Meter**

Fig 3.3 shows the Luminance Meter of "Konica Minolta" & Model –LS100 used for measurement of luminance.

Range →Fast: 0.001 to 299900cd/m^2, Slow: 0.001 to 49990 cd/m^2.

Fig 3.3: luminance meter

- **Supporting gear to hold luminance meter:**

A tripod is used to hold luminance meter at a fixed position.

- **Measuring Tape:**

It is used for measuring the distance between grid points which are marked by chalk marker.

3.2. Lamp details

Main Light Source	High Pressure Sodium Vapor (HPSV)
	Metal Halide (MH)
Surrounding Light Source (SLS)	Cool White Fluorescent Tube Light (CWFTL)
	Warm White Fluorescent Tube Light (WWFTL)

3.2.1. Main light sources:

A. HPSV (SON-T):

The specification of HPSV lamp that used in the luminaire of experiment given below-
Make: Philips
Operating voltage: 230v
Power: Rated-70w
Frequency-50 Hz
Current-0.98A
Luminous Flux-Rated-6000lm
CCT-1856K
Luminous Efficacy-Rated-84lm/W
CRI-35
S/P Ratio-0.70
In Fig 3.4 shows SPD curve of 70 watt HPSV LAMP & its picture.

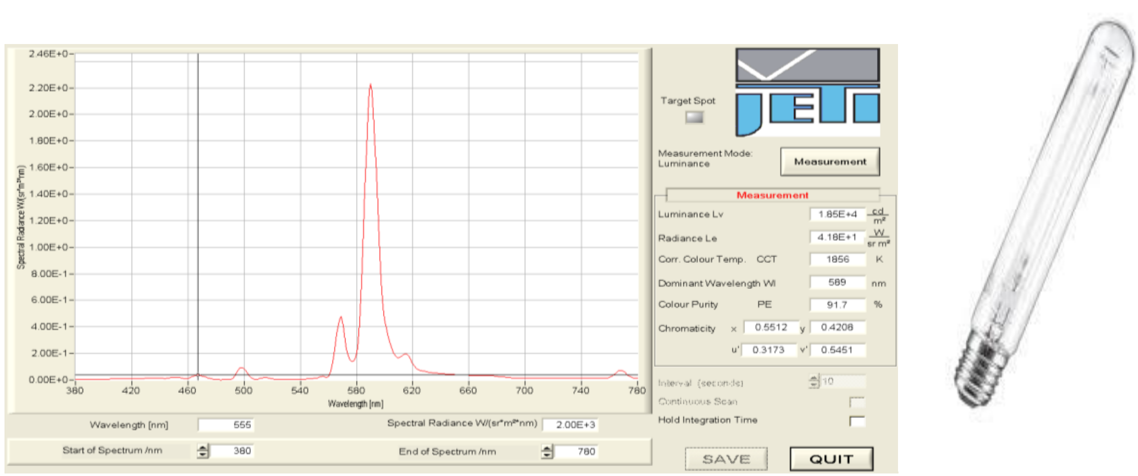


Fig 3.4: SPD curve for 70w HPSV lamp.

B. Metal Halide:

The specification of MH lamp that used in the luminaire of experiment given below-

Make: Philips

Operating voltage: 230v

Power: Rated-70w

Frequency-50 Hz

Current-0.98A

Luminous Flux-Rated-5600lm

CCT-6373K

Luminous Efficacy-Rated-80lm/W

CRI-60

S/P Ratio-1.36

Fig 3.5 shows 70 watt MH lamp and its SPD curve.

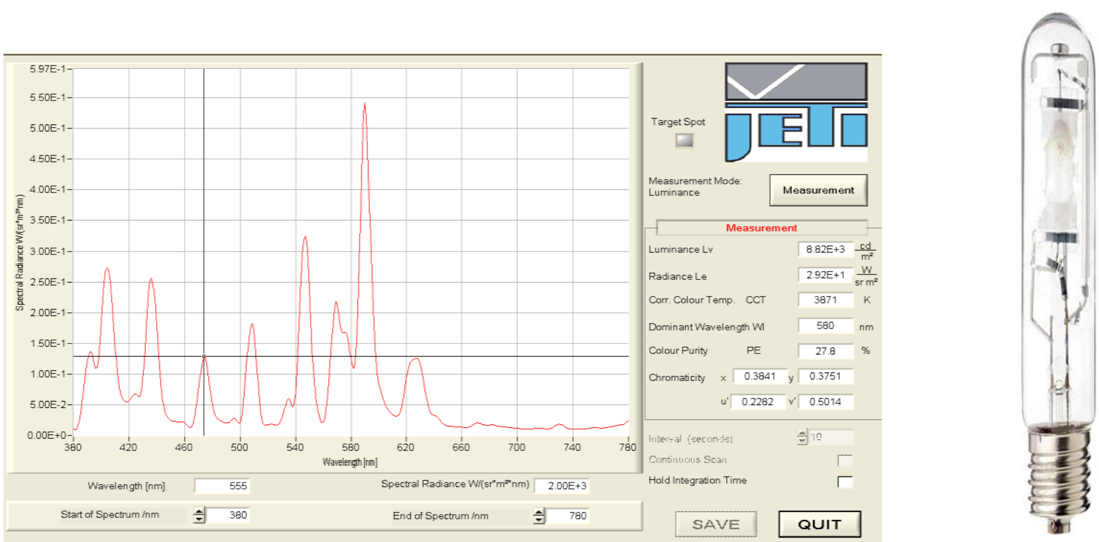


Fig 3.5: SPD curve for 70 w MH lamp

3.2.2. Surrounding Light Sources (SLS):

2 types of Fluorescent Tube Light (FTL) are used in the experiment as follows-

A. Warm white FTL (WWSLS)

B. Cool white FTL (CWSLS)

A. COOL WHITE FTL

The specification of MH lamp that used in the luminaire of experiment given below-

Make: Philips
Operating Voltage: 220V ac
Power: Rated- 36W.
Frequency-50Hz
Current- 0.44A
Luminous Flux: Rated- 2500lm
CCT-6500K
Luminous Efficacy- Rated-70lm/W
CRI-72

Fig 3.6 show a 36 w CWFTL lamp and its SPD curve.

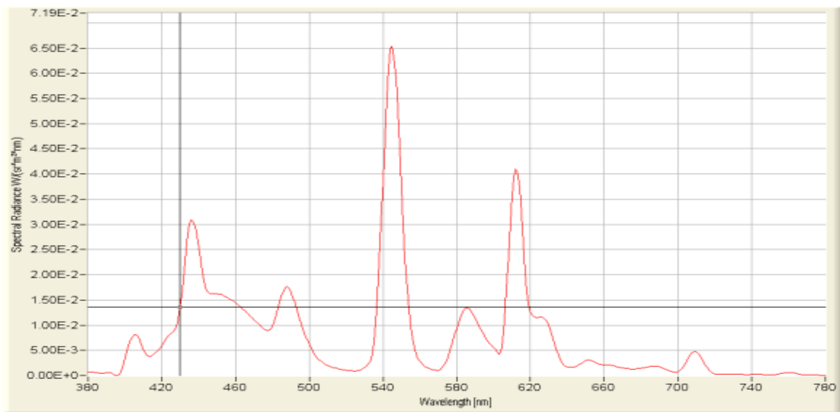


Fig 3.6: SPD curve for 36w CWFTL

B. WARM WHITE FTL

The specification of MH lamp that used in the luminaire of experiment given below-
Make:Philips
Operating Voltage: 220V ac
Power: Rated- 36W.
Frequency-50Hz
Current- 0.44A
Luminous Flux: Rated- 3250lm
CCT-2700K
Luminous Efficacy- Rated-90lm/W
CRI-82
Fig 3.7 shows 36 w WWFTL lamp and its SPD curve.

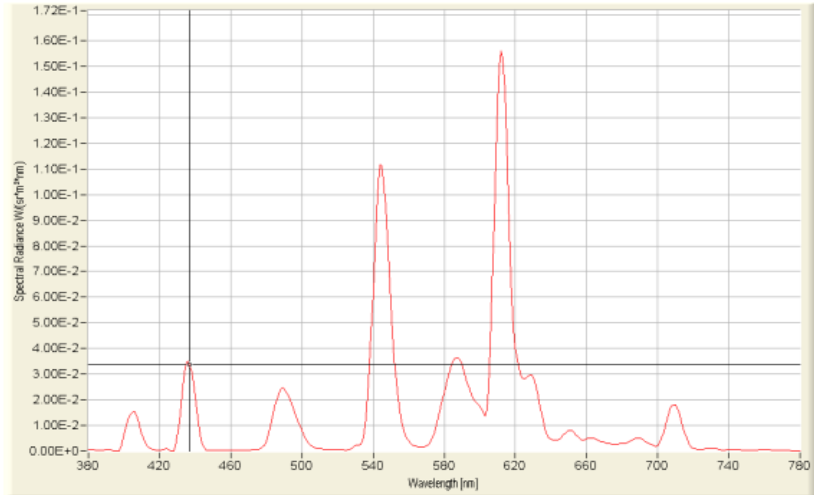


Fig 3.7: SPD curve for 36w WWFTL

3.3 Experimental Set Up:

Fig 3.8 & 3.9shows the set-up of experiment which was carried out in photometry lab of Illumination Engineering, Electrical Engineering department, Jadavpur University. Luminaires are at a fixed height of 3.6m. It is a rectangular area which is divided into 66 grids (11X6). Layouts of grid points are shown in fig 3.8. Grids are marked as 1, 2, 3 …11 throughout the length and along the breadth grids are marked as A, B, C, D, E and F. In both cases grids are marked in same distance of 0.5m. So dimension of a small square is 0.5m X 0.5m.

Luminance meter was mounted firmly on tripod at 1.4m height from ground. It is placed 6m horizontal distance from point (D, 6). Surrounding Light Sources (SLS) are placed at Pos 1, Pos 2, and Pos3. All of these SLS are 2.5 m height from ground. Pos 3 is 0.7m away from (F, 1) and Pos 2 is 0.7m away from (F, 8). Pos 1 is 2.9m away from Pos 2. The nadir point of main light source is at grid point (B, 6). All the heights and distances were measured by a 50m measuring tape.

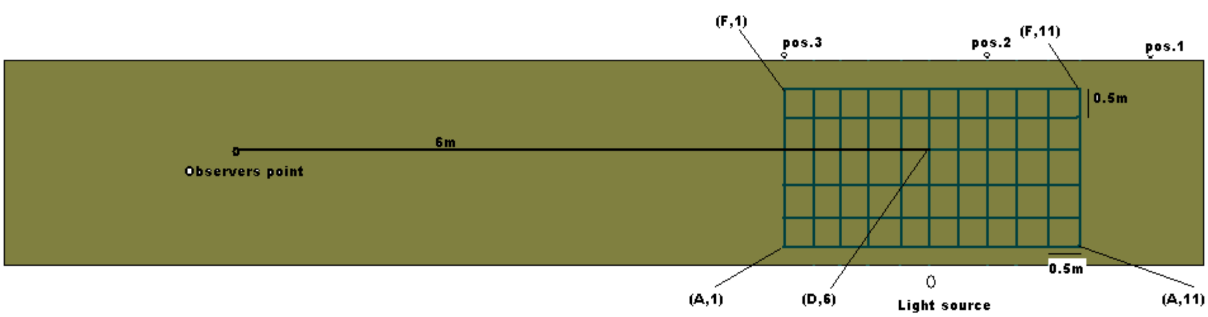


Fig 3.8: Layout of Grid

Fig 3.9: Experimental set up

In fig 3.9 is the experimental set up of experiment in dark lamp. The white spot of the floor is grid points. In right side main lamp is mounted on the poll. In left side three Fluorescent tube light are used as surrounding light source. Without these lamps any other lamps are fully off. Wall of the dark lab is fully black color as it consumes maximum incident rays to the wall.

Chapter 4: Measurement of Photopic Luminance

Photopic luminance measured in Experiment:

Point specific photopic luminance (L_p) for all grid points are measured for two Main Lamps and two Surrounding Light Sources (SLS) as described below-

A. Main Lamp

1. High Pressure Sodium Vapor(HPSV)
2. Metal Halide(MH)

B. Surrounding Light Source (SLS)

1. Cool White SLS (CWSLS)
2. Warm White SLS (WWSLS)

Main Lamp	Surrounding Light Source (SLS)
High Pressure Sodium Vapor (HPSV)	**SET1**: Cool White SLS (CWSLS)
	SET2:Warm White SLS (WWSLS)
Metal Halide (MH)	**SET1**: Cool White SLS (CWSLS)
	SET2:Warm White SLS (WWSLS)

4.1 Measurement of Photopic Luminance for HPSV

4.1.1 Measurement of Photopic Luminance when Only HPSV is glowing

Photopic luminance (L_p) for all grid points are measured (cd/m^2) are listed below in Table 4.1:

Table 4.1: L_p when HPSV is on & ALL SLSs are OFF

	A	B	C	D	E	F
1	1.71	2.703	4.6	0.8	1.054	0.56
2	3.317	3.396	3.05	1.09	1.015	0.524
3	2.903	3.58	2.96	1.49	0.82	0.635
4	2.18	2.88	2.6	1.223	1.132	0.649
5	3.672	4.35	2.3	1.402	0.96	0.848
6	2.816	3.6	2.9	1.53	1.03	0.611
7	3.189	3.52	2.62	1.559	1.124	0.737
8	3.288	2.85	1.9	1.423	1.36	0.716
9	2.12	2.33	2.14	1.32	0.945	0.675
10	1.92	1.65	1.75	1.21	0.89	0.774
11	1.525	1.364	1.27	1.09	0.789	0.732
AVERAGE LUMINANCE=1.84121212						

4.1.2 SET1: Measurement of Photopic Luminance when both HPSV & CWSLS are glowing

Photopic luminance (L_p) for all grid points are measured (cd/m^2) are listed below in Table 4.2:

Table4.2: L_p when HPSV & ALL CWSLSs are on

	A	B	C	D	E	F
1	1.62	2.58	5.69	1.97	0.51	0.28
2	2.22	2.99	3.81	2.14	0.65	0.42
3	2.23	3.42	2.89	2.2	0.95	0.5
4	2.51	3.85	3.35	2.02	1.12	0.68
5	2.45	2.57	3.36	2.24	1.73	0.56
6	2.19	2.79	3.11	2.56	1.43	0.63
7	2.23	2.85	2.54	1.96	1.2	0.62
8	2.25	3.15	3.37	2.06	1.42	0.77
9	2.54	2.54	2.79	1.83	1.36	0.63
10	1.83	1.55	2.64	2.12	1.34	0.68
11	1.29	1.72	2.46	1.53	1.11	0.66
AVERAGE LUMINANCE=1.9887878						

4.1.3 SET2: Measurement of Photopic Luminance when both HPSV &WWSLS are glowing

Photopic luminance (L_p) for all grid points are measured (cd/m^2) are listed below in Table 4.3:

Table4.3: L_p when HPSV & ALL WWSLSs are on

	A	B	C	D	E	F
1	1.62	2.73	5.03	2.24	0.53	0.26
2	2.21	3.11	4.04	2.18	0.64	0.45
3	2.26	3.07	2.99	2.25	0.94	0.48
4	2.36	3.45	3.31	2.24	1.11	0.67
5	2.26	2.43	3.27	2.22	1.86	0.53
6	2.02	2.69	2.93	2.81	1.57	0.6
7	2.11	2.97	2.46	1.97	1.22	0.58
8	1.89	2.93	3.95	1.95	1.27	0.62
9	2.34	2.54	2.75	1.84	1.36	0.59
10	1.52	1.84	2.54	2.11	1.34	0.65
11	1.26	1.56	2.39	1.58	1.15	0.65
AVERAGE LUMINANCE=1.95893939						

4.2 Measurement of Photopic Luminance for MH

4.2.1Measurement of Photopic Luminance When Only MH is glowing

Photopic luminance (L_p) for all grid points are measured (cd/m^2) are listed below in Table 4.4:

Table4.4: L_p when MH is on & ALL SLSs are off

	A	B	C	D	E	F
1	1.61	1.47	4.45	2.44	0.82	0.51
2	2.1	1.79	3.53	2.48	0.88	0.51
3	2.31	2.03	2.74	2.54	1.02	0.55
4	1.89	2.22	3.12	2.72	1.03	0.56
5	2.03	2.62	2.88	3.08	1.23	0.71
6	2.27	3.52	2.86	2.91	1.17	0.63
7	2.48	2.77	3.04	3.25	1.44	0.78
8	2.34	2.19	2.46	2.58	1.66	0.63
9	2.27	2.09	2.63	2.09	1.12	0.71
10	1.32	1.5	2.03	1.45	0.82	0.8
11	1.29	1.28	1.16	1.26	1.05	0.79
AVERAGE LUMINANCE=1.85621212						

4.2.2 SET1: Measurement of Photopic Luminance when both MH & CWSLS are glowing

Photopic luminance (L_p) for all grid points are measured (cd/m^2) are listed below in Table 4.5:

Table4.5: L_p when MH & ALL CWSLSs are on

	A	B	C	D	E	F
1	1.73	3.58	4.7	3.03	0.789	0.41
2	2.97	4.15	5.9	3.31	1.33	0.62
3	3.35	4.66	4.25	3.69	1.62	1.07
4	3.15	4.05	4.75	3.28	1.75	0.59
5	4.03	3.77	4.93	3.52	2.72	1.02
6	3.75	4.11	4.54	3.78	2.06	1.1
7	3.48	3.67	4.31	3.41	2.26	1.008
8	2.72	2.94	3.31	2.66	2.06	0.79
9	2.41	1.95	3.47	3.12	1.88	0.91
10	1.71	1.84	2.76	2.26	1.33	0.89
11	1.45	1.92	1.53	2.2	1.75	0.98
AVERAGE LUMINANCE=2.6520757						

4.2.3 SET2: Measurement of Photopic Luminance when both MH &WWSLS are glowing

Photopic luminance (L_p) for all grid points are measured (cd/m^2) are listed below in Table 4.6

Table4.6: L_p when MH & ALL WWSLSs are on

	A	B	C	D	E	F
1	1.67	3.37	4.45	2.85	0.96	0.43
2	2.36	3.66	3.61	2.77	0.95	0.67
3	2.39	3.92	2.18	3.01	1.21	0.79
4	1.58	3.65	3.57	2.74	2.2	0.61
5	2.43	3.54	2.94	3.45	2.35	0.75
6	2.48	3.67	3.47	3.63	2.02	0.81
7	2.98	3.91	3.8	3.44	2.16	0.83
8	2.96	3.53	3.14	3.36	1.97	0.75
9	3.22	3.09	3.05	3.37	1.75	0.92
10	2.89	2.39	2.52	2.54	1.29	0.95
11	2.78	2.17	1.65	2.46	1.4	0.84
AVERAGE LUMINANCE=2.41287879						

4.3 Measurement of Photopic Luminance when only CWSLSs are glowing

Photopic luminance (L_p) for all grid points are measured (cd/m^2) are listed below in Table 4.7:

Table4.7: L_p when main light is off & ALL CWSLSs are on

	A	B	C	D	E	F
1	0.429	0.677	1.46	1.857	0.576	0.058
2	0.83	0.857	1.05	1.222	0.541	0.049
3	0.632	0.722	1.209	1.345	0.386	0.048
4	0.515	0.851	0.926	1.088	2.029	0.056
5	0.79	0.68	0.91	1.075	2.1	0.077
6	0.65	0.878	0.903	0.945	0.85	0.087
7	0.732	0.744	0.704	0.943	0.303	0.07
8	1.004	0.68	0.648	0.821	0.408	0.075
9	0.745	0.774	0.932	1.215	0.305	0.073
10	0.73	0.732	0.99	1.082	0.29	0.087
11	0.573	0.645	0.635	1.07	0.342	0.091
AVERAGE LUMINANCE=0.724257						

4.4 Measurement of Photopic Luminance when only WWSLS sare glowing

Photopic luminance (L_p) for all grid points are measured (cd/m^2) are listed below in Table 4.8

Table4.8: L_p when main light is off & ALL WWSLSs are on

	A	B	C	D	E	F
1	0.66	0.53	1.059	1.3	2.43	0.064
2	0.95	0.56	1.25	1.67	2.52	0.059
3	0.91	0.71	1.075	1.77	2.65	0.069
4	0.65	0.75	1.086	1.41	1.9	0.072
5	0.82	0.81	0.98	1.15	2.19	0.083
6	0.71	0.95	0.91	1.15	0.94	0.068
7	0.82	0.87	0.95	1.2	0.62	0.098
8	0.98	0.79	0.91	1.16	0.53	0.087
9	0.99	0.92	1.342	1.36	0.62	0.094
10	0.69	0.87	1.34	2.33	0.535	0.103
11	0.74	0.97	0.72	1.22	0.584	0.107
AVERAGE LUMINANCE=0.9305303						

Chapter 5: Computation of Mesopic Luminance

In chapter 2 computation of mesopic luminance is given using CIE 191 TABLE through adaptation coefficient, ‘m’.

Mesopic luminance values are directly calculated by interpolation from photopic luminance by CIE 191 Table shown in Table 5.1. In this study mesopic luminances are calculated in different combination of Main Lamp & SLS lamp and their individual cases also. Here photopic luminance was measured by Luminance Meter& S/P ratio by S/P ratio meter. By using Table 5.1 mesopic luminance are interpolated from photopic luminance & S/P ratio.

Different condition of lamp in which mesopic luminance is calculated described in the table:

	HPSV (on)	MH (on)	CWSLS (on)	WWSLS (on)
Only HPSV	√	–	–	–
HPSV & CWSLS	√	–	√	–
HPSV & WWSLS	√	–	–	√
Only MH	–	√	–	–
MH & CWSLS	–	√	√	–
MH & WWSLS	–	√	–	√

Tick marks indicate the combination in which mesopic luminance is calculated.

Table 5.1: Values of L_{mes} of the recommended Mesopic system as a function of photopic luminance and S/P ratio [CIE 191]

		Photopic luminance / cd·m^{-2}						
	S/P	**0,01**	**0,03**	**0,1**	**0,3**	**1**	**3**	**4,5**
LPS ~	**0,25**	0,002 5	0,014 5	0,070 5	0,246 7	0,913 0	2,926 5	4,478 2
	0,35	0,003 5	0,017 4	0,075 0	0,254 5	0,925 3	2,936 7	4,481 2
	0,45	0,004 5	0,019 8	0,079 3	0,262 0	0,937 3	2,946 8	4,484 2
	0,55	0,005 7	0,022 0	0,083 4	0,269 3	0,949 2	2,956 8	4,487 2
HPS ~	**0,65**	0,006 9	0,023 9	0,087 3	0,276 4	0,960 8	2,966 6	4,490 1
	0,75	0,007 9	0,025 8	0,091 1	0,283 3	0,972 2	2,976 3	4,492 9
	0,85	0,008 8	0,027 5	0,094 7	0,290 1	0,983 5	2,985 9	4,495 8
	0,95	0,009 6	0,029 2	0,098 3	0,296 7	0,994 5	2,995 3	4,498 6
	1,05	0,010 4	0,030 8	0,101 7	0,303 2	1,005 4	3,004 6	4,501 4
MH warm white ~	**1,15**	0,011 1	0,032 3	0,105 1	0,309 6	1,016 1	3,013 9	4,504 1
	1,25	0,011 8	0,033 8	0,108 3	0,315 8	1,026 7	3,023 0	4,506 8
	1,35	0,012 5	0,035 3	0,111 5	0,322 0	1,037 1	3,031 9	4,509 5
	1,45	0,013 2	0,036 7	0,114 7	0,328 0	1,047 3	3,040 8	4,512 2
	1,55	0,013 8	0,038 1	0,117 8	0,333 9	1,057 5	3,049 6	4,514 8
	1,65	0,014 5	0,039 5	0,120 8	0,339 8	1,067 4	3,058 2	4,517 4
	1,75	0,015 1	0,040 8	0,123 8	0,345 5	1,077 3	3,066 8	4,520 0
	1,85	0,015 7	0,042 1	0,126 7	0,351 2	1,087 0	3,075 3	4,522 5
	1,95	0,016 3	0,043 4	0,129 5	0,356 8	1,096 6	3,083 6	4,525 0
	2,05	0,016 9	0,044 6	0,132 4	0,362 3	1,106 0	3,091 9	4,527 5
	2,15	0,017 4	0,045 9	0,135 2	0,367 7	1,115 4	3,100 1	4,529 9
	2,25	0,018 0	0,047 1	0,137 9	0,373 1	1,124 6	3,108 2	4,532 3
MH day-light ~	**2,35**	0,018 5	0,048 3	0,140 6	0,378 4	1,133 8	3,116 2	4,534 7
	2,45	0,019 1	0,049 5	0,143 3	0,383 6	1,142 8	3,124 1	4,537 1
	2,55	0,019 6	0,050 6	0,145 9	0,388 8	1,151 7	3,131 9	4,539 5
	2,65	0,020 1	0,051 8	0,148 5	0,393 9	1,160 5	3,139 6	4,541 8
	2,75	0,020 7	0,052 9	0,151 1	0,398 9	1,169 3	3,147 3	4,544 1

5.1. Steps of Computation

Steps to calculate Mesopic luminance by CIE 191 BY MATLAB:

Step 1: First photopic vision in the photometry lab is measured.

Step 2: Then measurement of S/P ratio of each lamp.

Step 3: Now checking of CIE 191:2010. Here values of L_{mes} are provided with respect to photopic luminance and S/P ratio of light source.

Step 4: According to S/P ratio evaluation of mesopic luminance at different photopic region.

Step 5: If S/P ratio or photopic luminance is not properly match then S/P ratio is to be done by liner interpolation.

Step 6: Now to evaluate L_{mes} formula is formed from interpolation & write it to MATLAB programming.
Step 7: Selection of photopic luminance & put its name to MATLAB
Step 8: Run the program and save the plot (if required) & evaluated excel (L_{mes})

5.2. COMPUTATION OF MESOPIC LUMINANCE FROM PHOTOPIC LUMINANCE:

5.2.1. For only HPSV lamp

5.2.1.1 MATLAB PROGRM

```
filename ='son.xlsx'
L=xlsread('son.xlsx')
for r=1:11
for c=1:6
if L(r,c)>0.3 & L(r,c)<1
        Lmes1(r,c)=(L(r,c)-0.3)*0.687/0.7+0.279

elseif L(r,c)>1 & L(r,c)<3
        Lmes1(r,c)=(L(r,c)-1)*1.0025+0.966
elseif L(r,c)>3 & L(r,c)<4.5
        Lmes1(r,c)=(L(r,c)-3)*1.52/1.5+2.971
end
end
end
xlswrite('sonresult1',Lmes1)
```

5.2.1.2. CALCULATION OF MESOPIC LUMINANCE WHEN ONLY HPSV IS GLOWING

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.2: L_{mes} when only HPSV is on

	A	B	C	D	E	F
1	1.677775	2.6732575	4.470733333	0.769714286	1.020135	0.534171429
2	3.292226667	3.37228	3.021666667	1.056225	0.9810375	0.49884
3	2.8737575	3.558733333	2.9309	1.457225	0.789342857	0.607778571
4	2.14895	2.8507	2.57	1.1895575	1.09833	0.621518571
5	3.65196	4.339	2.26925	1.369005	0.926742857	0.816822857
6	2.78654	3.579	2.87075	1.497325	0.996075	0.584224286
7	3.16252	3.497933333	2.59005	1.5263975	1.09031	0.707884286
8	3.26284	2.820625	1.86825	1.3900575	1.3269	0.687274286
9	2.0888	2.299325	2.10885	1.2868	0.912021429	0.647035714
10	1.8883	1.617625	1.717875	1.176525	0.858042857	0.744197143
11	1.4923125	1.33091	1.236675	1.056225	0.758918571	0.702977143
AVERAGE LUMINANCE=1.812212242						

5.2.2. For only MH lamp

5.2.2.1. MATLAB PROGRAM

```
filename ='mh.xlsx'
L=xlsread('mh.xlsx')
for r=1:11
for c=1:6
if L(r,c)>0.3 & L(r,c)<1
        Lmes1(r,c)=(L(r,c)-0.3)*0.7154/0.7+0.3226

elseif L(r,c)>1 & L(r,c)<3
        Lmes1(r,c)=(L(r,c)-1)*0.99695+1.038
elseif L(r,c)>3 & L(r,c)<4.5
        Lmes1(r,c)=(L(r,c)-3)*1.4774/1.5+3.0319
end
end
end
xlswrite('mhresult1',Lmes1)
```

5.2.2.2. CALCULATION OF MESOPIC LUMINANCE WHEN ONLY MH IS GLOWING

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.3: L_{mes} when only MH is ON

	A	B	C	D	E	F
1	1.6461395	1.5065665	4.460053333	2.473608	0.85404	0.53722
2	2.134645	1.8255905	3.553914667	2.513486	0.91536	0.53722
3	2.3440045	2.0648585	2.772693	2.573303	1.057939	0.5781
4	1.9252855	2.254279	3.150092	2.752754	1.0679085	0.58832
5	2.0648585	2.653059	2.912266	3.110694667	1.2672985	0.74162
6	2.3041265	3.544065333	2.892327	2.9421745	1.2074815	0.65986
7	2.513486	2.8026015	3.071297333	3.278133333	1.476658	0.81316
8	2.373913	2.2243705	2.493547	2.613181	1.695987	0.65986
9	2.3041265	2.1246755	2.6630285	2.1246755	1.157634	0.74162
10	1.357024	1.536475	2.0648585	1.4866275	0.85404	0.8336
11	1.3271155	1.317146	1.197512	1.297207	1.0878475	0.82338
AVERAGE LUMINANCE=1.889424237						

5.2.3. For CWSLS lamp

5.2.3.1. MATLAB PROGRAM

```
filename ='cwsls.xlsx'
L=xlsread('cwsls.xlsx')
for r=1:11
for c=1:6
if L(r,c)>0.03 & L(r,c)<0.1
```

```
        Lmes1(r,c)=(L(r,c)-0.03)*0.088/0.07+0.044
elseif L(r,c)>0.1 & L(r,c)<0.3
        Lmes1(r,c)=(L(r,c)-0.1)*0.23/0.2+0.132

elseif L(r,c)>0.3 & L(r,c)<1
        Lmes1(r,c)=(L(r,c)-0.3)*1.063+0.362
elseif L(r,c)>1 & L(r,c)<3
        Lmes1(r,c)=(L(r,c)-1)*1.985/2+1.106
end
end
end
xlswrite('cwlsresult',Lmes1)
```

5.2.3.2. CALCULATION OF MESOPIC LUMINANCE WHEN ONLY CWSLS IS GLOWING

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.4: L_{mes} when MAIN LIGHT is OFF & ALL CWSLSs are ON

	A	B	C	D	E	F
1	0.499127	0.762751	1.56255	1.9565725	0.655388	0.0792
2	0.92539	0.954091	1.155625	1.326335	0.618183	0.067885714
3	0.714916	0.810586	1.3134325	1.4484125	0.453418	0.066628571
4	0.590545	0.947713	1.027438	1.19334	2.1272825	0.076685714
5	0.88287	0.76594	1.01043	1.1804375	2.19775	0.103085714
6	0.73405	0.976414	1.002989	1.047635	0.94665	0.115657143
7	0.821216	0.833972	0.791452	1.045509	0.365189	0.094285714
8	1.10997	0.76594	0.731924	0.915823	0.476804	0.100571429
9	0.835035	0.865862	1.033816	1.3193875	0.367315	0.098057143
10	0.81909	0.821216	1.09547	1.187385	0.3505	0.115657143
11	0.652199	0.728735	0.718105	1.175475	0.406646	0.120685714
AVERAGE LUMINANCE=0.803949955						

5.2.4. For WWSLS lamp

5.2.4.1. MATLAB PROGRAM

```
filename ='wwsls.xlsx'
L=xlsread('wwsls.xlsx')
for r=1:11
for c=1:6
if L(r,c)>0.03 & L(r,c)<0.1
        Lmes1(r,c)=(L(r,c)-0.03)*0.0734/0.07+0.0322
elseif L(r,c)>0.1 & L(r,c)<0.3
        Lmes1(r,c)=(L(r,c)-0.1)*0.2044/0.2+0.1056

elseif L(r,c)>0.3 & L(r,c)<1
```

```
        Lmes1(r,c)=(L(r,c)-0.3)*1.0114+0.31
elseif L(r,c)>1 & L(r,c)<3
        Lmes1(r,c)=(L(r,c)-1)*1.997/2+1.018
end
end
end
xlswrite('wwslsresult',Lmes1)
```

5.2.4.2. CALCULATION OF MESOPIC LUMINANCE WHEN ONLY WWSLS IS GLOWING

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.5: L_{mes} when MAIN LIGHT is OFF & ALL WWSLSs are ON

	A	B	C	D	E	F
1	0.674104	0.542622	1.0769115	1.31755	2.445855	0.067851429
2	0.96741	0.572964	1.267625	1.686995	2.53572	0.062608571
3	0.926954	0.724674	1.0928875	1.786845	2.665525	0.073094286
4	0.66399	0.76513	1.103871	1.427385	1.91665	0.07624
5	0.835928	0.825814	0.997752	1.167775	2.206215	0.087774286
6	0.724674	0.96741	0.926954	1.167775	0.957296	0.072045714
7	0.835928	0.886498	0.96741	1.2177	0.633648	0.103502857
8	0.997752	0.805586	0.926954	1.17776	0.542622	0.091968571
9	1.007866	0.937068	1.359487	1.37746	0.633648	0.099308571
10	0.704446	0.886498	1.35749	2.346005	0.547679	0.108666
11	0.755016	0.987638	0.734788	1.23767	0.5972376	0.112754
AVERAGE LUMINANCE=0.944801968						

5.2.5 When HPSV & CWSLS TAKEN TOGETHER

5.2.5.1. MATLAB PROGRAM

```
filename ='sncwss.xlsx'
L=xlsread('sncwss.xlsx')
for r=1:11
for c=1:6
if L(r,c)>0.3 & L(r,c)<1
        Lmes1(r,c)=(L(r,c)-0.3)*0.687/0.7+0.279

elseif L(r,c)>1 & L(r,c)<3
        Lmes1(r,c)=(L(r,c)-1)*1.0025+0.966
elseif L(r,c)>3 & L(r,c)<4.5
        Lmes1(r,c)=(L(r,c)-3)*1.52/1.5+2.971
elseif  L(r,c)>4.5
        Lmes1(r,c)=L(r,c)
end
end
end
```

```
xlswrite('soncsls',Lmes1)
```

5.2.5.2. CALCULATION OF MESOPIC LUMINANCE WHEN BOTH HPSV& CWSLS ARE GLOWING

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.6: L_{mes} when HPSV is ON & ALL CWSLSs are ON

	A	B	C	D	E	F
1	1.58755	2.54995	5.69	1.938425	0.4851	0.298628571
2	2.18905	2.960975	3.7918	2.10885	0.6225	0.396771429
3	2.199075	3.3966	2.860725	2.169	0.916928571	0.475285714
4	2.479775	3.832333333	3.325666667	1.98855	1.0863	0.651942857
5	2.419625	2.539925	3.3358	2.2091	1.697825	0.534171429
6	2.158975	2.760475	3.082466667	2.5299	1.397075	0.602871429
7	2.199075	2.820625	2.50985	1.9284	1.1665	0.593057143
8	2.219125	3.123	3.345933333	2.02865	1.38705	0.740271429
9	2.50985	2.50985	2.760475	1.798075	1.3269	0.602871429
10	1.798075	1.517375	2.6101	2.0888	1.30685	0.651942857
11	1.256725	1.6878	2.42965	1.497325	1.076275	0.632314286
AVERAGE LUMINANCE=1.960496699						

5.2.6. When HPSV & WWSLS TAKEN TOGETHER

5.2.5.1. MATLAB PROGRAM

```
filename ='sonwwsls.xlsx'
L=xlsread('sonwwsls.xlsx')
for r=1:11
for c=1:6
if L(r,c)>0.3 & L(r,c)<1
        Lmes1(r,c)=(L(r,c)-0.3)*0.687/0.7+0.279

elseif L(r,c)>1 & L(r,c)<3
        Lmes1(r,c)=(L(r,c)-1)*1.0025+0.966
elseif L(r,c)>3 & L(r,c)<4.5
        Lmes1(r,c)=(L(r,c)-3)*1.52/1.5+2.971
elseif L(r,c)>4.5
        Lmes1(r,c)=L(r,c)
end
end
end
xlswrite('snwsls',Lmes1)
```

5.2.5.2. CALAULATION OF MESOPIC LUMINANCE WHEN BOTH HPSV & WWSLS ARE GLOWING

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.7: L_{mes} when HPSV is ON & ALL WWSLSs are ON

	A	B	C	D	E	F
1	1.58755	2.700325	5.69	2.2091	0.504728571	0.298628571
2	2.179025	3.082466667	4.024866667	2.14895	0.612685714	0.426214286
3	2.22915	3.041933333	2.960975	2.219125	0.907114286	0.455657143
4	2.3294	3.427	3.285133333	2.2091	1.076275	0.642128571
5	2.22915	2.399575	3.2446	2.18905	1.82815	0.504728571
6	1.98855	2.660225	2.900825	2.780525	1.537425	0.573428571
7	2.078775	2.940925	2.42965	1.938425	1.18655	0.5538
8	1.858225	2.900825	3.933666667	1.918375	1.236675	0.593057143
9	2.30935	2.50985	2.720375	1.8081	1.3269	0.563614286
10	1.4873	1.8081	2.50985	2.078775	1.30685	0.6225
11	1.22665	1.5274	2.359475	1.54745	1.116375	0.6225
AVERAGE LUMINANCE=1.930822926						

5.2.7. When MH & CWSLS TAKEN TOGETHER

5.2.7.1. MATLAB PROGRAM

```
filename ='mhslscool.xlsx'
L=xlsread('mhslscool.xlsx')
for r=1:11
for c=1:6
if L(r,c)>0.3 & L(r,c)<1
        Lmes1(r,c)=(L(r,c)-0.3)*0.7154/0.7+0.3226

elseif L(r,c)>1 & L(r,c)<3
        Lmes1(r,c)=(L(r,c)-1)*0.99695+1.038
elseif L(r,c)>3 & L(r,c)<4.5
        Lmes1(r,c)=(L(r,c)-3)*1.4774/1.5+3.0319
elseif L(r,c)>4.5
        Lmes1(r,c)=L(r,c)
end
end
end
xlswrite('mhslscoolresult1',Lmes1)
```

5.2.7.2. CALCULATION OF MESOPIC LUMINANCE WHEN BOTH MH & CWSLS ARE GLOWING

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.8: L_{mes} when MH is ON & All CWSLSs are ON

	A	B	C	D	E	F
1	1.7657735	3.603161333	4.7	3.061448	0.822358	0.43502
2	3.0019915	4.164573333	5.9	3.337229333	1.3669935	0.64964
3	3.376626667	4.66	4.263066667	3.711504	1.656109	1.1077865
4	3.17964	4.06608	4.75	3.307681333	1.7857125	0.61898
5	4.046381333	3.790298667	4.93	3.544065333	2.752754	1.057939
6	3.7706	4.125176	4.54	3.800148	2.094767	1.137695
7	3.504668	3.691805333	4.322162667	3.435722667	2.294157	1.0459756
8	2.752754	2.972083	3.337229333	2.692937	2.094767	0.82338
9	2.4436995	1.9851025	3.494818667	3.150092	1.915316	0.94602
10	1.7458345	1.875438	2.792632	2.294157	1.3669935	0.92558
11	1.4866275	1.955194	1.5663835	2.23434	1.7857125	1.01756
AVERAGE LUMINANCE=2.67924761						

5.2.8. When MH & WWSLS TAKEN TOGETHER

5.2.8.1. MATLAB PROGRAM

```
filename ='mhslswarm.xlsx'
L=xlsread('mhslswarm.xlsx')
for r=1:11
for c=1:6
if L(r,c)>0.3 & L(r,c)<1
        Lmes1(r,c)=(L(r,c)-0.3)*0.7154/0.7+0.3226

elseif L(r,c)>1 & L(r,c)<3
        Lmes1(r,c)=(L(r,c)-1)*0.99695+1.038
elseif L(r,c)>3 & L(r,c)<4.5
        Lmes1(r,c)=(L(r,c)-3)*1.4774/1.5+3.0319
end
end
end
xlswrite('mhslswarmresult1',Lmes1)
```

5.2.8.2. CALCULATION OF MESOPIC LUMINANCE WHEN BOTH MH & CWSLS ARE GLOWING

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.9: L_{mes} when MH is ON & ALL WWSLSs are ON

	A	B	C	D	E	F
1	1.7059565	3.396325333	4.460053333	2.8823575	0.99712	0.45546
2	2.393852	3.681956	3.632709333	2.8026015	0.9869	0.70074
3	2.4237605	3.938038667	2.214401	3.041749333	1.2473595	0.82338
4	1.616231	3.672106667	3.593312	2.772693	2.23434	0.63942
5	2.4636385	3.563764	2.972083	3.47512	2.3838825	0.7825
6	2.513486	3.691805333	3.494818667	3.652408	2.054889	0.84382
7	3.011961	3.928189333	3.819846667	3.465270667	2.194462	0.86426
8	2.992022	3.553914667	3.169790667	3.386476	2.0050415	0.7825
9	3.248585333	3.120544	3.081146667	3.396325333	1.7857125	0.95624
10	2.9222355	2.4237605	2.553364	2.573303	1.3271155	0.9869
11	2.812571	2.2044315	1.6860175	2.493547	1.43678	0.87448
AVERAGE LUMINANCE=2.443361091						

5.3 ADDITION

5.3.1. For HPSV & CWSLS

5.3.1.1. MATLAB PROGRAM

```
filename ='son.xlsx'
L1=xlsread('son.xlsx')
filename ='cwsls1.xlsx'
L2=xlsread('cwsls1.xlsx')
L=L1+L2
xlswrite ('soncwslsaddition', L )
```

5.3.1.2. CALCULATION OF TOTAL MESOPIC LUMINANCE WHEN BOTH INDIVIDUAL MESOPIC LUMINANCE OF HPSV& CWSLS ARE ADDED

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.10: Addition of L_{mes} when HPSV & ALL CWSLSs are glowing separately

	A	B	C	D	E	F
1	2.176902	3.4360085	6.033283333	2.726286786	1.675523	0.613371429
2	4.217616667	4.326371	4.177291667	2.38256	1.5992205	0.566725714
3	3.5886735	4.369319333	4.2443325	2.9056375	1.242760857	0.674407142
4	2.739495	3.798413	3.597438	2.3828975	3.2256125	0.698204285
5	4.53483	5.10494	3.27968	2.5494425	3.124492857	0.919908571
6	3.52059	4.555414	3.873739	2.54496	1.942725	0.699881429
7	3.983736	4.331905333	3.381502	2.5719065	1.455499	0.80217
8	4.37281	3.586565	2.600174	2.3058805	1.803704	0.787845715

9	2.923835	3.165187	3.142666	2.6061875	1.279336429	0.745092857
10	2.70739	2.438841	2.813345	2.36391	1.208542857	0.859854286
11	2.1445115	2.059645	1.95478	2.2317	1.165564571	0.823662857
AVERAGE LUMINANCE=2.616162197						

5.3.2 For HPSV & WWSLS

5.3.2.1. MATLAB PROGRAM

```
filename ='son.xlsx'
L1=xlsread('son.xlsx')
filename ='wwsls1.xlsx'
L2=xlsread('wwsls1.xlsx')
L=L1+L2
xlswrite ('sonwwslsaddition', L )
```

5.3.2.2. CALCULATION OF TOTAL MESOPIC LUMINANCE WHEN BOTH INDIVIDUAL MESOPIC LUMINANCE OF HPSV& CWSLS ARE ADDED

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.11: Additionv of L_{mes} when HPSV is ON & ALL WWSLSs are OFF AND L_{mes} when HPSV is OFF & ALL WWSLSs are ON

	A	B	C	D	E	F
1	2.351879	3.2158795	5.547644833	2.087264286	3.46599	0.602022858
2	4.259636667	3.945244	4.289291667	2.74322	3.5167575	0.561448571
3	3.8007115	4.283407333	4.0237875	3.24407	3.454867857	0.680872857
4	2.81294	3.61583	3.673871	2.6169425	3.01498	0.697758571
5	4.487888	5.164814	3.267002	2.53678	3.132957857	0.904597143
6	3.511214	4.54641	3.797704	2.6651	1.953371	0.65627
7	3.998448	4.384431333	3.55746	2.7440975	1.723958	0.811387143
8	4.260592	3.626211	2.795204	2.5678175	1.869522	0.779242857
9	3.096666	3.236393	3.468337	2.66426	1.545669429	0.746344285
10	2.592746	2.504123	3.075365	3.52253	1.405721857	0.852863143
11	2.2473285	2.318548	1.971463	2.293895	1.356156171	0.815731143
AVERAGE LUMINANCE=2.75701421						

5.3.3. For MH & CWSLS

5.3.3.1. MATLAB PROGRAM

```
filename ='mh1.xlsx'
L1=xlsread('mh1.xlsx')
filename ='cwsls1.xlsx'
L2=xlsread('cwsls1.xlsx')
L=L1+L2
xlswrite ('mhcwslsaddition', L )
```

5.3.3.2. CALCULATION OF TOTAL MESOPIC LUMINANCE WHEN BOTH INDIVIDUAL MESOPIC LUMINANCE OF MH & CWSLS ARE ADDED

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.12: Addition of L_{mes} when MH is ON & ALL CWSLSs are OFF AND L_{mes} when MH is OFF & ALL CWSLSs are ON

	A	B	C	D	E	F
1	2.1452665	2.2693175	6.022603333	4.4301805	1.509428	0.61642
2	3.060035	2.7796815	4.709539667	3.839821	1.533543	0.605105714
3	3.0589205	2.8754445	4.0861255	4.0217155	1.511357	0.644728571
4	2.5158305	3.201992	4.17753	3.946094	3.195191	0.665005714
5	2.9477285	3.418999	3.922696	4.291132167	3.4650485	0.844705714
6	3.0381765	4.520479333	3.895316	3.9898095	2.1541315	0.775517143
7	3.334702	3.6365735	3.862749333	4.323642333	1.841847	0.907445714
8	3.483883	2.9903105	3.225471	3.529004	2.172791	0.760431429
9	3.1391615	2.9905375	3.6968445	3.444063	1.524949	0.839677143
10	2.176114	2.357691	3.1603285	2.6740125	1.20454	0.949257143
11	1.9793145	2.045881	1.915617	2.472682	1.4944935	0.944065714
AVERAGE LUMINANCE=2.693374192						

5.3.4. For MH & WWSLS

5.3.4.1. MATLAB PROGRAM

```
filename ='mh1.xlsx'
L1=xlsread('mh1.xlsx')
filename ='wwsls1.xlsx'
L2=xlsread('wwsls1.xlsx')
L=L1+L2
xlswrite ('mhwwslsaddition', L )
```

5.3.4.2. CALCULATION OF TOTAL MESOPIC LUMINANCE WHEN BOTH INDIVIDUAL MESOPIC LUMINANCE OF MH & CWSLS ARE ADDED

Mesopic luminance (L_p) for all grid points are calculated (in cd/m^2) and listed below:

Table5.13: Addition of L_{mes} when MH is ON & ALL WWSLSs are OFF AND L_{mes} when MH is OFF & ALL WWSLSs are ON

	A	B	C	D	E	F
1	2.3202435	2.0491885	5.536964833	3.791158	3.299895	0.605071429
2	3.102055	2.3985545	4.821539667	4.200481	3.45108	0.599828571

3	3.2709585	2.7895325	3.8655805	4.360148	3.723464	0.651194286
4	2.5892755	3.019409	4.253963	4.180139	2.9845585	0.66456
5	2.9007865	3.478873	3.910018	4.278469667	3.4735135	0.829394286
6	3.0288005	4.511475333	3.819281	4.1099495	2.1647775	0.731905714
7	3.349414	3.6890995	4.038707333	4.495833333	2.110306	0.916662857
8	3.371665	3.0299565	3.420501	3.790941	2.238609	0.751828571
9	3.3119925	3.0617435	4.0225155	3.5021355	1.791282	0.840928571
10	2.06147	2.422973	3.4223485	3.8326325	1.401719	0.942266
11	2.0821315	2.304784	1.9323	2.534877	1.6850851	0.936134
AVERAGE LUMINANCE=2.834226205						

Chapter 6:
Result Analysis

Performance of different lamps has been studied in this work. For the given experimental set up in Chapter 3, HPSV & MH Lamps have been considered as main light source one by one. For each case, two sets have been considered. In first set cool white fluorescent tubes (CWFTL) are considered as surrounding light source (CWSLS). In second set warm white FTL (WWFTL) lamps have been considered as SLS (WWSLS). Same experiment has been repeated for metal Halide (MH) lamps then. Combinations are given below:

Main Lamp	**Surrounding Light Source (SLS)**
High Pressure Sodium Vapor (HPSV)	**SET1**: Cool White SLS (CWSLS)
	SET2:Warm White SLS (WWSLS)
Metal Halide (MH)	**SET1**: Cool White SLS (CWSLS)
	SET2:Warm White SLS (WWSLS)

In this chapter comparison of photopic and mesopic luminance for different combinations are given. Distribution of luminance for both photopic and mesopic region is also given for following cases:

- CWSLS Lamps
- WWSLS Lamps
- HPSV Lamp
    - Alone
    - With CWSLS
    - With WWSLS
- MH Lamp
    - Alone
    - With CWSLS
    - With WWSLS

6.1 Only CWSLS Lamps

Here the average luminances (Photopic & Mesopic) of CWSLS are shown in Table 6.1.

Table 6.1: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	**Photopic**	**Mesopic**
CWSLS	0.724257	0.803949955

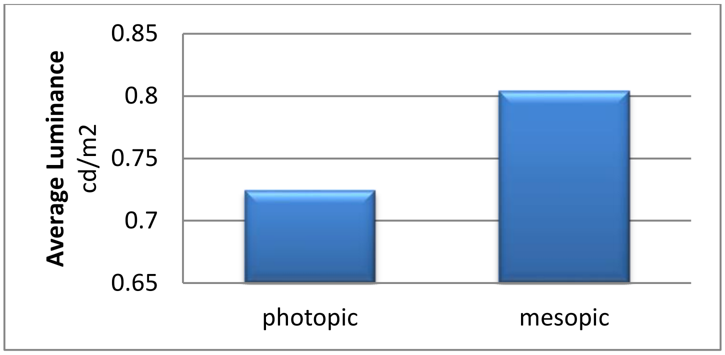


Fig 6.1: Photopic & Mesopic Luminance

Here it is seen from Fig 6.1 that in case of CWSLS lamp photopic luminance is less than that of mesopic luminance due to higher S/P ratio of CW FTL lamps of 2.05.

6.1.1. Isoluminance plot:

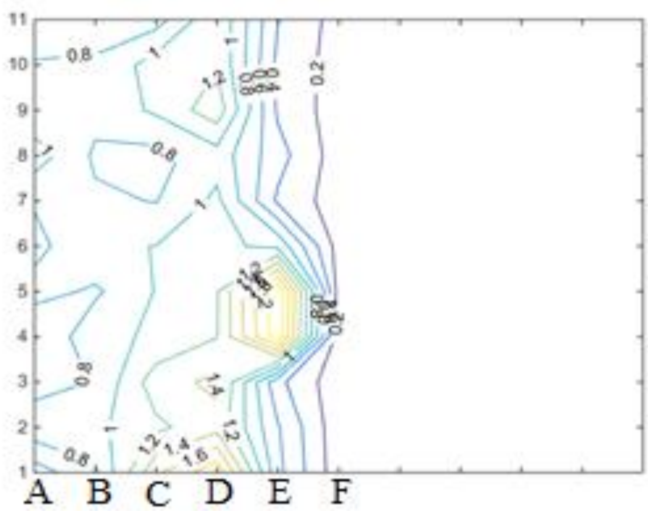


Fig 6.2:- Iso Luminance Distribution

It is the iso-luminance plot of CWSLS lamp from Table 5.4. Here three SLS lamps are placed beside the length of grids F1 to F11. As luminaires are directed upwards, so luminance just below the lamps (i.e. length through row F) is less than that of other rows. Through the middle rows (i.e. through C, D& E) luminance indicate its maximum value due to reflected light from ceiling as shown in Fig 6.2.

6.2 Only WWSLS Lamps

Here the average luminances (Photopic & Mesopic) of WWSLS are shown in Table 6.2.

Table 6.2: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	Photopic	Mesopic
WWSLS	0.9305303	0.944801968

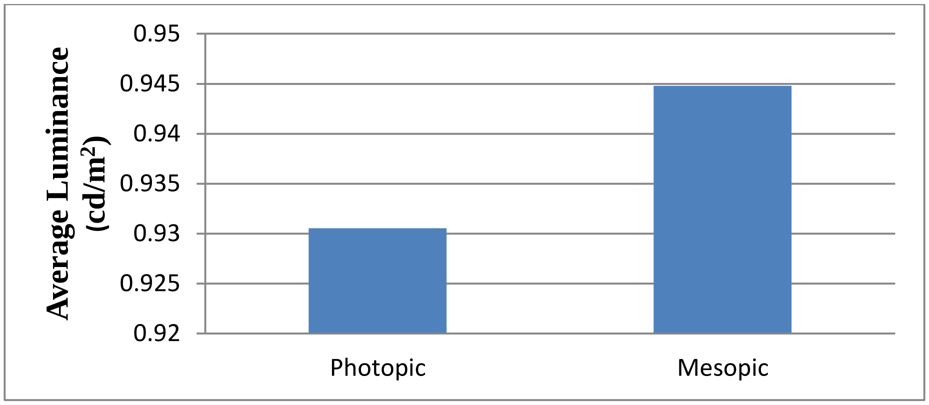


Fig 6.3: Photopic& Mesopic Luminance

Here it is seen from Fig 6.3 that in case of WWSLS lamp photopic luminance is more than that of mesopic luminance due to higher S/P ratio of WW FTL lamps of 1.79.

6.2.1. Iso Luminance plot:

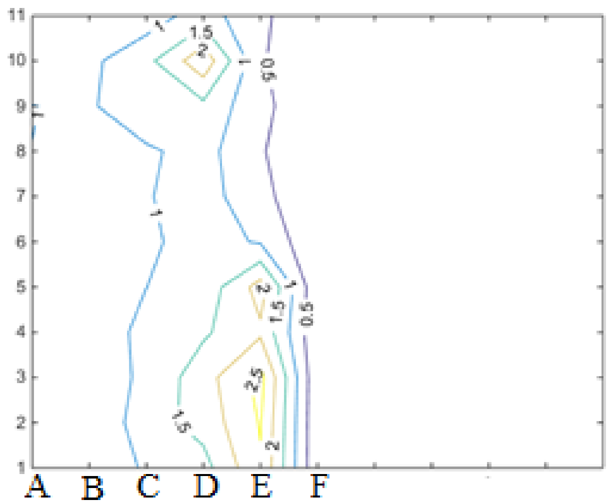


Fig 6.4:- Iso Luminance Distribution

It is the iso-luminance plot of CWSLS lamp from Table 5.5. Here three SLS lamps are placed beside the length of grids F1 to F11. As luminaires are directed upwards, so luminance just below the lamps (i.e. length through row F) is less than that of other rows. Through the middle rows (i.e. through C, D& E) luminance indicate its maximum value due to reflected light from ceiling as shown in Fig 6.4.

6.3 For HPSV Lamp

6.3.1 When only HPSV is glowing

Distribution of photopic luminance& mesopic luminance for only HPSV lamp is shown in Fig. 6.5& 6.6. These plots indicate luminance distribution of different grid points where luminances are taken from a particular distance.

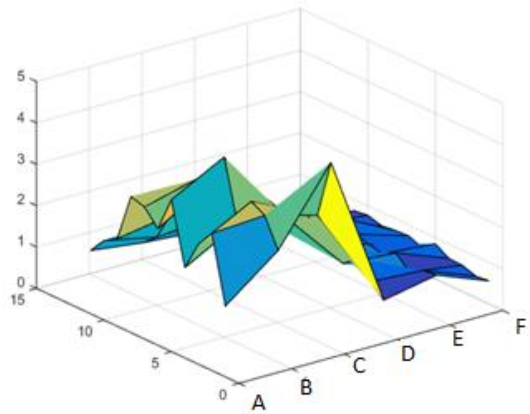


Fig 6.5: Distribution of Photopic Luminance

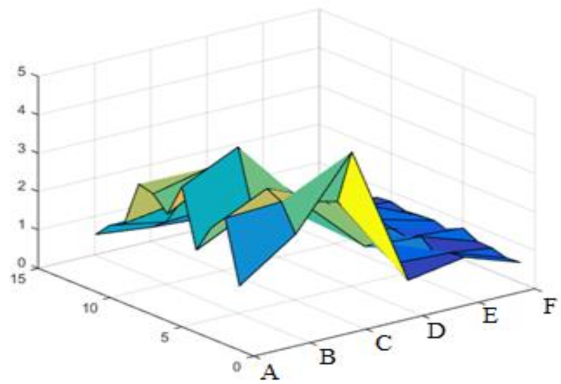


Fig 6.6: Distribution of Mesopic Luminance

6.3.1.1 Comparison of Average Luminance:

Here the average luminance (Photopic & Mesopic) is compared when only HPSV is glowing & all the Surrounding Light Sources (SLS) are off. From Fig 6.7, it is seen that in case of HPSV lamp photopic luminance is more than that of mesopic luminance due to its lower S/P ratio of 0.708. Here the average luminances (Photopic & Mesopic) of HPSV are shown in Table 6.3.

Table 6.3: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	Photopic	Mesopic
HPSV	1.84121212	1.812212242

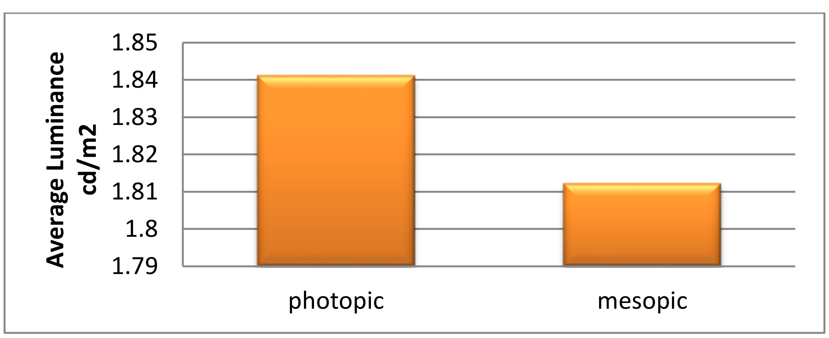


Fig 6.7: Photopic & Mesopic Luminance for HPSV

Here it is seen from Fig 6.7 that in case of HPSV lamp photopic luminance is more than that of mesopic luminance due to lower S/P ratio of HPSV lamps of 0.708.

6.3.1.2 Iso luminance diagram of Mesopic Luminance:

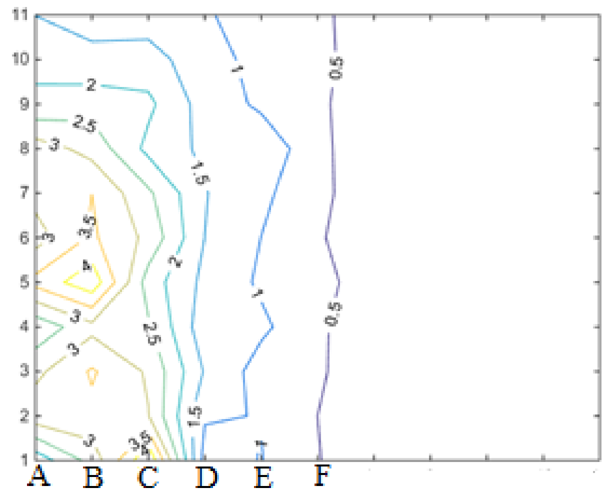


Fig 6.8:- Iso luminance diagram of Mesopic Luminance

It is the iso-luminance plot of HPSV lamp from Table 5.2. Here the Main Lamp is placed below the points between grids B6 and B7. As front of the luminaires is downwards, so luminance just below the lamp (i.e. between B6 and B7) is more than that of other grids. Luminance of C1 is also high as some of the direct reflected luminance component also entered into the luminance meter from this grid. Through the rows A & B luminance indicate its maximum value as shown in Fig 6.8.

6.3.2 For HPSV & CWSLS

Distribution of photopic luminance, mesopic luminance and addition of Mesopic luminance for both HPSV & CWSLS lamps are shown in Fig. 6.9, 6.10 & 6.11. These plots indicate luminance distribution of different grid points where luminances are taken from a particular distance.

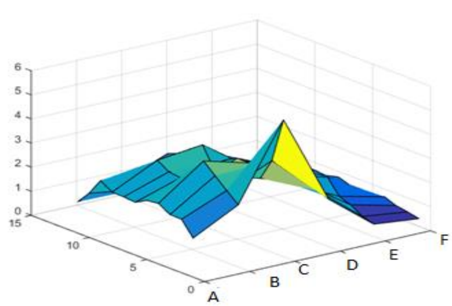


Fig 6.9:- Photopic Luminance

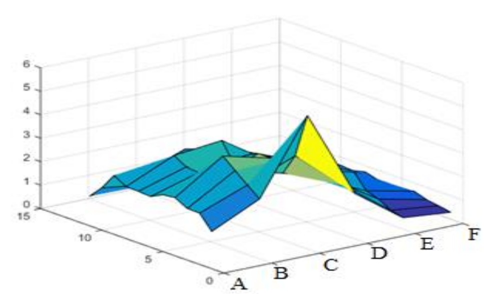


Fig 6.10:- Mesopic Luminance

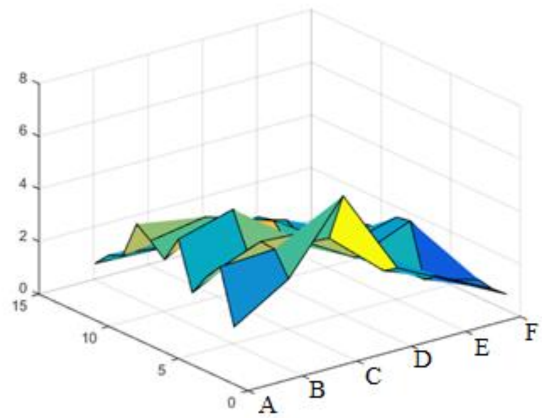


Fig 6.11: Mesopic Luminance

These are the 3D plots for Photopic luminance, Mesopic Luminance & addition of Mesopic luminance of HPSV & CWSLS lamps taken together from Table 4.5, Table5.6& Table 5.10 respectively. These plots indicate photopic luminance &mesopic luminance distribution of different grid points where photopic luminances are taken from a particular point.

6.3.2.1 Comparison of Average Luminance:

Here the average luminance (Photopic & Mesopic) is compared when HPSV lamp along with all the Surrounding Light Sources (SLS) are on. From Fig 6.12, it is seen that in case of HPSV & CWSLS lamp combination photopic luminance is more than that of mesopic luminance due to its lower S/P ratio of 0.708.

Here the average luminances (Photopic & Mesopic) of HPSV & CWSLS are shown in Table 6.4.

Table 6.4: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	**Photopic**	**Mesopic**
HPSV-CWSLS	1.9887878	1.960496699

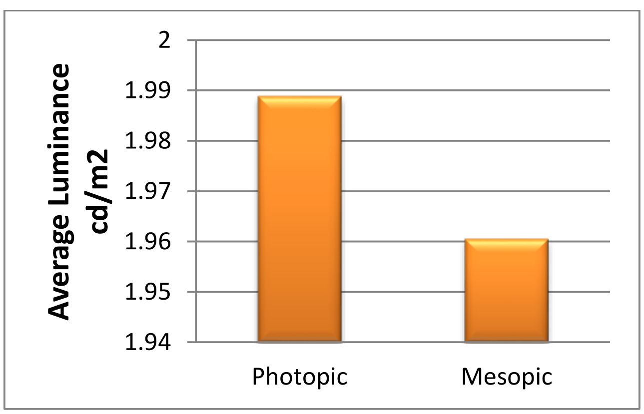


Fig 6.12: Photopic & Mesopic Luminance for HPSV & CWSLS lamps taken together.

Here it is seen from Fig 6.12 that in case of HPSV-CWSLS lamp photopic luminance is more than that of mesopic luminance due to lower S/P ratio of HPSV-CW FTL lamps of 0.708.

From 6.12 Mesopic Luminance for corresponding photopic luminance is shown when both HPSV& CWSLS lamps were glowing. Now when both the lamps are glowing separately then their effects are calculated and added to get the combined effect.

Table 6.5: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	Mesopic	Mesopic Addition
Only HPSV	1.812212242	1.812212242+0.803949955= 2.616162197
Only CWSLS	0.803949955	
Both HPSV & CWSLS	1.960496699	

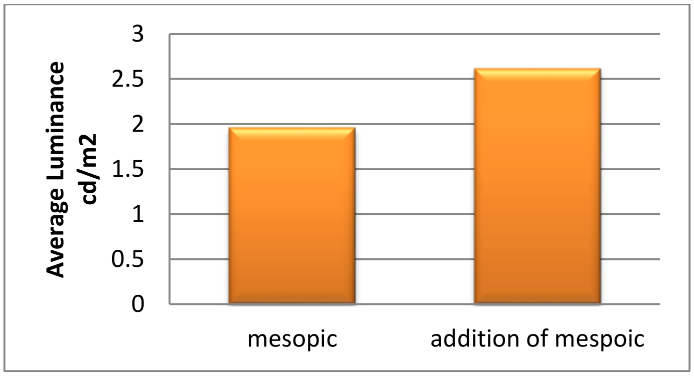


Fig 6.13: Mesopic Luminance for HPSV & CWSLS

6.3.2.2. Iso luminance diagram of Mesopic Luminance:

6.3.2.2.1. When both lamp glowing together

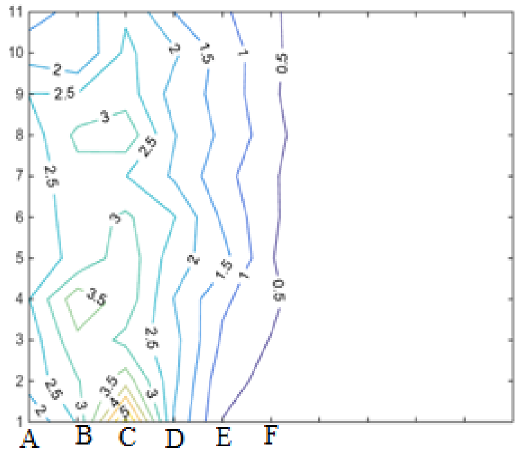


Fig 6.14:- Iso luminance diagram of Mesopic Luminance

It is the iso-luminance plot of HPSV & CWSLS lamp from Table 5.6when both glow together. Here Main Lamp is placed 3.6 m height the points between B6 and B7. Here three SLS lamps are placed beside the length of F1 to F11. As front of the Main luminaries is lower and front of SLS is upper so luminance is to be more where both lamp focused together. Through the rows B & C luminance indicates its maximum value as shown in Fig 6.14.Luminance of C1 is also high as some of the direct reflected luminance component also entered into the luminance meter from this grid.

6.3.2.2.2. When both lamp glowing separately

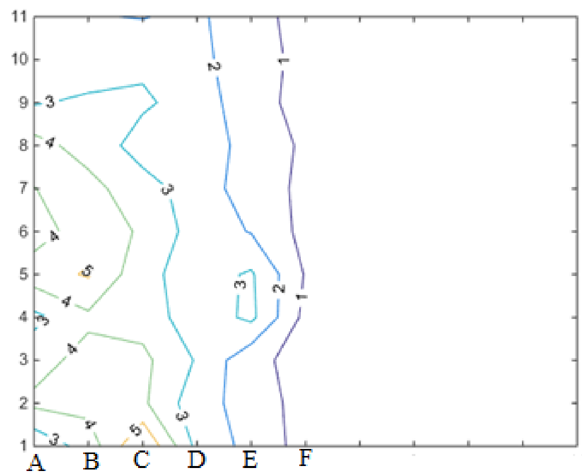


Fig 6.15:- Iso luminance diagram of Mesopic Luminance

It is the iso-luminance plot of HPSV & CWSLS lamp from table 5.10 when both individual mesopic luminance is added. Here Main Lamp is placed at 3.6 m height of the points between B6 and B7. Here three SLS lamps are placed beside the length of F1 to F11. Here mesopic luminance of lamps are measure individually. So at first case when only Main Lamp glow maximum luminance is through length wise A, B & C. At second case when only Main Lamp glow maximum luminance is through length wise B, C & D. When addition is done through the rows B & C luminance indicate its maximum value as shown in Fig 6.15.

6.3.3. For HPSV & WWSLS

Distribution of photopic luminance, mesopic luminance& addition of mesopic luminance for both HPSV & CWSLS lamps are shown in Fig. 6.16, 6.17 & 6.18. These plots indicate luminance distribution of different grid points where luminances are taken from a particular distance.

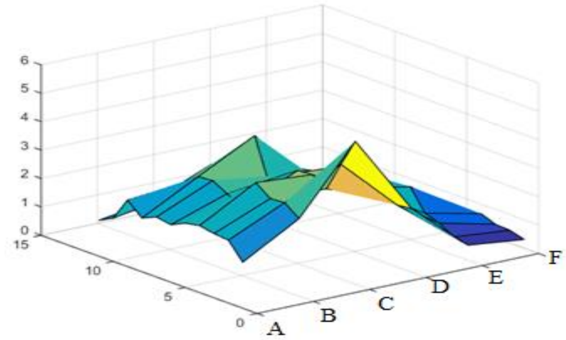


Fig 6.16: Photopic Luminance

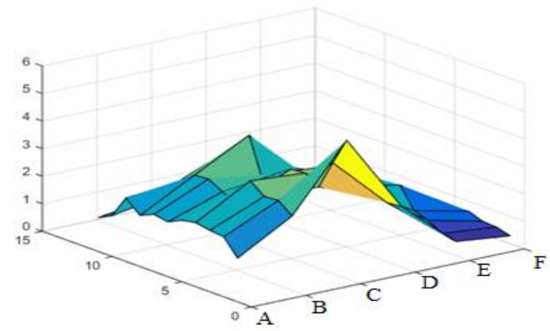


Fig 6.17: Mesopic Luminance

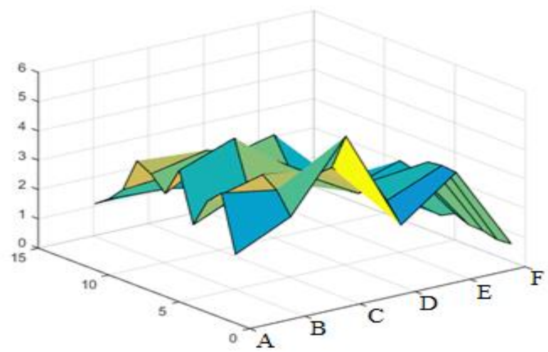


Fig 6.18:- Addition of Mesopic Luminance

These are the 3D plots for Photopic luminance, Mesopic Luminance & addition of Mesopic luminance of HPSV & WWSLS lamps taken together from Table 4.6, Table 5.7 & Table 5.11 respectively. These plots indicate photopic luminance & mesopic luminance distribution of different grid points where photopic luminances are taken from a particular point.

6.3.3.1. Comparison of Average Luminance:

Here the average luminance (Photopic & Mesopic) is compared when HPSV as well as all the Surrounding Light Sources (SLS) are off. From Fig 6.19, it is seen that in case of HPSV lamp photopic luminance is more than that of mesopic luminance due to its lower S/P ratio of 0.708.
Here the average luminances (Photopic & Mesopic) of HPSV & WWSLS are shown in Table 6.6.

Table 6.6: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	**Photopic**	**Mesopic**
HPSV-WWSLS	1.95893939	1.930822926

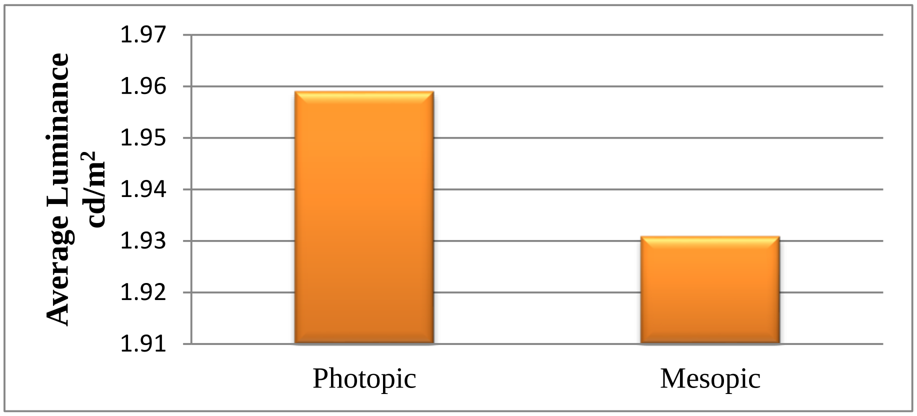


Fig 6.19: Photopic & Mesopic Luminance for HPSV & WWSLS lamps taken together

Here it is seen from Fig 6.19 that in case of HPSV-WWSLS lamp photopic luminance is less than that of mesopic luminance due to lower S/P ratio of HPSV-CW FTL lamps of 0.708.

From 6.19 Mesopic Luminance for corresponding photopic luminance is shown when both HPSV& CWSLS lamps were glowing. Now when both the lamps are glowing separately then their effects are calculated and added to get the combined effect.

Table 6.7: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	Mesopic	Mesopic Addition
Only HPSV	1.812212242	1.812212242+0.944801968= 2.75701421
Only WWSLS	0.944801968	
Both HPSV & WWSLS	1.930822926	

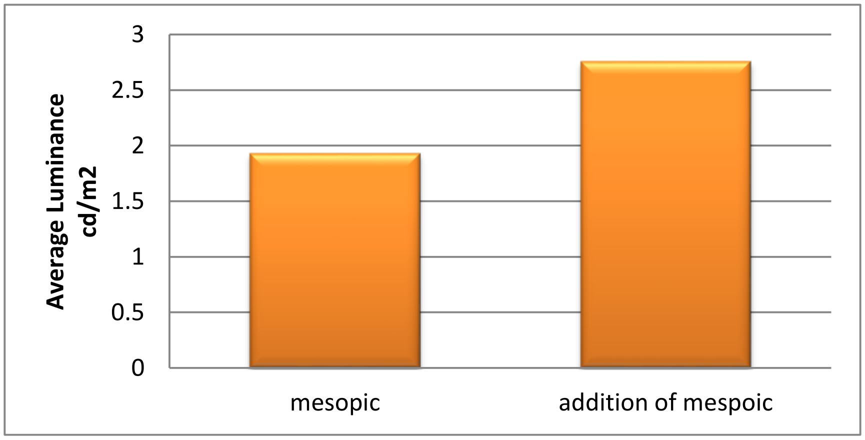


Fig 6.20: Mesopic Luminance for HPSV & WWSLS

6.3.3.2 Iso luminance diagram of Mesopic Luminance:

6.3.3.2.1 When both lamp glowing together

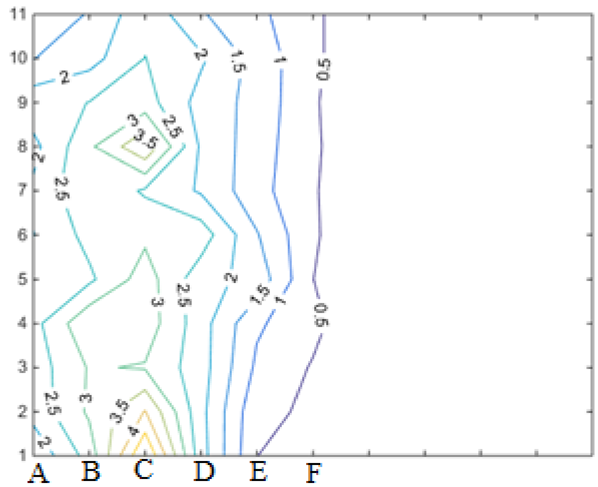


Fig 6.21: Iso luminance diagram of Mesopic Luminance

It is the iso-luminance plot of HPSV & WWSLS lamp from table 5.7 when both glow together. Here Main Lamp is placed 3.6 m height the points between B6 and B7. Here three SLS lamps are placed beside the length of F1 to F11. As front of the Main luminaries is lower and front of SLS is upper so luminance is to be more where both lamp focused together. Through the rows B & C luminance indicates its maximum value as shown in Fig 6.21.Luminance of C1 is also high as some of the direct reflected luminance component also entered into the luminance meter from this grid.

6.3.3.2.2 When both lamp glowing separately

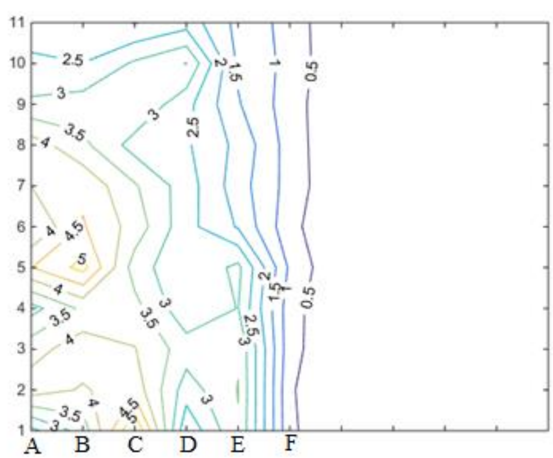


Fig 6.22:- Iso luminance diagram of Mesopic Luminance

It is the iso-luminance plot of HPSV & WWSLS lamp when both individual mesopic luminance is added. This plot is drawn from Table 5.11. Here Main Lamp is placed at 3.6 m height of the points between B6 and B7. Here three SLS lamps are placed beside the length of F1 to F11. Here mesopic luminances of lamps are measure individually. So in first case when only Main Lamp glow maximum luminance is through lengthwise A, B & C. At second case when SLS lamps glow maximum luminance is through lengthwise B, C & D. When addition is done through the rows B & C luminance indicate its maximum value as shown in Fig 6.22.

Here the average luminance (MESOPICs) of HPSV lamp along with one type of the Surrounding Light Sources (SLS) are on (either CWSLS or WWSLS) and addition of their individual mesopic luminance are compared.

Table 6.4 Fig 6.4.9; both lamp 6.4.10 shows two lighting conditions of mesopic for Main Lamp (HPSV) and SLS lamp. When both lamp glow, take photopic luminance from the grid points and convert it to mesopic [$(HPSV + SLS)_M$] by CIE: 191. Then measure photopic luminance of Main lamp [$(HPSV)_M$] and SLS lamp[$(SLS)_M$] and then convert it to mesopic by CIE: 191. At last the average values of [$(HPSV + SLS)_M$] and [$(HPSV)_M$] + [$(SLS)_M$] in bar plot are compared.

6.4 For MH Lamp

6.4.1 When only MH is glowing

Distribution of photopic luminance& mesopic luminance for only MH lamp is shown in Fig. 6.23& 6.24. These plots indicate luminance distribution of different grid points where luminances are taken from a particular distance.

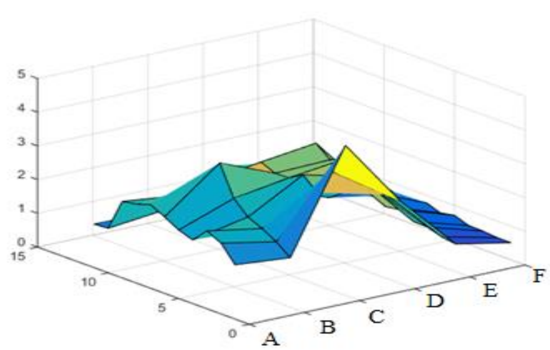


Fig 6.23: Photopic Luminance

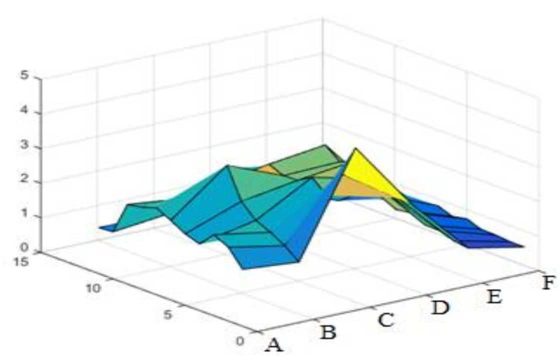


Fig 6.24: Mesopic Luminance

These are the 3D plots for Photopic luminance & Mesopic Luminance of MH lamp taken together from Table 4.2, & Table 5.3 respectively. These plots indicate photopic luminance & mesopic luminance distribution of different grid points where photopic luminances are taken from a particular point.

6.4.1.1 Comparison of Average Luminance:

Here the average luminance (Photopic & Mesopic) is compared when only MH is glowing & all the Surrounding Light Sources (SLS) are off. From Fig 6.25, it is seen that in case of MH lamp photopic luminance is less than that of mesopic luminance due to its higher S/P ratio of 1.35. Here the average luminance (Photopic & Mesopic) of MH are shown in Table 6.8.

Table 6.8: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	Photopic	Mesopic
MH	1.85621212	1.889424237

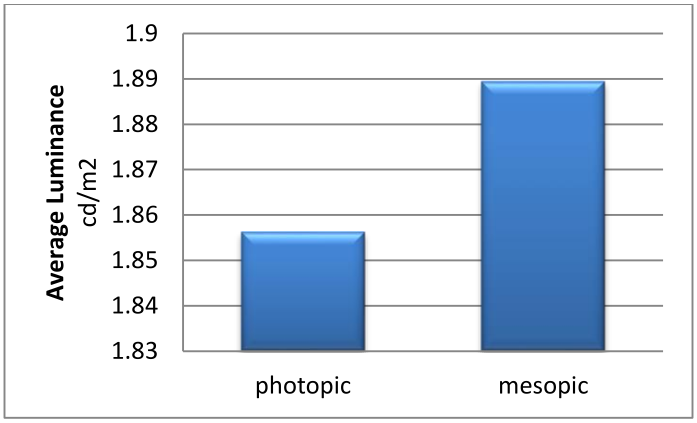


Fig 6.25 Photopic & Mesopic Luminance for MH lamp.

Here it is seen from Fig 6.25 that in case of MH lamp photopic luminance is less than that of mesopic luminance due to higher S/P ratio of MH lamps of 1.36.

6.4.1.2 Iso luminance diagram of Mesopic Luminance:

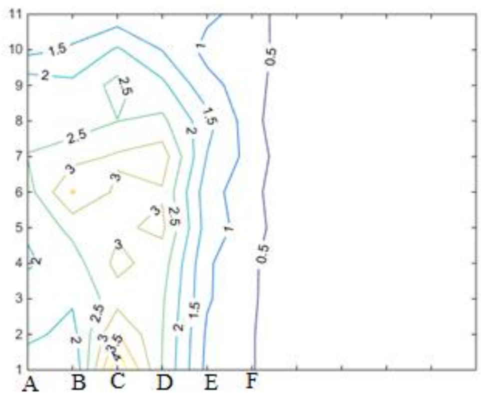


Fig 6.26:- Iso luminance diagram of Mesopic Luminance

It is the iso-luminance plot of MH lamp. This plot is drawn from Table 5.3. Here the Main Lamp is placed below the points between grids B6 and B7. As front of the luminaries is lower, so luminance just below the lamp (i.e. between B6 and B7) is more than that of other grids. Luminance of C1 is also high as some of the direct reflected luminance component also entered into the luminance meter from this grid. Through the rows A & B luminance indicate its maximum value as shown in Fig 6.26.

6.4.2 For MH & CWSLS

Distribution of photopic luminance, mesopic luminance & addition of mesopic luminance for both MH & CWSLS lamps are shown in Fig. 6.27, 6.28 & 6.29. These plots indicate luminance distribution of different grid points where luminances are taken from a particular distance.

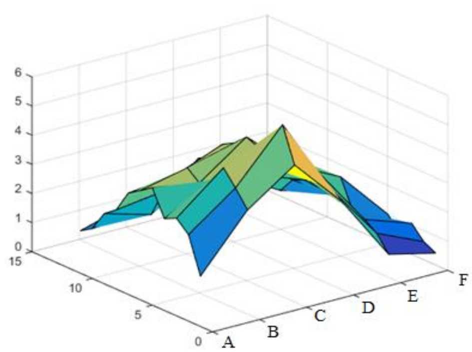


Fig 6.27: Photopic Luminance

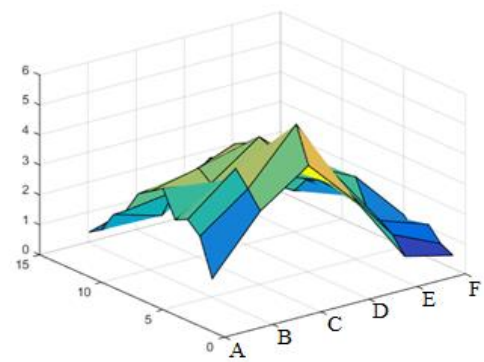


Fig 6.28:- Mesopic Luminance

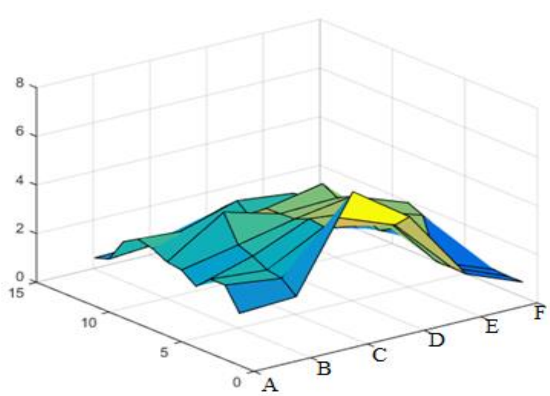


Fig 6.29 :Addition of individual Mesopic Luminance

These are the 3D plots for Photopic luminance, Mesopic Luminance & addition of Mesopic luminance of MH & CWSLS lamps taken together from Table 4.7, Table 5.8 & Table 5.12 respectively. These plots indicate photopic luminance & mesopic luminance distribution of different grid points where photopic luminances are taken from a particular point.

6.4.2.1 Comparison of Average Luminance:

Here the average luminance (Photopic & Mesopic) is compared when MH as well as all the Surrounding Light Sources (SLS) is on. From Fig 6.30, it is seen that in case of MH lamp photopic luminance is less than that of mesopic luminance due to its higher S/P ratio of 1.35.
Here the average luminances (Photopic & Mesopic) of MH & CWSLS are shown in Table 6.9.

Table 6.9: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	Photopic	Mesopic
MH-CWSLS	2.6520757	2.67924761

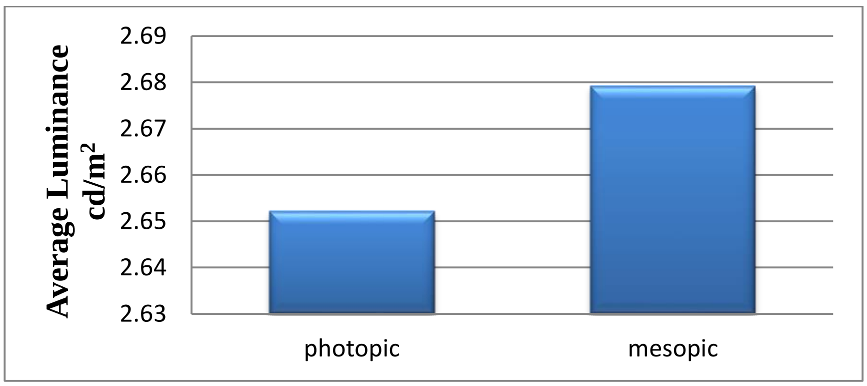


Fig 6.30: Photopic & Mesopic Luminance for MH & CWSLS lamps taken together

Here it is seen from Fig 6.30 that in case of MH-CWSLS lamp photopic luminance is less than that of mesopic luminance due to higher S/P ratio of MH-CWSLS lamps of 1.36.

From 6.30 Mesopic Luminance for corresponding photopic luminance is shown when both MH & CWSLS lamps were glowing. Now when both the lamps are glowing separately then their effects are calculated and added to get the combined effect.

Table 6.10: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	Mesopic	Mesopic Addition
Only MH	1.85621212	1.85621212+0.803949955=2.693374192
Only CWSLS	0.803949955	
Both MH & CWSLS	2.67924761	

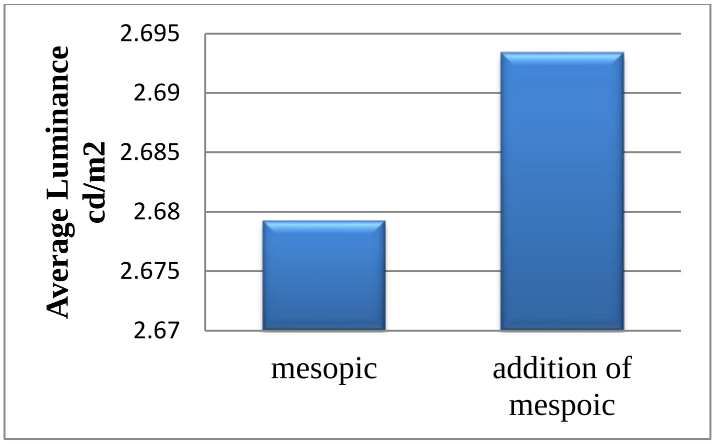


Fig 6.31: Mesopic Luminance for MH & CWSLS

6.4.2.2 Iso luminance diagram of Mesopic Luminance:

6.4.2.2.1 When both lamp glowing together

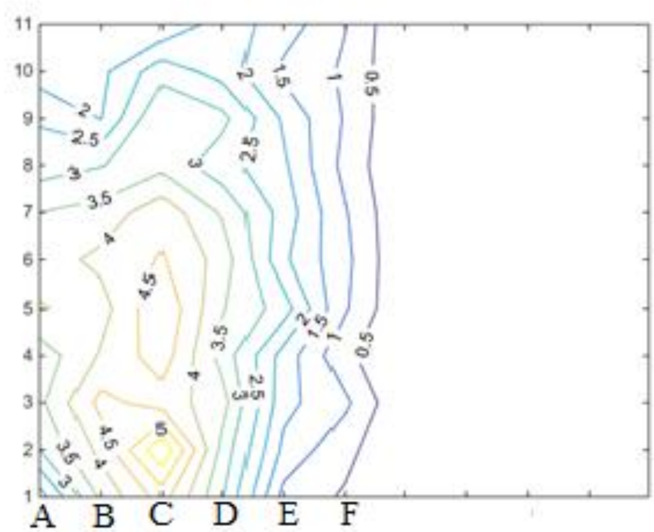


Fig 6.32:- Iso luminance diagram of Mesopic Luminance

It is the iso-luminance plot of MH & CWSLS lamp when both glow together. This plot is drawn from Table 5.8. Here Main Lamp is placed 3.6 m height the points between B6 and B7. Here three SLS lamps are placed beside the length of F1 to F11. As front of the Main luminaries is lower and front of SLS is upper so luminance is to be more where both lamp focused together. Through the rows B & C luminances indicate its maximum value as shown in Fig 6.32. Luminance of C1 & C2 is also high as some of the direct reflected luminance component also entered into the luminance meter from this grid and in that case it act as photopic.

6.4.2.2.2 When both lamp glowing separately

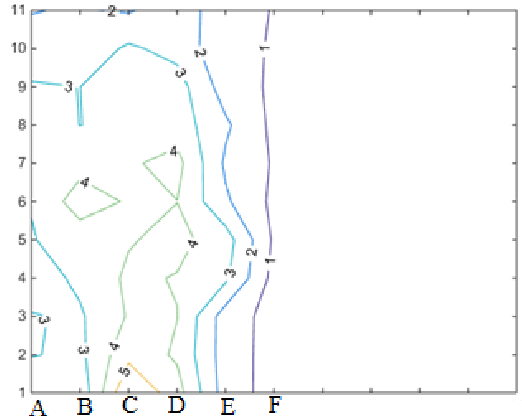


Fig 6.33:- Iso luminance diagram of Mesopic Luminance

It is the iso-luminance plot of MH & CWSLS lamp when both individual mesopic luminance is added. This plot is drawn from Table 5.12. Here Main Lamp is placed at 3.6 m height of the points between B6 and B7. Here three SLS lamps are placed beside the length of F1 to F11. Here mesopic luminances of lamps are measure individually. So at first case when only Main Lamp glow maximum luminance is through lengthwise A, B & C. At second case when SLS Lamps glow maximum luminance is through lengthwise B, C & D. When addition is done through the rows B & C luminance indicate its maximum value as shown in Fig 6.33.Luminance of C1 & C2 is also high as some of the direct reflected luminance component also entered into the luminance meter from this grid.

6.4.3 For MH & WWSLS

Distribution of photopic luminance, mesopic luminance & addition of mesopic luminance for both MH& WWSLS lamps are shown in Fig. 6.34, 6.35& 6.36. These plots indicate luminance distribution of different grid points where luminances are taken from a particular distance.

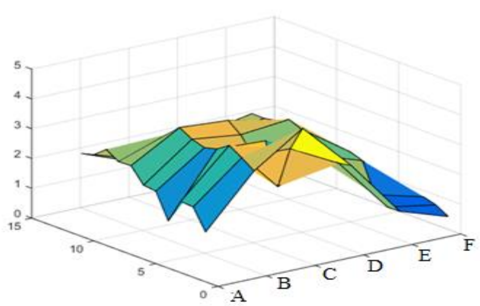


Fig 6.34: Photopic Luminance

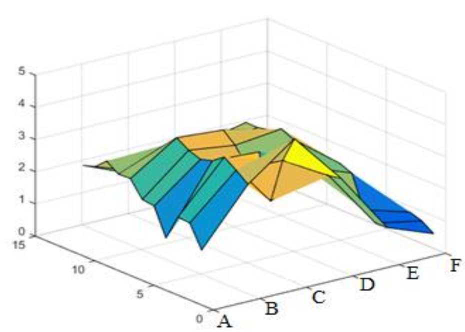


Fig 6.35:- Mesopic Luminance

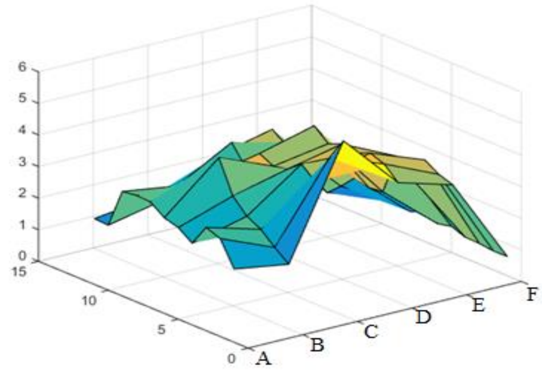


Fig 6.36:- Mesopic Luminance

These are the 3D plots for Photopic luminance, Mesopic Luminance & addition of Mesopic luminance of MH & WWSLS lamps taken together from Table 4.8, Table 5.9 & Table 5.13 respectively. These plots indicate photopic luminance & mesopic luminance distribution of different grid points where photopic luminances are taken from a particular point.

6.4.3.1 Comparison of Average Luminance:

Here the average luminance (Photopic & Mesopic) is compared when MH as well as all the Surrounding Light Sources (SLS) are on. From Fig 6.37, it is seen that in case of MH lamp photopic luminance is less than that of mesopic luminance due to its higher S/P ratio of 1.35. Here the average luminances (Photopic & Mesopic) of MH & WWSLS are shown in Table 6.11.

Table 6.11: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	Photopic	Mesopic
MH-WWSLS	2.41287879	2.443361091

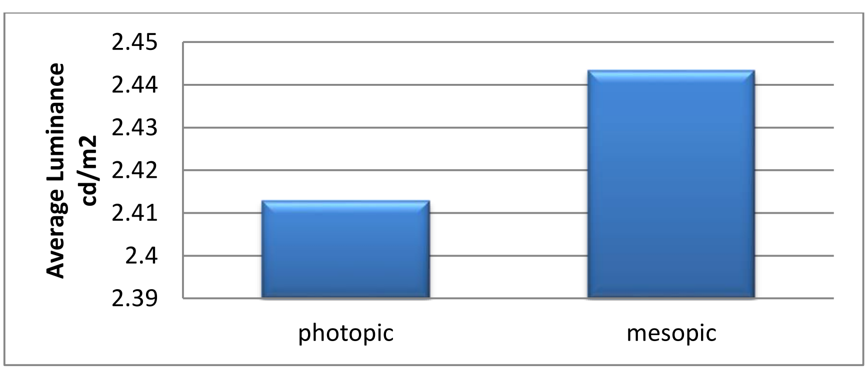


Fig 6.37: Photopic & Mesopic Luminance for MH & WWSLS lamps taken together

Here it is seen from Fig 6.37 that in case of MH-WWSLS lamp photopic luminance is less than that of mesopic luminance due to higher S/P ratio of MH-WWSLS lamps of 1.36.

From 6.37 Mesopic Luminance for corresponding photopic luminance is shown when both MH& CWSLS lamps were glowing. Now when both the lamps are glowing separately then their effects are calculated and added to get the combined effect.

6.12: Average Luminance in cd/m^2 (Photopic & Mesopic)

Lamp	Mesopic	Mesopic Addition
Only MH	1.889424237	1.889424237+0.944801968=2.834226205
Only WWSLS	0.944801968	
Both MH & WWSLS	2.443361091	

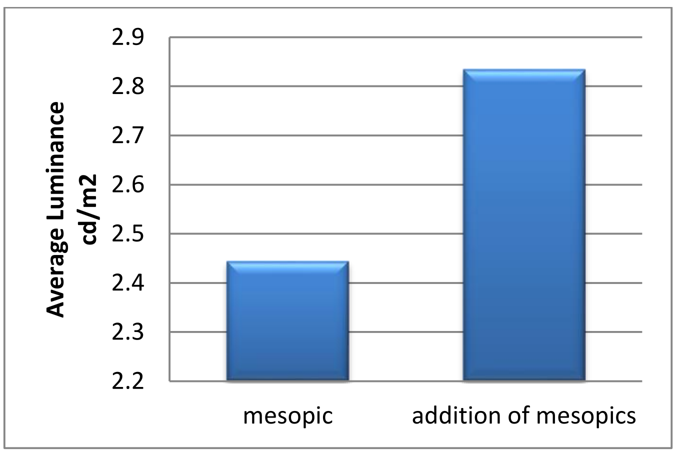


Fig 6.38: Mesopic Luminance for MH & CWSLS

It is the iso-luminance plot of MH & WWSLS lamp when both individual mesopic luminances are added. This plot is drawn from Table 5.13. Here Main Lamp is placed at 3.6 m height of the points between B6 and B7. Here three SLS lamps are placed beside the length of F1 to F11. Here mesopic luminance of lamps are measure individually. So at first case when only Main Lamp glow maximum luminance is through lengthwise A, B & C. At second case when SLS Lamps glow maximum luminance is through lengthwise B, C & D. When addition is done through the rows B & C luminance indicate its maximum value as shown in Fig 6.40.Luminance of C1 and C2 is also high as some of the direct reflected luminance component also entered into the luminance meter from this grid and in that case it act as photopic.

Above figures shows two lighting conditions of mesopic for Main Lamp (MH) and SLS lamp. First both lamp are glowing and photopic luminance from the grid points are taken and then converted it to mesopic [$(MH + SLS)_M$] by CIE: 191. Then photopic luminance of Main lamp [$(MH)_M$] and SLS lamp[$(SLS)_M$] are measured and then converted to mesopic by CIE: 191.At last all the average values of [$(MH + SLS)_M$] and [$(MH)_M$] +[$(SLS)_M$] are compared.

6.4.3.2 Iso luminance diagram of Mesopic Luminance:

6.4.3.2.1 When both lamp glowing together

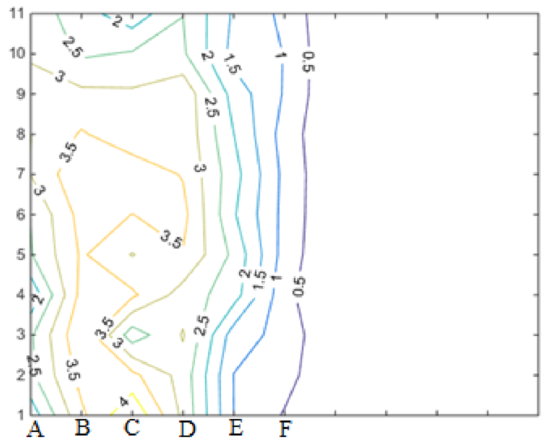


Fig 6.39:- Iso luminance diagram of Mesopic Luminance

It is the iso-luminance plot of MH & WWSLS lamp when both glow together. This plot is drawn from Table 5.9. Here Main Lamp is placed 3.6 m height the points between B6 and B7. Here three SLS lamps are placed beside the length of F1 to F11. As front of the Main luminaries is lower and front of SLS is upper so luminance is to be more where both lamp focused together. Through the rows B & C luminance indicate its maximum value as shown in Fig 6.39.Luminance of C1 is also high as some of the direct reflected luminance component also entered into the luminance meter from this grid.

6.4.3.2.2 When both lamp glowing separately

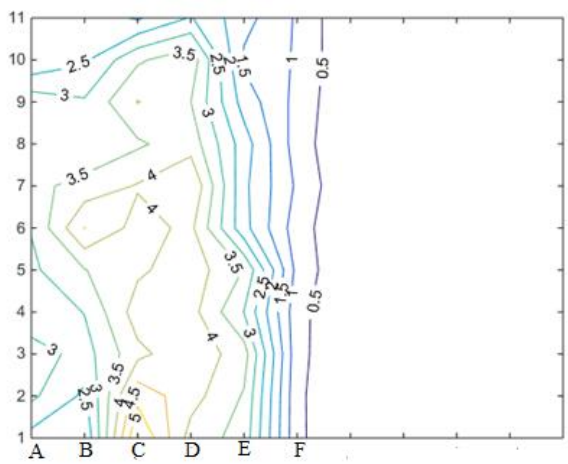


Fig 6.39:- Iso luminance diagram of Mesopic Luminance

Therefore from the above work it can be concluded that

- Lamps with more blue content in its spectrum i.e. lamp with higher S/P ratio provides better performance in mesopic region.

- Although HPSV lamp shows better performance in photopic region but the effective luminance in mesopic region of MH is higher than HPSV.

- In case of outdoor lighting due to presence of any surrounding sources with different spectrum characteristics, lamp performances change significantly on the application field.

- Presence of light source of different S/P ratio than that of main source shows opposite performance than main light source.

- Among all combinations MH lamp with CWSLS sources shows best performance. Effective luminance in mesopic region increases significantly, causing it more efficient lighting options.

Chapter 7:
Conclusion & Future Scope

To see any object in outdoor lighting human eye need a good brightness & contrast. In this thesis it is concluded that if S/P ratio is lower (e.g. HPSV) the mesopic luminance (L_{mes}) is less than that of photopic luminance (L_p) in the area. As a result human eye perceives less brightness in that environment. To achieve proper brightness it should be retrofitted with a proper high wattage lamp. So energy consumption also becomes higher. Thus according to efficient energy management the lamp's lower S/P ratio is not recommended in mesopic zone. Here we have to find out an alternate way to solve this problem.

The lamps with higher S/P ratio (e.g. MH, CWSLS, and WWSLS) provide significantly higher mesopic value (L_{mes}) than that of photopic value (L_p).So we get a sufficient brightness in mesopic region. In another way it can be said that a less wattage lamp can also provide more brightness. As a result energy consumption is reduced. So according to efficient energy management this system is more reliable for energy saving & brightness.

The thesis is about mesopic photometry in outdoor lighting. But the measurement has been done in Dark room of Illumination Engineering Laboratory. Though all the walls are dark some of rays are reflected from ceiling or walls. It causes some error. Length of the room is only 8m. So we cannot measure luminance from a long distance. As a result many reflected light enters into the luminance meter along with the luminance of that particular grid. It is a cause of error. Another most important fact is taking the photopic luminance accurately. When luminance is taken from luminance meter its result fluctuates several times and it cannot be taken accurate luminance of a particular grid in case of different time, different lamp and individual lamp conditions.

As an example in the calculation of the mesopic photometry of main lamp and SLS taken together, is less than that of the addition of their individual mesopic luminance for most of times. Sometimes opposite cases also happen.

Another problem is that for some grid points luminance meter take the luminance as direct reflected from light source and these points are too much bright ,their luminance is also more than 5 cd/m^2 i.e. in photopic region. In excel sheet mesopic luminance of these grid are considered as photopic luminance of that grid. When this value is added with any SLS lamp the value increased too much but when lamps are taken together the value of photopic is considered as mesopic and not increased. So there is a huge fluctuation of mesopic results.

In other case it is also a fact that front of surrounding light sources (SLS) are upper. As a result most of the beam of SLS is spread through upper side. Only some portion of rays and some reflected rays fall on the grid. So luminance shows some less value.

In future the experiment may be performed in real application area and measurement distance between grid point and luminance meter can be increased. The outdoor effect such as dust, rain, fog, moisture and ambient temperature variations, will significantly affect lamp performance as well as visual performance of eye, should be taken into consideration. It has proved that in foggy weather performance of HPSV is too much better than that of other lamps. There are so many items in the room from is light is reflected and effect on measuring data. So in future, in case of outdoor lighting this kind of error will be reduced and set up will be reliable.

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