10. ENERGY PERFORMANCE ASSESSMENT OF LIGHTING SYSTEMS

10.1 Introduction

Lighting is provided in industries, commercial buildings, indoor and outdoor for providing comfortable working environment. The primary objective is to provide the required lighting effect for the lowest installed load i.e highest lighting at lowest power consumption.

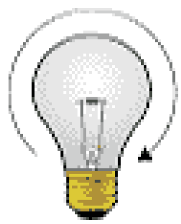
10.2 Purpose of the Performance Test

Most interior lighting requirements are for meeting average illuminance on a horizontal plane, either throughout the interior, or in specific areas within the interior combined with general lighting of lower value.

The purpose of performance test is to calculate the installed efficacy in terms of lux/watt/m² (existing or design) for general lighting installation. The calculated value can be compared with the norms for specific types of interior installations for assessing improvement options.

The installed load efficacy of an existing (or design) lighting installation can be assessed by carrying out a survey as indicated in the following pages.

10.3 Performance Terms and Definitions



Lumen is a unit of light flow or luminous flux. The lumen rating of a lamp is a measure of the total light output of the lamp. The most common measurement of light output (or luminous flux) is the lumen. Light sources are labeled with an output rating in lumens.

Lux is the metric unit of measure for illuminance of a surface. One lux is equal to one lumen per square meter.

Circuit Watts is the total power drawn by lamps and ballasts in a lighting circuit under assessment.

Installed Load Efficacy is the average maintained illuminance provided on a horizontal working plane per circuit watt with general lighting of an interior. **Unit: lux per watt per square metre (lux/W/m²)**

Lamp Circuit Efficacy is the amount of light (lumens) emitted by a lamp for each watt of power consumed by the lamp circuit, i.e. including control gear losses. This is a more meaningful measure for those lamps that require control gear. **Unit: lumens per circuit watt (lm/W)**

Installed Power Density. The installed power density per 100 lux is the power needed per square metre of floor area to achieve 100 lux of average maintained illuminance on a horizontal working plane with general lighting of an interior. Unit: watts per square metre per 100 lux ($W/m^2/100$ lux)

$$\text{Installed power density } (W/m^2/100 \text{ lux}) = \frac{100}{\text{Installed load efficacy } (lux/W/m^2)}$$

Installed Load Efficacy Ratio (**ILER**)

$$= \frac{\text{Actual Lux}/W/m^2}{\text{Target Lux}/W/m^2} \quad \text{or} \quad \frac{\text{Target } W/m^2/100lux}{\text{Actual } W/m^2/100lux}$$

Average maintained illuminance is the average of lux levels measured at various points in a defined area.

Color Rendering Index (CRI) is a measure of the effect of light on the perceived color of objects. To determine the CRI of a lamp, the color appearances of a set of standard color chips are measured with special equipment under a reference light source with the same correlated color temperature as the lamp being evaluated. If the lamp renders the color of the chips identical to the reference light source, its CRI is 100. If the color rendering differs from the reference light source, the CRI is less than 100. A low CRI indicates that some colors may appear unnatural when illuminated by the lamp.

10.4 Preparation (before Measurements)

Before starting the measurements, the following care should be taken:

- All lamps should be operating and no luminaires should be dirty or stained.
- There should be no significant obstructions to the flow of light throughout the interior, especially at the measuring points.
- Accuracies of readings should be ensured by
  - Using accurate illuminance meters for measurements
  - Sufficient number and arrangement of measurement points within the interior
  - Proper positioning of illuminance meter
  - Ensuring that no obstructions /reflections from surfaces affect measurement.
- Other precautions
  - If the illuminance meter is relatively old and has not been checked recently, it should be compared with one that has been checked over a range of illuminances, e.g. 100 to 600 lux, to establish if a correction factor should be applied.
  - that the number and arrangement of measurement points are sufficient and suitable to obtain a reasonably accurate assessment of the average illuminance throughout an interior. The procedure recommended in the CIBSE Code for such site measurements is as follows:

The interior is divided into a number of equal areas, which should be as square as possible. The illuminance at the centre of each area is measured and the mean value calculated. This gives an estimate of the average illuminance on the horizontal working plane.

10.5 Procedure for Assessment of Lighting Systems

10.5.1 To Determine the Minimum Number and Positions of Measurement Points

Calculate the Room Index: $RI = \dfrac{L \times W}{Hm(L + W)}$

Where L = length of interior; W = width of interior; Hm = the mounting height, which is the height of the lighting fittings above the horizontal working plane. The working plane is usually assumed to be 0.75m above the floor in offices and at 0.85m above floor level in manufacturing areas.

It does not matter whether these dimensions are in metres, yards or feet as long as the same unit is used throughout. Ascertain the minimum number of measurement points from Table10.1.

TABLE 10.1 DETERMINATION OF MEASUREMENT POINTS

Room Index	Minimum number of measurement points
Below 1	9
1 and below 2	16
2 and below 3	25
3 and above	36

To obtain an approximately "square array", i.e. the spacing between the points on each axis to be approximately the same, it may be necessary to increase the number of points.

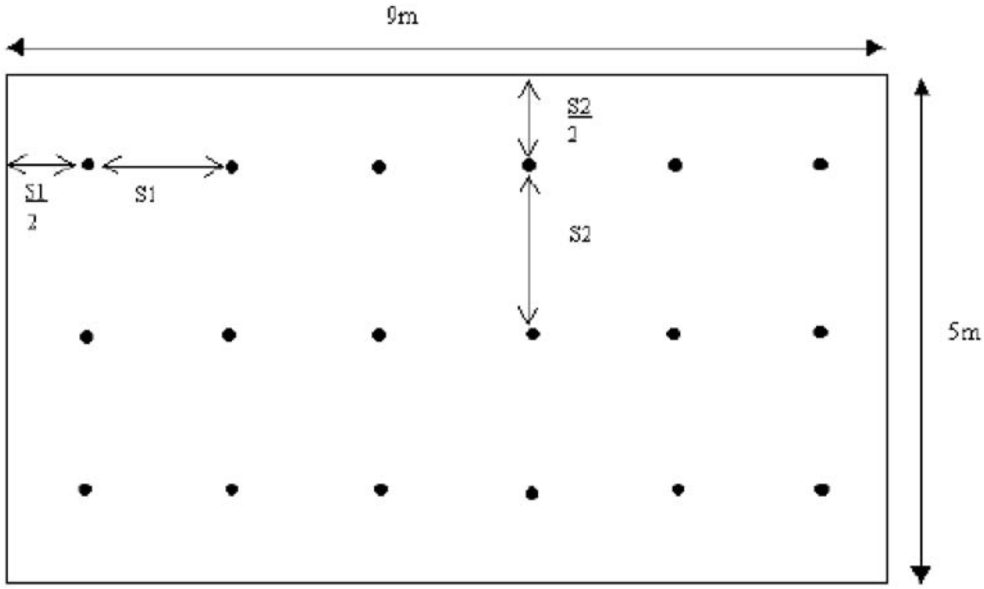
For example, the dimensions of an interior are:

Length = 9m, Width = 5m, Height of luminaires above working plane (Hm) = 2m

Calculate $RI = \dfrac{9 \times 5}{2(9 + 5)} = 1.607$

From Table 10.1 the minimum number of measurement points is 16

As it is not possible to approximate a "square array" of 16 points within such a rectangle it is necessary to increase the number of points to say 18, i.e. 6 x 3. These should be spaced as shown below:



Therefore in this example the spacing between points along rows along the length of the interior = 9 ÷ 6 = 1.5m and the distance of the 'end' points from the wall = 1.5 ÷ 2 = 0.75m.

Similarly the distance between points across the width of the interior = 5 ÷ 3 = 1.67m with half this value, 0.83m, between the 'end' points and the walls.

If the grid of the measurement points coincides with that of the lighting fittings, large errors are possible and the number of measurement points should be increased to avoid such an occurrence.

10.5.2 Calculation of the Installed Load Efficacy and Installed Load Efficacy Ratio of a General Lighting Installation in an Interior

STEP 1	Measure the floor area of the interior:	Area = -------------------- m²
STEP 2	Calculate the Room Index	RI = -----------------------
STEP 3	Determine the total circuit watts of the installation by a power meter if a separate feeder for lighting is available. If the actual value is not known a reasonable approximation can be obtained by totaling up the lamp wattages including the ballasts:	Total circuit watts = --------
STEP 4	Calculate Watts per square metre, Value of step **3** ÷ value of step 1	W/m² = ----------------------
STEP 5	Ascertain the average maintained illuminance by using lux meter, Eav. Maintained	Eav.maint. = ----------------
STEP 6	Divide **5** by **4** to calculate lux per watt per square Metre	Lux/W/m² = ---------------
STEP 7	Obtain target Lux/W/m² lux for type of the type of interior/application and RI (2):	Target Lux/W/m² =
STEP 8	Calculate **I**nstalled **L**oad **E**fficacy **R**atio (**6** ÷ **7**).	ILER =

TABLE 10.2 Target lux/W/m² (W/m²/100lux) values for maintained illuminance on horizontal plane for all room indices and applications:

Room Index	Commercial lighting, (Offices, Retail stores etc.) & very clean industrial applications, Standard or good colour rendering. Ra: 40-85	Industrial lighting (Manufacturing areas, Workshops, Warehousing etc.) Standard or good colour rendering. Ra: 40-85	Industrial lighting installations where standard or good colour rendering is not essential but some colour discrimination is required. Ra: 20-40
5	53 (1.89)	49 (2.04)	67 (1.49)
4	52 (1.92)	48 (2.08)	66 (1.52)
3	50 (2.00)	46 (2.17)	65 (1.54)
2.5	48 (2.08)	44 (2.27)	64 (1.56)
2	46 (2.17)	42 (2.38)	61 (1.64)
1.5	43 (2.33)	39 (2.56)	58 (1.72)
1.25	40 (2.50)	36 (2.78)	55 (1.82)
1	36 (2.78)	33 (3.03)	52 (1.92)

Ra : Colour rendering index

The principal difference between the targets for Commercial and Industrial Ra: 40-85 (Cols.2 & 3) of Table 10.2 is the provision for a slightly lower maintenance factor for the latter. The targets for very clean industrial applications, with Ra: of 40 -85, are as column 2.

10.5.3 ILER Assessment

Compare the calculated ILER with the information in Table 10.3.

TABLE 10.3 INDICATORS OF PERFORMANCE

ILER	*Assessment*
0.75 or over	*Satisfactory to Good*
0.51 – 0.74	*Review suggested*
0.5 or less	*Urgent action required*

ILER Ratios of 0.75 or more may be considered to be satisfactory. Existing installations with ratios of 0.51 - 0.74 certainly merit investigation to see if improvements are possible. Of course there can be good reasons for a low ratio, such as having to use lower efficacy lamps or less efficient luminaires in order to achieve the required lighting result -but it is essential to check whether there is a scope for a more efficient alternative. Existing installations with an ILER of 0.5 or less certainly justify close inspection to identify options for converting the installation to use more efficient lighting equipment.

Having derived the ILER for an existing lighting installation, then the difference between the actual ILER and the best possible (1.0) can be used to estimate the energy wastage. For a given installation:

Annual energy wastage (in kWh)
= (1.0 - ILER) x Total load (kW) x annual operating hours (h)

This process of comparing the installed load efficacy (ILE) with the target value for the Room Index and type of application can also be used to assess the efficiency of designs for new or replacement general lighting installations. If, when doing so, the calculated ILE (lux/W/m²) is less than the target value then it is advisable to ascertain the reasons. It may be that the requirements dictate a type of luminaire that is not as efficient as the best, or the surface reflectances are less than the normal maxima, or the environment is dirty, etc., Whatever the reasons, they should be checked to see if a more efficient solution is possible.

10.6 Example of ILER Calculation (for the room as mentioned in paragraph 10.5.1)

STEP 1	Measure the floor area of the interior:	Area = 45 m²
STEP 2	Calculate the Room Index	RI = 1.93
STEP 3	Determine the total circuit watts of the installation by a power meter if a separate feeder for lighting is available. If the actual value is not known a reasonable approximation can be obtained by totaling up the lamp wattages including the ballasts:	Total circuit watts = 990 W
STEP 4	Calculate Watts per square metre, **3 ÷1** :	W/m² = 22
STEP 5	Ascertain the average maintained illuminance, Eav. Maintained (average lux levels measured at 18 points)	Eav.maint. = 700
STEP 6	Divide **5** by **4** to calculate the actual lux per watt per square Metre	Lux/W/m² = 31.8
STEP 7	Obtain target Lux/W/m² lux for type of the type of interior/ application and RI (2):(Refer Table 10.2)	Target Lux/W/m² = 46
STEP 8	Calculate **I**nstalled **L**oad **E**fficacy **R**atio (**6** ÷ **7**).	ILER = 0.7

Referring to table 3, ILER of 0.7 means that there is scope for review of the lighting system.

Annual energy wastage = (1 - ILER) x watts x no. of operating hours
= (1 - 0.7) x 990 x 8 hrs/day x 300 days
= 712 kWh/annum

10.7 Areas for Improvement

- Look for natural lighting opportunities through windows and other openings
- In the case of industrial lighting, explore the scope for introducing translucent sheets
- Assess scope for more energy efficient lamps and luminaries
- Assess the scope for rearrangement of lighting fixtures

10.8 Other Useful Information

10.8.1 IES - Recommendations

The Illuminating Engineering Society (IES) has published illuminance recommendations for various activities. These tables cover both generic tasks (reading, writing etc), and 100's of very specific tasks and activities (such as drafting, parking, milking cows, blowing glass and baking bread).

All tasks fall into 1 of 9 illuminance categories, covering from 20 to 20,000 lux, (2 to 2000 foot candles). The categories are known as A - I, and each provide a range of 3 iluminance values (low, mid and high). See Table 10.4.

TABLE 10.4 IES ILLUMINANCE CATEGORIES AND VALUES - FOR GENERIC INDOOR ACTIVITIES

ACTIVITY	CATEGORY	LUX	FOOTCANDLES
Public spaces with dark surroundings	**A**	20-30-50	2-3-5
Simple orientation for short temporary visits	**B**	50-75-100	5-7.5-10
Working spaces where visual tasks are only occasionally performed	**C**	100-150-200	10-15-20
Performance of visual tasks of high contrast or large size	**D**	200-300-500	20-30-50
Performance of visual tasks of medium contrast or small size	**E**	500-750-1000	50-75-100
Performance of visual tasks of low contrast or very small size	**F**	1000-1500-2000	100-150-200
Performance of visual tasks of low contrast or very small size over a prolonged period	**G**	2000-3000-5000	200-300-500
Performance of very prolonged and exacting visual tasks	**H**	5000-7500-10000	500-750-1000
Performance of very special visual tasks of extremely low contrast	**I**	10000-15000-20000	1000-1500-2000

A-C for illuminances over a large area (i.e. lobby space)

D-F for localized tasks

G-I for extremely difficult visual tasks

10.8.2 Example Using IES Recommendations

Let us determine the appropriate light level for a card file area in a library.

Step 1: The visual task is reading card files in a library. A number of tasks are accomplished in the room. In such a cases, a category is chosen based on the generic descriptions in the IES Illuminance Category and Illuminance table discussed in step 3. For example, offices will usually require Category E: 500-750-1000 lux.

Step 2: More detailed task descriptions are given in the recommended illuminance level tables in the IES Handbook. (For an intensive lighting survey) Under the task category "Libraries," subheading "Card files," the illuminance category is E.

Step 3: From the IES Illuminance Category and Ranges table, find category E and choose 500-750-1000 lux for the range of illuminance recommended. The first column in the table is illuminance values in units of lux, the metric version of footcandle. Notice that categories A through C are for general illumination throughout the area, but D through I are for illuminance on the task. Categories G through I would require a combination of general lighting and task lighting.

Step 4: Use the weighting factors to decide which of the values in the illuminance range to use. Since libraries are public facilities, there may be many individuals over 55 years of age so select the category 'Over 55' for a weighting factor of +1.

Next, decide whether the demand for speed and accuracy is not important, important or critical. Filing of cards correctly is not a critical activity, so the weighting factor of zero (0) is selected. An example of critical might be drafting work. The task background reflectance for black type on a white page is 85%. So choose "greater than 70 percent" for a weighting factor of -1. The total weighting factor is 0. So use the middle recommended illuminance, or 750 lux.

For more detailed information on this the IES handbook may be referred.

10.8.3 Characteristics of Different Types of Lamps

Type of Lamp	Lamp Wattage (Watts)	Lumens	Lamp Efficiency (Lumens/Watt)	Choke Rating (Watts)	Life of Lamp (Hours)	Capacitor Rating Required (Micro farads)	Color Rendering Index
HPSV	70	5600	80	13	15000 - 20000	0.2 - 0.39	12
HPSV	150	14000	93	20	15000 - 20000	0.2 - 0.39	20
HPSV	250	25000	100	20	15000 - 20000	0.2 - 0.39	32
HPSV	400	47000	118	40	15000 - 20000	0.2 - 0.39	45
HPSV Super	70	---	---	---	---	---	---
HPSV Super	100	9500	95	18	15000 - 20000	0.2 - 0.39	---
HPSV Super	150	15500	103	20	15000 - 20000	0.2 - 0.39	---
HPSV Super	250	30000	120	25	15000 - 20000	0.2 - 0.39	---
HPSV	400	54000	129	40	15000 -	0.2 - 0.39	---

Super					20000		
HPSV Super	600	---	---	---	---	---	---
HPMV	80	3400	43	9	4000 - 5000	0.6 - 0.69	8
HPMV	125	6300	50	12	4000 - 5000	0.6 - 0.69	10
HPMV	250	13000	52	16	4000 - 5000	0.6 - 0.69	18
HPMV	400	22000	55	25	4000 - 5000	0.6 - 0.69	18
Metal Halide	70	4200	84	26	10000	0.9 - 0.93	---
Metal Halide	150	10500	70	20	10000	0.9 - 0.93	---
Metal Halide	250	19000	76	25	10000	0.9 - 0.93	---
Metal Halide	400	31000	76	60	10000	0.9 - 0.93	---
Metal Halide	1000	80000	80	65	10000	0.9 - 0.93	---
FTL	40	2400	60	15	4400	0.8 - 0.89	3.2 - 3.8
FTL Super	36	3250	90	5	14000	0.8 - 0.89	3.2 - 3.8

QUESTIONS	
1)	What is circuit watts?
2)	Define ILER and its significance.
3)	Distinguish between lux and lumens.
4)	What do you understand by the term colour rendering index?
5)	Define room index?
6)	For a room of length 10 m and width 20 m, calculate room index?
7)	For a room of 9 x 6 m, determine the appropriate number of measuring points for lux levels?
8)	What possible improvement measures you would look for in a general lighting system?
9)	Which of the following lamps has the maximum lamp efficiency? (lumes/Watt) a) Metal Hallide b) Fluorescent c) Incandescent d) HPSV

REFERENCES

1. Illumination engineering for energy efficient luminous environments by Ronald N. Helms, Prentice-Hall, Inc.
2. The 'LIGHTSWITCH' programme, Energy Saving Trust, UK