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LIGHT POLLUTION MEASUREMENT OF LUMINARIES BY A NEW TECHNIQUE

Environmental Science

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ABSTRACT

This study is devoted to a quantitative measurement of light pollution (LP) caused by some of the commonly used luminaries such as street lights. A simple simulating experimental method based on the mathematical modelling has been developed to measure LP by a street light. The measurement can be extended to any number of luminaries installed in an area. The technique can be used in standardizing various street lights and subsequently in LP management against our lighting needs. The LP level performance of the street lights, measured in terms of the scattered Upward Light Ratio (ULR) [1], was found to be the best for LED lights, of course, installed with suitable orientation.

KEYWORDS

luminaries, light pollution, illuminance, Upward Light Ratio (ULR), light pollution management

Introduction:

Light pollution is a matter of serious concern. It has become an all pervasive intrusion into city/town life. There is a large variation in LP level for Indian cities/towns which are related to demographic and socio economic factors with a few exceptions. However, there is not much awareness about the issue. Hence various aspects related to LP should be brought to the notice of the common people. The extensive study of LP and its correlation with various factors and subsequently their analysis could be of great use in minimizing the LP and for our present city planning, apart from its academic importance. The LP measurement technique may help in standardizing and improving various street lights being in common use [2], as street lights significantly contribute to LP.

Light pollution can be defined as the artificial, misdirected, misplaced, unshielded and excessive light which pollutes area not intended to be lit. Measuring the total amount of light pollution in a certain area is very difficult and a complex procedure because the environment, which is very diverse, impacts LP levels.

Avoidable light pollution refers to light flow emitted at night by artificial light sources which are inappropriate in intensity, direction and/or spectral range unnecessary to carry out the function they are intended for, or when artificial lighting is used in particular sites, such as observatories, natural areas or sensitive landscapes.

Light pollution has the maximum negative effect among all the factors affecting the night sky quality [3]. However, LP can be reduced through viable solutions.

Significance of Studying Street Lights:

The very definition of light pollution indicates that light pollution is nothing but the unwanted radiations that are emitted in the atmosphere. This light could be generated from any source, household lights, decorative lights, street lights, flash lights, beacons, etc. Considering the different contributors of light pollution, household lights cause a minimal addition to the light pollution as their light fail to escape into environment. Other sources like beacons and flash lights fail to cause much contribution in LP levels as their number is quite low as compared to the street lights. Thus, it was evaluated that street lights were in general the most prominent of all the sources causing light pollution.

Another factor intensifying this issue is the increase in the public lighting at the rate of 8% per annum [4] on an average over the past decade on world scale, and with this continuing factor light pollution levels will double itself in next nine years. Though public lighting are efficient in their own way, but since they have high hours-of-use (4,000 hours per year) they contribute much in light pollution. Thus, the associated light pollution is set to increase if proper mitigating steps are not taken.

Inspecting all the effects and causes from the outdoor lighting, it was decided to study the amount of light pollution caused by each type of individual street lights common in use.

The data provided by the enlighten initiative of UNEP [5] and Energy Efficient Street Lighting Guidelines [6] suggest a number of luminary types with their percentage contributions in units and energy consumptions. Out of these the three luminaries commonly used for public lighting are high pressure sodium bulb (HPS), tungsten halogen and light emitting diodes (LEDs).

ELCOMAS (Electric Lamp and Component Manufacturers Association of India) [7] tracks the data from the manufactures perspective, sighted that High Pressure Sodium Light fixtures are the most commonly used streetlights in India. The similar data was presented by the world-bank in its energy efficient urban street lightening report in June 2015[8].

LED area lights are highly efficient light source which generally last long up to 100,000 hours. Running an approximate of 12 hours per day, they serve almost every area requiring the need. While other light systems fade quickly and change colour over time, LED area lights maintain their colour temperature for years, giving long lasting hours and higher quality light. At the same time they are economic from electric consumption aspect. Because LEDs are naturally directional, there is no light trapped in the fixture. Considering all these factors, the old street lights are being replaced with new LEDs.

Another light fixture which is used for specific purposes is the tungsten halogen of 500 watt. These types of fixtures are commonly used in the construction areas, institutional buildings, stadiums, theatres and hoardings. These generally fill the purpose to illuminate the large open areas at night. Although these fixtures are not there in very large number, their installations are often done poorly, ignoring the LP factor. Hence, contrary to the objective for which they are set up, these type of fixtures results in more light pollution rather than lightening the required area. Thus, scrutinizing them was a significant involvement in studying LP levels.

We have selected these three luminaries in our experiment to measure the amount of light going in the sky from each of them thereby estimating their LP contributions. To manage LP we must have a suitable method to measure it at the source level so that the source may be altered to minimize the pollution level preferably below the 'threshold level'.

Here we have tried to present a simple simulating experiment method to measure light pollution caused by any luminary. This measurement can be extended to any number of lights installed in an area simply by unitary method of multiplication and summation, thereby giving the amount of pollution that may be caused due to a specific type(s) of light in a specific orientation before installing them.

Theory:

The method involves measuring amount of LP caused by any particular type of light in any specific orientation and summing up this for N number of lights installed in a given orientation in that area. It could be extended to a mixed lighting system as well.

To have standard LP measurement, the source needs to be standardised. Apart from the direct upward light, the two other sources of the LP are reflected from the surroundings of different lights that may vary, as well as the scattered part that varies with weather conditions. It was decided in this experiment not to consider the reflected part and also to take observations at least twice, once when in India the LP levels are maximum (in January) and minimum (in June). These maxima and minima times for a particular area could be identified using satellite data [9].

In order to measure scattered upward light we considered a virtual sphere around the light source with the source at its centre. The upward polluting light is any light above the plane of light source parallel to the ground. Thus we need to calculate the total light going through the upper hemisphere.

To avoid the reflected light component from the ground we turn the light upside down. This not only eliminates reflected component of LP but also simplifies the earlier task of measurement in a hemisphere above the plane of suspension of light, since the upper virtual hemisphere becomes lower hemisphere after the rotation, and the observer has advantage to take readings on ground itself. By calculating the amount of radiation, the LP level can be estimated.

Illuminance of an ideal source of light at a point is inversely proportional to the square of its distance from the source [1]. As the light source used is not ideally a point source therefore; we chose the radius of the sphere greater than five times the major dimensions of the lighting unit, which brings the lighting unit in close approximation (better than 1%) to the dimensions of an infinitesimally small unit. This makes the illuminance of the source, at such large distances, to follow the above mentioned inverse square law. Thus, the illuminance of the source can be expressed as,

$$E(\theta, \phi) = I(\theta, \phi)/R^2$$

Where, R is the radius of the sphere and E (θ, φ) is the illuminance at the point defined by theta and phi in lumens (lm) per unit area (or lux). Here, I (θ, φ) is the luminous intensity of the source at the point of measurement. It is the measure of light intensity at a given point in terms of brightness of a 'standard candle'. The SI unit of luminous intensity is candela (cd).

The illuminance at any given point was measured using a standard Luxmeter having a least count of 0.1 lux (lx).

Since the luxmeter gives the illuminance [1] in a particular direction, we divided the sphere into small area elements corresponding to suitable values of θ and φ.

Thus, Luminous Flux, or total light energy passing through an area can obtained by using the following expression.

Amount of light passing through one area element
= Illuminance on the area element (E)×area of the area element

The extent of light pollution is being measured in terms of Scattered Upward Light Ratio (ULR). This can be expressed as,

Upward Light Ratio(ULR)
=(Amount of light going upward)/(Total light emitted by the source)

The amount of light going upward can be calculated by considering area elements of upper hemisphere only. Also, the total light emitted by the source (total luminous flux) is provided in the lighting unit rating information.

Thus, total light going upward can be expressed as,

$$Total\ Light\ (TL)\ going\ upward = \sum_1^n \sum_1^m E_{n,m} \times A_{n,m}$$

Where, $E_{n,m}$ = Illuminance on n^{th} plane's m^{th} area element, and

$A_{n,m}$ = Area of n^{th} plane's m^{th} area element

= Constant, since zones of similar areas are used

= $length \times breadth$

= $(R \times \Delta\theta)(R \times \Delta\phi)$

= $R^2 \times \Delta\theta \times \Delta\varphi$

n = number of planes having area elements with detectable illuminance
m = number of area elements in each such plane

Δθ = Latitudinal angle subtended by one area element at the centre
Δϕ = Longitudinal angle subtended by one area element at the centre

The reading for various θ and φ can be obtained using the set up as shown in Figure 1. The intensity distributions are expressed through a polar graph by joining points of the same plane.

Experimental:

The geometry and terminology used in a typical road lighting i.e. street light has been depicted in Figure 2. For practical purpose schematic arrangement of the experimental set up is shown in Figure 3.
As illuminance in each area element was to be measured, it was needed that the area element be uniformly illuminated [1]. This required a point light source. The practical light source like a street light being an extended source, there was a threat of non-uniform illumination of the area elements. In order to reduce the variation of illuminance we have taken the radius of the virtual sphere R very large.

With the help of a movable clamp and rod arrangement we fixed the light source to a pole (of suitable height). Put a protractor at the base of the pole-light arrangement and a laser pointer for accurate angle measurements. The one end of an inextensible rope of length R was tied to the base of light source and the other to the lux meter which measured the illuminance.

By moving the light source up and down by calculated distances using the movable clamp, we changed the latitudinal angle θ by a fixed amount, and by moving the lux meter around with the help of laser fixed protractor, we could change the longitudinal angle φ by a fixed amount. θ can also be defined as the angle between horizontal line passing through lux meter and the line joining lux meter to the centre of light source. And φ as the angle between line joining the pole to the centre of light source and horizontal projection of line joining lux meter to the centre of the light source.

We began observation by keeping the light source and the lux meter at same height from the ground that is θ was 0 □□and taking illuminance readings for different φ values at small intervals (say 10□□(from 0 □□to 360 .□□After a complete set we calculated the height to which we needed to move the light source in order to change θ by a small interval of 10 .□□Then readings for different φ values at small intervals of 10 □□from 0 □□to 360 □□were taken as earlier. The θ values were increased and the corresponding illuminances were measured with changing φ values. Such observations continued till illuminance became zero.

The observed data were plotted on a polar graph to have an idea about directional changes in illuminance at orientation studied (Figures 4, 5 and 7). It may help in correcting design flaws in the luminary.

Now the area of the experimental area is calculated. Since the radius of the virtual sphere was very large, the area element could be considered to be rectangular whose area is equal to the product of (R×θ) and (R×φ). Multiplying each illumination value with area of element and summing up the net upward light due to one light source in lumens and further the upward light ratio. The obtained result can be extended to N number of such sources and also to mixed lighting systems where different type of lights are installed in different numbers. This gives an estimated figure of LP caused by installing N such lights in a particular orientation, before their practical installation.

Results and Discussions:

The illuminance measured by the lux-meter to calculate intensities at various planes for different luminaries are tabulated below. The data were used for computational work and the results are depicted in the form of polar graphs and ULR values for them. We also obtain the intensity versus angle graphs other than polar graphs, to understand the radiance pattern of the luminaries. The plots for LED and tungsten halogen are given below as figure 4 and 5. The pattern obtained is similar to standard intensity pattern for most of the luminaries, with maximum upcast angle corresponding to the maximum intensity of luminaire. The angles have been plotted from 180° – 0° – 170° to show the significant peak in the intensity.

Case 1: High Pressure Sodium Lamp (150 W, 220-240 V, 16000 lumen)

As per the ELCOMAS (Electric Lamp and Component Manufacturers Association of India) Report [7], the high pressure sodium light fixtures were the most commonly used street lights in India. The similar data was also presented by the World Bank in its Energy Efficiency Urban Street Lighting Report in June 2015 [8].

The polar graph plotted using the data for HP sodium lamp is shown in Figure 4. The graph is similar to the candle power distribution curve which is often used by technicians to study the radiance pattern at various heights of the luminaire. The graph is similar in structure but the angles depicting the planes are above the photometric plane. One such example of candle power distribution curve of HPSL is given in Design Of An Energy Efficient Outdoor Night-time Urban Lightening System [10].

At 80°, 140°, 210° and 280° in the lower three planes, a sudden rise in illuminance levels can be observed. By altering the design of the luminary we can reduce the amount of upward light significantly. By comparing this polar graph with the polar graph obtained in case of LED (Figure 5) we can clearly see how poorly efficient HPSL street lights are.

Case 2: LED (36W, 220-240 V, 120 lm/W (4520 lm), type 2 LED fixture)

The LED light studied here was chosen in accordance with Energy Efficient Street Lighting Guidelines issued by USAID and Bureau of Energy Efficiency Government of India [6]. They are typically installed on the side of small streets, jogging paths and entrance roadways.

The observation table to calculate intensities at various planes and the corresponding polar graph for LED street light are shown in Table 2 and figure 5 respectively.

A polar graph plotted from above data has been shown in Figure 5. Negligible amount of upward light was observed for 0° plane. Thus, LEDs were studied at different orientations. The polar graph shows that the LEDs are much more efficient and these leak very little light in unintended directions.

A similar observation can be made from a bar graph given in Figure 6. A very little amount of light escapes upward at zero installation angle, but light pollution level increases rapidly with increase in installation angle.

From Figure 6 and Table 3, it is evident that LED street lights cause very little LP when suspended at 0° inclination from the horizontal. However the pollution level shoots up to two to three times with every five degree increase in angle of inclination.

Case 3: Tungsten Halogen Light (500 W; 220-240 V; 9,500 lumen)

The design of these fixtures was so efficient that no light intensity was observed at planes corresponding to 0° and 5° below the light fixture. Hence, the angle of installation was prioritized while studying the tungsten halogen. These types of fixtures are installed generally at 90° with respect to horizontal as they are commonly used to illuminate large areas. Sometimes they are installed at 45° facing upwards at construction sites or to illuminate large buildings. However, the team calculated the flux when the lamp was installed at 45° facing downwards.

Observations table to calculate intensities at various planes.

A polar graph has been plotted for tungsten halogen light. We can infer from the polar graph that this light like LED street light is also very efficient. But they are usually installed in ways which cause direct light pollution.

A comparative performance of the three luminaries in view of the light pollution has been shown through Table 5.

Angle 0° indicates observations taken along the plane of suspension of the luminary. In case of Tungsten halogen observations at 45°were taken keeping in mind that the lamps are in general installed at 45°with respect to horizontal or even at greater angle as per requirement.

From the result it is clear that HPSL causes maximum light pollution compared to the others. The problem becomes more serious with the fact that these fixtures are installed in maximum number across the country. In a single unit 0.5% of the total light is wasted and proportionately contributing LP. Based on a rough calculation, it is found that all the HPSL fixtures taken together causes an LP equivalent to directly lighting the sky with at least 11000 such street lights alone in Delhi city. This also means a huge wastage of energy when the actual number is considered.

It is evident from the observations that the design needs serious amendments to control the light going upwards. One of the possible solutions to this is to use the reflection shields in the fixture to direct the light at the required area. This will ensure unidirectional radiation of fixture. It was learnt from the LED analysis that installation is a major factor of light pollution. Thus, it is highly recommended to install streetlights at 90° with the vertical axis.

The angles of installations for the HPSL fixture could not be studied as the fixture was damaged. If this factor is to be considered, the lumen loss is sure to be large, which is again a issues of concern.

Analysis based on observations of LED show the efficient design of the fixture. A minimal lumen of value 5.2 escapes above the plane of suspension from the fixture. Still the light pollution factor caused by the LEDs could not be ignored. The angles of installation of fixtures were also studied in this experiment and the same factor was found to be the highest contributor in light pollution. The escaping lumens increased by many folds, each time the angle of fixture was increased. According to the data received from municipal authorities, maximum number of installations is done at 105° with respect to pole in India. Due to these improper installations, 288 lumens are lost into the sky for each fixture. To estimate how big the problem is, assume 900 thousand of LED units installed in Delhi. Out of these, 60,000 fixtures are lighted directly towards the Delhi sky. Hence the installation angle from the horizontal is very critical in regulating the LP.

The tungsten halogen fixture has the most efficient design among all three. There is no light which is going beyond the plane of suspension. Moreover, there is a little flux escaping at 10° in the direction of light source. However, the installation of these fixtures is again a major problem. These lights are mainly used to illuminate large areas or as decorative lights, to illuminate large buildings. Hence, they are setup at an angle convenient to the viewers, ignoring the factor of light pollution. The lumen loss counts are found to be the highest in this fixture, considering the angle of installation. Assuming that the fixture is installed at 45° with respect to horizontal, facing downwards, a total of 2344.3 lumens is lost into the sky. Unfortunately, these fixtures are installed at even worst angles. At construction sites, these are setup either at 90° or 45°. In former case, all the lumens (in this case, 9500) are lost in the space whereas; in latter case more than half of the lumens are lost in the space. This is again a serious contributor in accordance with light pollution.

Conclusion:

As evident from these three experiments, this method can be used as a tool to study various types of outdoor lights except the ones which cause light pollution majorly due to reflection. After calculating amount of light pollution associated with one light source, we can scale it for any number of light sources to be installed in an area. The amount of light pollution calculated may not be perfectly correct as it neglects one component, but it offers a standard procedure in lieu of this compromise. This method can closely predict in advance, the amount of light pollution that may be caused after installing a given type of light source in any given number. Hence, this could become a tool of "Light Pollution Management" for planning observatories, eco-sensitive zones and city lighting.

Figures:

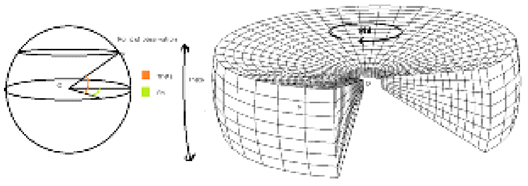

Figure 1: Virtual sphere with latitudinal (θ) and longitudinal (Φ) angles

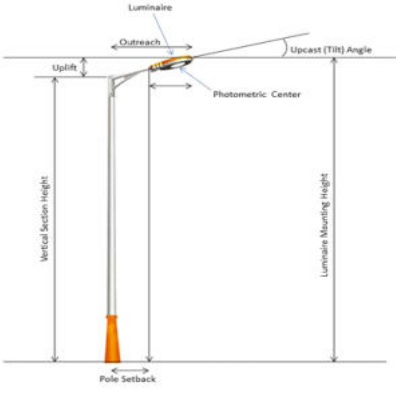

Figure 2: A typical Street Light arrangement

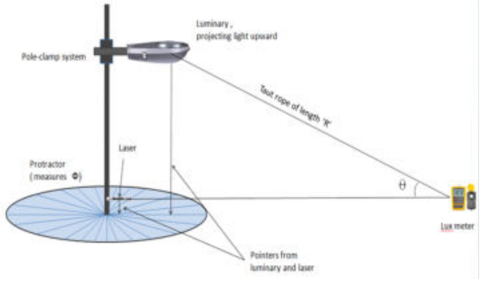

Figure 3: Experimental Setup

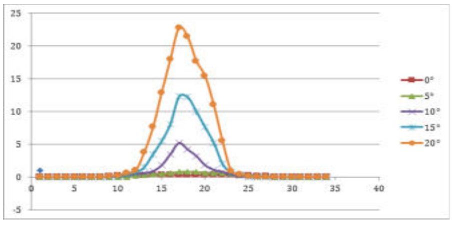

Figure 4 : Intensity v/s angle graph for various upcast angles of LED

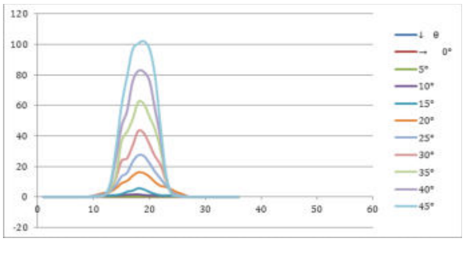

Figure 5 : Intensity v/s angle graph for various upcast angles of tungsten halogen

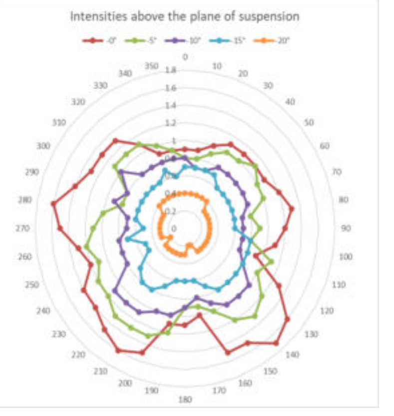

Figure 4: Polar graph for HPSL. These plots can assess the directional distributions[11].

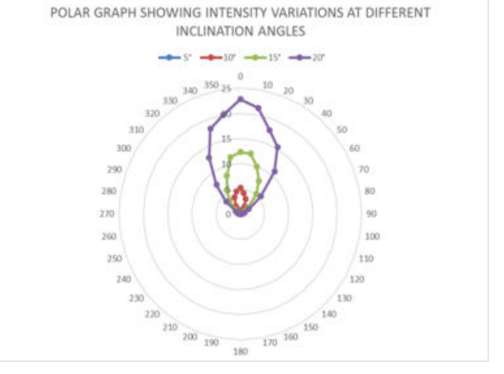

Figure 5: Polar graph for LED lights.[11]

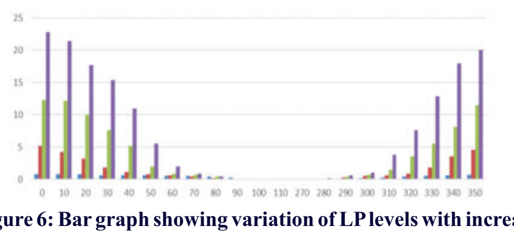

Figure 6: Bar graph showing variation of LP levels with increase in angle of inclination of LEDs with respect to plane of suspension.

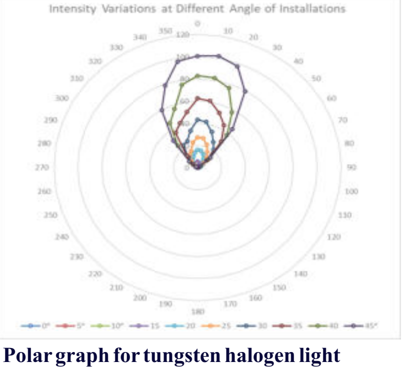

Figure 7: Polar graph for tungsten halogen light

Tables:

Table 1: Experimental data for High Pressure Sodium Light (HPSL) *Minus sign is used to indicate the angle above the plane of suspension.

φ↓	θ→	0°	- 5°	- 10°	- 15°	- 20°
0°		0.9	0.8	0.8	0.7	0.4
10°		0.9	0.8	0.7	0.7	0.4

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20°	1	0.9	0.7	0.7	0.4
30°	1.1	1	0.8	0.7	0.4
40°	1.1	1	0.8	0.6	0.4
50°	1.1	1.1	0.8	0.6	0.3
60°	1.1	1	0.8	0.6	0.3
70°	1.2	1	0.8	0.6	0.3
80°	1.3	0.8	0.7	0.6	0.3
90°	1.2	0.9	0.7	0.6	0.3
100°	1.1	0.8	0.7	0.8	0.3
110°	0.9	1.1	0.7	0.8	0.3
120°	1.3	1	0.8	0.8	0.3
130°	1.6	1.2	1	0.8	0.3
140°	1.7	1.3	1	0.8	0.3
150°	1.5	1.2	1	0.8	0.3
160°	1.5	1	0.9	0.7	0.2
170°	1	0.9	0.8	0.6	0.2
180°	1.1	0.9	0.9	0.6	0.3
190°	1.1	1.2	1	0.6	0.3
200°	1.5	1.3	1	0.7	0.3
210°	1.6	1.3	1.1	0.8	0.3
220°	1.5	1.3	1.1	0.8	0.3
230°	1.4	1.2	1.1	0.7	0.3
240°	1.4	1.2	0.8	0.5	0.2
250°	1.2	1.1	0.8	0.5	0.3
260°	1.3	1.2	0.8	0.7	0.3
270°	1.5	1.1	0.7	0.5	0.3
280°	1.6	1	0.7	0.6	0.3
290°	1.4	0.8	0.9	0.6	0.3
300°	1.3	0.8	0.8	0.6	0.3
310°	1.3	1.1	1	0.6	0.4
320°	1.3	1.1	0.8	0.6	0.4
330°	1.1	1.1	0.8	0.6	0.4
340°	0.9	1	0.8	0.7	0.4
350°	0.9	0.9	0.8	0.6	0.4

Table 2: Experimental data for LED lights

φ ↓ θ →	- 5°	0°	5°	10°	15°	20°
0°	0	0.3	0.8	5.2	12.3	22.8
10°	0	0.3	0.8	4.2	12.2	21.4
20°	0	0.3	0.8	3.2	10	17.7
30°	0	0.3	0.6	1.8	7.6	15.4
40°	0	0.3	0.6	1.1	5.2	11
50°	0	0.3	0.6	0.8	2	5.5
60°	0	0.3	0.5	0.6	0.9	2
70°	0	0.3	0.5	0.4	0.7	0.9
80°	0	0.2	0.4	0.2	0.4	0.4
90°	0	0.2	0.3	0	0.1	0.1
100°	0	0.1	0.1	0	0	0
110°	0	0.1	0.1	0	0	0
120°	0	0	0	0	0	0
130°	0	0	0	0	0	0
140°	0	0	0	0	0	0
150°	0	0	0	0	0	0
160°	0	0	0	0	0	0
170°	0	0	0	0	0	0
180°	0	0	0	0	0	0
190°	0	0	0	0	0	0
200°	0	0	0	0	0	0
210°	0	0	0	0	0	0
220°	0	0	0	0	0	0
230°	0	0	0	0	0	0
240°	0	0	0	0	0	0
250°	0	0	0	0	0	0
260°	0	0	0	0	0	0
270°	0	0.1	0	0	0	0.1
280°	0	0.2	0	0.1	0.1	0.2
290°	0	0.2	0	0.3	0.4	0.6
300°	0	0.3	0.2	0.5	0.7	1
310°	0	0.2	0.3	0.6	1.5	3.8
320°	0	0.3	0.4	0.9	3.5	7.6
330°	0	0.3	0.5	1.8	5.5	12.9
340°	0	0.3	0.6	3.5	8.1	18
350°	0	0.3	0.7	4.6	11.5	20

Table 3

Angle of Inclination	0°	5°	10°	15°	20°
Resultant value of lost lumens	0.00017	0.0004 5	0.0014	0.0041 3	0.00942
Percentage	0.017%	0.045%	0.14%	0.41%	0.942%

Table 4: Experimental data for Tungsten Halogen Light

φ ↓θ →	0^0	5^0	10^0	15^0	20^0□	25^0□	30^0□	35^0	40^0□	45^0□
0^0	0	0.2	1.6	5.6	16.1	27.3	43.2	62.3	82.6	100.5
10^0	0	0.2	1.2	4.9	15.6	26.8	41.7	60.9	81.9	102.1
20^0	0	0.2	1	3.2	13.2	22.1	34.4	52.6	76.2	97.1
30^0	0	0.2	0.9	1.9	9.7	16.4	26.6	44.2	57.3	79.2
40^0	0	0.2	0.8	1	7.2	11.8	20.8	30.7	38.1	45.1
50^0	0	0.2	0.7	0.8	6.4	7.1	10.2	11	13.3	14
60^0	0	0.1	0.7	0.8	4.8	3.2	2.5	1.7	1.9	2.1
70^0	0	0.2	0.6	0.7	2.9	1.3	0.5	0.8	0.6	0.8
80^0	0	0.2	0.5	0.6	1.8	0.8	0.2	0.1	0.2	0.3
90^0	0	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0
100^0	0	0.1	0.1	0	0	0	0	0	0	0
110^0	0	0	0	0	0	0	0	0	0	0
120^0	0	0	0	0	0	0	0	0	0	0
130^0	0	0	0	0	0	0	0	0	0	0
140^0	0	0	0	0	0	0	0	0	0	0
150^0	0	0	0	0	0	0	0	0	0	0
160^0	0	0	0	0	0	0	0	0	0	0
170^0	0	0	0	0	0	0	0	0	0	0
180^0	0	0	0	0	0	0	0	0	0	0
190^0	0	0	0	0	0	0	0	0	0	0
200^0	0	0	0	0	0	0	0	0	0	0
210^0	0	0	0	0	0	0	0	0	0	0
220^0	0	0	0	0	0	0	0	0	0	0
230^0	0	0	0	0	0	0	0	0	0	0
240^0	0	0	0	0	0	0	0	0	0	0
250^0	0	0	0	0	0	0	0	0	0	0
260^0	0	0.1	0.1	0	0	0	0	0	0	0
270^0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0
280^0	0	0.1	0.5	0.5	0.8	0.8	0.1	0.2	0.1	0.1
290^0	0	0.1	0.6	0.7	1.9	1.2	0.2	0.3	0.4	0.6
300^0	0	0.1	0.7	0.9	2.7	1.9	1	1.3	1.2	1.5
310^0	0	0.2	0.8	0.9	3.4	3.5	4.9	5.1	7.9	9
320^0	0	0.2	0.9	1.2	5.6	7.8	12.3	14.1	25.4	31.5
330^0	0	0.2	1.1	1.9	8.9	13.4	23.7	36.4	46.1	59.7
340^0	0	0.2	1.4	3.4	10.5	15.8	25.2	42.7	56.4	78.9
350^0	0	0.2	1.5	4.1	13.8	23.1	33.8	50.9	75.8	96.9

Table 5

Luminaries	Calculated area of element ()	Net flux (lumen)	Lumen loss (lm)	ULR	Percentage loss
HPSL (at)	0.5483	16000	81.1484	0.00507	0.5%
LED (at)	0.1413	4320	5.2	0.00017	0.01%
Tungsten Halogen ()	0.14135	9500	331.965	0.03494	3.5%

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