

# BEE CODE

# LIGHTING

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# CONTENTS

<b>1</b>	<b>OBJECTIVE &amp; SCOPE</b> .....	<b>3</b>
1.1	OBJECTIVE.....	3
1.2	SCOPE.....	3
<b>2</b>	<b>DEFINITIONS AND DESCRIPTION OF TERMS</b> .....	<b>4</b>
2.1	BASIC UNITS AND SYMBOLS.....	4
2.2	DESCRIPTION OF TERMS.....	4
<b>3</b>	<b>GUIDING PRINCIPLES</b> .....	<b>6</b>
3.1	PRINCIPLE.....	6
3.2	PRE-TEST REQUIREMENTS.....	6
3.3	PRECAUTIONS.....	7
<b>4</b>	<b>INSTRUMENTS AND METHODS OF MEASUREMENTS</b> .....	<b>8</b>
4.1	MEASUREMENT/ESTIMATION OF PARAMETERS.....	8
4.2	ILLUMINANCE MEASUREMENTS.....	8
4.3	POWER MEASUREMENTS.....	9
4.4	SUMMARY OF INSTRUMENT ACCURACIES.....	9
<b>5</b>	<b>COMPUTATION OF RESULTS</b> .....	<b>10</b>
5.1	MEASUREMENT OF ILLUMINANCE, CIRCUIT POWER AND INSTALLED LOAD EFFICACY RATIO.....	10
5.2	ESTIMATING TASK LIGHTING EFFECTIVENESS (DIVERSITY RATIO).....	11
5.3	SAMPLE CALCULATION.....	12
<b>6</b>	<b>FORMAT OF TEST RESULTS</b> .....	<b>15</b>
6.1	FORMAT OF MEASUREMENTS & CALCULATIONS.....	15
<b>7</b>	<b>UNCERTAINTY ANALYSIS</b> .....	<b>16</b>
7.1	INTRODUCTION.....	16
7.2	METHODOLOGY.....	16
7.3	UNCERTAINTY EVALUATION.....	18
<b>8</b>	<b>GUIDELINES FOR IDENTIFYING ENERGY SAVING OPPORTNITIES</b> .....	<b>19</b>
	<b>ANNEXURE-1: RECOMMENDED ILLUMINANCE LEVELS</b> .....	<b>20</b>
	<b>ANNEXURE-2: REFERENCES</b> .....	<b>27</b>

List of Tables

TABLE 2-1:	BASIC UNITS AND SYMBOLS.....	4
TABLE 2-2:	SUBSCRIPTS.....	4
TABLE 4-1:	CORRECTION FACTORS FOR LUX METERS.....	8
TABLE 4-2:	NUMBER OF POINTS FOR MEASURING ILLUMINANCE.....	9
TABLE 4-3:	SUMMARY OF INSTRUMENT ACCURACY.....	9
TABLE 5-1:	RECOMMENDED TLE VALUES.....	11
TABLE 5-2:	INDICATORS OF PERFORMANCE BASED ON ILER.....	11
TABLE 5-3:	ESTIMATION OF ROOM INDEX & ILLUMINANCE MEASUREMENT GRID.....	12
TABLE 5-4:	ESTIMATION OF ILER AND DIVERSITY RATIO.....	13
TABLE 7-1:	UNCERTAINTY EVALUATION SHEET-1.....	17
TABLE 7-2:	UNCERTAINTY EVALUATION SHEET-2.....	17
TABLE 7-3:	UNCERTAINTY EVALUATION SHEET-3.....	17
TABLE 7-4:	INSTRUMENT ACCURACY TABLE.....	18

# 1 OBJECTIVE & SCOPE

## 1.1 Objective

- ❑ To determine the overall energy efficiency of lighting systems using measurements and methods suitable for field conditions.
- ❑ To determine the energy efficiency of lighting with respect to the illuminance available at task areas and non-task areas.
- ❑ To recommend illuminance levels suitable for various activities
- ❑ To provide guidelines for identifying energy saving options in lighting

## 1.2 Scope

**1.2.1** This code defines and describes the methods for evaluating energy efficiency of indoor lighting systems in the following end user categories.

1. Industrial buildings
2. Hospitals
3. Hotels
4. Commercial buildings

**1.2.2** The following standards have been referred for preparing this code.

1. IS 3646: Code of practice for interior illumination- July 1991
2. IS 6665: Code of practice for industrial lighting – May 1997
3. SP: 32 Handbook on functional requirements of Industrial Buildings- 1986 (BIS publication)
4. CIBSE Code for Interior Lighting- Chartered Institution of Building Service Engineers - UK
5. IES-ASHRAE Standard 90.1
6. Code of practice for Energy Efficiency of Lighting Installations- EMCD – The Govt. of Hongkong S.A. R

**1.2.3** Efficiency evaluation of lighting system defined and described in this code includes the Measurement of following parameters.

1. Illuminance levels
2. Power consumption in light fittings
3. Building parameters like area, room index etc.

## 2 DEFINITIONS AND DESCRIPTION OF TERMS

### 2.1 Basic Units and Symbols

The basic units and symbols used in this code are given in Table-2.1.

*Table 2-1: Basic Units and Symbols*

Symbol	Description	Units
P	Power	Watts
U	Terminal r.m.s. Voltage	V
I	Current	A
Φ	Luminous Flux	lm
E	Illuminance	lux
K	Luminous efficacy	lm/W
L	Length of space	m
W	Width of space	m
H	Height of fixture from the plane of measurement	m
A	Area	m <sup>2</sup>

Table 2.2 gives description of subscripts

*Table 2-2: Subscripts*

Symbol	Description
m	Measured value
R	Rated value
av	Average value

### 2.2 Description of terms

**Circuit watts:** Total power consumption of lamps plus ballasts in the lighting feeder/circuit under consideration

**Color Rendering Index (CRI)** is a measure of the effect of light on the perceived color of objects. A low CRI indicates that some colors may appear unnatural when illuminated by the lamp.

**Installed Load Efficacy:** This is the average maintained illuminance provided on a horizontal working plane per circuit watt with general lighting of an interior expressed in **lux/W/m<sup>2</sup>**

**Installed Load efficacy ratio:** This is the ratio of Target Load efficacy and Installed load efficacy.

**Lumen:** Unit of luminous flux; the flux emitted within a unit solid angle by a point source with a uniform luminous intensity of one candela. One lux is one lumen per square meter.

**Luminaire:** A luminaire is a complete lighting unit, consisting of a lamp or lamps together with the parts designed to distribute the light, position and protect the lamps, and connect the lamps to the power supply.

**Lux: This** is the metric unit of measure for illuminance of a surface. Average maintained illuminance is the average of lux levels measured at various points in a defined area. One lux is equal to one lumen per square meter.

**Mounting height:** The height of the fixture or lamp above the working plane.

**Rated luminous efficacy:** The ratio of rated lumen output of the lamp and the rated power consumption expressed in lumens per watt.

**Room Index:** This is a ratio, which relates the plan dimensions of the whole room to the height between the working plane and the plane of the fittings.

**Target Load Efficacy:** The value of Installed load efficacy considered being achievable under best efficiency, expressed in lux/W/m<sup>2</sup>

**Utilisation factor (UF):** This is the proportion of the luminous flux emitted by the lamps, which reaches the working plane. It is a measure of the effectiveness of the lighting scheme.

## 3 GUIDING PRINCIPLES

### 3.1 Principle

- ❑ The efficiency of a light source is indicated by luminous efficacy, lm/Watt. Manufacturers usually give this value after testing the lamps at laboratories. It is difficult to establish the luminous efficacy value of lamps at site conditions.
- ❑ All the light emitted by the lamp does not reach the work area. Some light is absorbed by the luminaire, walls, floors & roof etc. The illuminance measured, in lumens/m<sup>2</sup> i.e. lux, indicates how much light i.e. lumens is available per sq. metre of the measurement plane.
- ❑ Target luminous efficacy (lm/Watts) of the light source is the ratio of lumens that can be made available at the work plane under best luminous efficacy of source, room reflectance, mounting height and the power consumption of the lamp circuit. Ideally, we would expect the target luminous efficacy to be available on the work plane.
- ❑ However, over a period of time the light output from the lamp gets reduced, room surfaces becomes dull, luminaires becomes dirty and hence the light available on the work plane deviates from the target value. The ratio of the actual luminous efficacy on the work plane and the target luminous efficacy at the work plane is the Installed Load Efficacy Ratio (ILER).
- ❑ A second aspect of efficiency of utilisation is to take into account, the light available at task and non-task areas. Usually for commercial areas, the recommended illuminance at the non-task areas is at least one-third of the average task illuminance, while keeping a minimum illuminance required at the horizontal plane to be 20 lux. From illuminance measurements the ratio of illuminance at non task areas and task areas can be estimated to understand whether the non-task illuminance level is more than required or not.
- ❑ Illuminance levels recommended at various work spaces are given in Annexure-1.

### 3.2 Pre-test Requirements

- ❑ Measurement of illuminance in an electrical lighting system should be done after dark. This is essential especially in outdoor installations. For indoor lighting, measurements with lights ON and Lights OFF technique can be followed provided the daylight variation is not too much and the survey time is not too long.
- ❑ In an installation of fluorescent discharge lamps, the lamps must be switched on at least 30 minutes before the measurement to allow for the lamps to be completely warmed up.
- ❑ In many situations, the measuring plane may not be specified or even non-existent. Hence it is necessary to define measurement height, typically 0.8 to 1 meter from the ground or floor level.
- ❑ Stray light from surrounding rooms, spaces and through external windows should be minimised by use of blinds, curtains, etc.
- ❑ Any automatic lighting control or daylight linked controls should be set such that the output of the lamps is at full power and will not vary during the tests. All lighting in the area that would normally illuminate the area test grid should be operating.
- ❑ It is convenient to have a second person recording the readings called out by the person moving the photocell.

### **3.3 Precautions**

- ❑ Care must be taken not to shadow the photocell when making measurements.
- ❑ In single-phase supply of power for lighting in an area, when measuring lamp circuit power using a clamp on type meter, measure the power preferably on the phase conductor. If current/power is measured on the main cable, which encloses both phase and neutral conductors, the current and power will indicate zero.

## 4 INSTRUMENTS AND METHODS OF MEASUREMENTS

### 4.1 Measurement/estimation of parameters

The measurement of following parameters is required.

1. Illuminance
2. Power input
3. Length & width of room, Mounting height

### 4.2 Illuminance measurements

#### 4.2.1 Instruments

Lux meters corrected for V-lambda should be used for measurement of illuminance. The accuracy of 5% and suitable range up to 10000 lux should be used.

Usually lux meters are calibrated under the “standard light tungsten source of 2856 K” precisely. If these are used under different type of light source, the following correction factor is used on the measured value of lux.

Table 4-1: Correction factors for lux meters

Light source	Correction factor
Mercury Lamp	X 1.14
Fluorescent Lamp	X 1.08
Sodium Lamp	X 1.22
Daylight	X 1.00
Metal halide	X 1.00

The above corrections factors are dependent on the type of lux meter used. Actual figures for the type of instrument used for measurement will be available in the calibration certificate.

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.

#### 4.2.2 Determination of Illuminance measurement points

Based on the room index, the minimum number of illuminance measurement points is decided as per the following table 4.2.

$$\text{Room index, RI} = \frac{L \times W}{H_m \times (L + W)}$$

Where L = Length

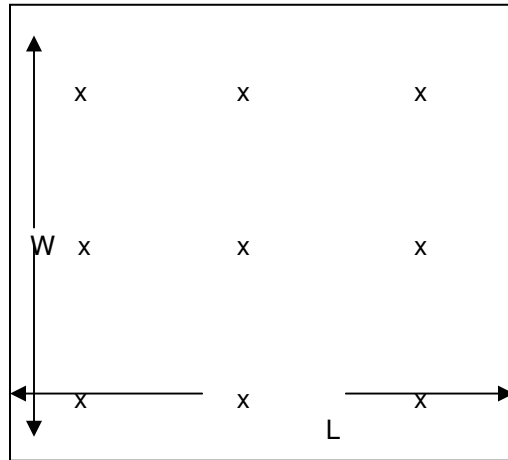
W = Width

H<sub>m</sub> = Height of the luminaires above the plane of measurement



Table 4-2: Number of points for measuring illuminance

Room index	Minimum number of measurement points	
	For $\pm 5\%$ accuracy	For $\pm 10\%$ accuracy
RI < 1	8	4
1 < RI < 2	18	9
2 < RI < 3	32	16
RI > 3	50	25



For a space having length  $L = 5\text{ m}$ , width  $W = 5\text{ m}$  and lamp mounting height of  $2.6\text{ m}$ ,  $RI = 0.96$  i.e. there must be at least 8 measurement points. In figure above, 9 points are selected in view of the symmetry of the space.

The measurement grid should be positioned to cover a representative area of the working plane. To accurately determine the illuminance on the working plane, the greater the number of measurement points the better. This will account for any wide variations of illuminance in calculation of the average.

### 4.3 Power measurements

Portable power analysers of preferably  $\pm 1.0\%$  error or less can be used for power measurements.

If power to all the lamps for an area is supplied from a single source/panel, measurement can be done at the panel. If power to the lamps is supplied from many points, we recommend measuring the power consumption of as many fittings as possible and then estimating the total power consumption by extrapolation.

### 4.4 Summary of instrument accuracies

The table given below summarises accuracy requirements of various instruments.

For calibrating various instruments, visit [www.nabl-india.org](http://www.nabl-india.org) for a detailed list of accredited laboratories. Calibration interval suggested for instruments is 6 months.

Table 4-3: Summary of instrument accuracy

Instrument and range	Accuracy
Power	1.0%
Voltage	0.5%
Illuminance	5%

## 5 COMPUTATION OF RESULTS

### 5.1 Measurement of Illuminance, Circuit Power and Installed Load Efficacy Ratio

Chronological order of measurements and calculations are as follows.

**To estimate average illuminance and total lumens available on measurement plane:**

1. Read and comply with the pre-test requirements explained in section 3.2
2. Define workspace where evaluation is to be done, say an office room, restaurant etc.
3. Measurement of room length 'L', width 'W' and mounting height 'H<sub>m</sub>'
4. Calculate of room index Room Index,  $RI = \frac{L \times W}{H_m \times (L + W)}$
5. Based on Room Index, determine the minimum number of illuminance measurement points required and distribute these points evenly in the room. Refer section 4.2.2.
6. Measure illuminance using a calibrated lux meter at each point. Calculate the average value of measured illuminance at all points. If E<sub>1</sub>, E<sub>2</sub>,..., E<sub>n</sub> are illuminance measurements at points 1,2,...., n

$$\text{Average illuminance, } E_{av} = \frac{E_1 + E_2 + E_3 + \dots + E_n}{N} \times \text{correction factor}$$

The correction factor is given in table 4.1 for different types of lamps.

7. Multiply average illuminance with the area to get total luminous flux (lumens) incident on the measurement plane.

$$\begin{aligned} \text{Total available lumens on the measurement plane} &= \text{Average illuminance} \times (L \times W) \\ \text{i.e. } \phi_m &= E_{av} \times L \times W \end{aligned}$$

$$\text{Installed Load Efficacy, ILE} = \frac{\text{Average luminous flux on the surface}}{\text{Circuit watts}}, \text{ lm/W}$$

**To estimate total circuit power consumption:**

8. Measure power consumption of lamps. If all lamps are supplied from a single source of power, total power of all light fittings can be measured. If total power is not measurable, try to measure power consumption of at least 1 or 2 lamps and calculate the total power consumption.

**To estimate Target Installed Load Efficacy:**

9. The values of target installed load efficacy, TLE, is given in table 5.1 for different types of applications and room index values.
10. From the estimated Room Index, find out the corresponding TLE for the type of installation from table 5.1.

Table 5-1: Recommended TLE values

Room index	Commercial & clean industrial areas such as offices, retail stores, hospitals, hotels, control rooms. Requirement of standard or good colour rendering. CRI = 40-85	Industrial lighting (manufacturing areas, work shops, warehousing etc.) Requirement of standard colour rendering. CRI = 40-85	Industrial lighting (Areas where colour rendering is not essential, but some colour discrimination is required) CRI=20-40
1	36	33	52
1.25	40	36	55
1.5	43	39	58
2	46	42	61
2.5	48	44	64
3	50	46	65
4	52	48	66
5	53	49	67

### To Estimate ILER:

The Installed load efficacy ratio, ILER =  $\frac{\text{Installed load efficacy}}{\text{Target Installed Load efficacy}}$

ILER indicates the efficiency of lighting end use. The following table 5.2 can be used to qualify comments.

Table 5-2: Indicators of performance based on ILER

ILER	Assessment
0.75 or above	Satisfactory to good
0.51 to 0.74	Review suggested
0.5 or less	Urgent action required

The reasons for ILER to be lower than desired can be due to any of the following.

1. Inefficient lamps and/or ballasts
2. Mounting height of lamps too high
3. Reflectors of poor luminaire efficiency
4. Maintenance of reflectors not proper due to dirt/dust accumulation
5. Poor Maintenance of wall, floor and roof reflectance levels
6. Reduction in light output of lamps over time due to lumen depreciation
7. Low voltage

## 5.2 Estimating Task Lighting Effectiveness (Diversity Ratio)

Estimation of task lighting effectiveness involves measurement of illuminance on task and non-task areas. The diversity ratio is the ratio of average illuminance on task area and average illuminance on non-task area and is expected to be 3:1 for effective task lighting for usual commercial areas. For fine reading applications requiring lumens more than 700 lux, this ratio can be 10:1.

Chronological order of measurements and calculation is as follows.

1. The calculation of effectiveness of task lighting is given for illuminance upto 300 lux, which is a good lighting level for usual commercial tasks, manufacturing areas etc. From the illuminance measurements as described in section 4.2.2, estimate the average illuminance on task areas and average illuminance on no-task areas separately.
2. If task area =  $A_{\text{task}}$  and non-task area =  $A_{\text{non-task}}$ ,

The number of illuminance measurements points on task areas

$$= \frac{A_{\text{task}}}{(A_{\text{task}} + A_{\text{non-task}})} \times \text{Total number of illuminance measurement points as per Table 4.2}$$

It is recommended to take measurements at more number of points additionally to improve accuracy.

3. Measure illuminance at task & non task areas
4. Calculate the diversity ratio  $E_{\text{av-task}} : E_{\text{av-non task}}$  .

$E_{\text{av-task}}$  = Average illuminance on task area

$E_{\text{av-non task}}$  = Average illuminance on non-task area

If Diversity Ratio =  $E_{\text{av-task}} : E_{\text{av-non task}} = 3:1$ , the task lighting effectiveness can be considered to be satisfactory for general lighting purposes.

If high illuminance of the order of 700-1000-2000 lux is required for tasks, the diversity ratio can be 10:1.

If the diversity ratio is less than 3:1, that is, if the non task area lighting is more than 33% of task lighting, there is a need to review lighting scheme. However, it should be noted that at least 20 lux should be available at non task areas.

The measures to improve diversity ratio can include:

1. Reducing mounting heights or providing task lights for task areas
2. Switching off/relocating lamps in non- task areas.

### 5.3 Sample calculation

An office room is chosen for estimation of ILER and effectiveness of task lighting in this example. For length, L = 7.5 m and width W = 5 m. Calculations are summarised in table 5.3. The illuminance measurements are marked on the grid.

Table 5-3: Estimation of room index & illuminance measurement grid

1	A	B	C	D
2		Equation to be used in column C	Value	Unit
3	Date:			-
4	Time of measurement		4:00 pm	
5	Room identification		Office area	
6	Type of activity		Reading, writing	
7	Number of lamps		7	
8	Length of room		7.5	m
9	Width of room		5	m
10	Floor area	$C8 \times C9$	37.5	$m^2$
11	Height of lamp from the plane of measurement		2	m
12	Room index	$C10 / (C11 * (C8 + C9))$	1.5	
13	Number of illuminance measurement points taken	Take value from Table 4.2	18	

Based on the layout of the room, 20 points were selected and mapped as given below in fig 5.1

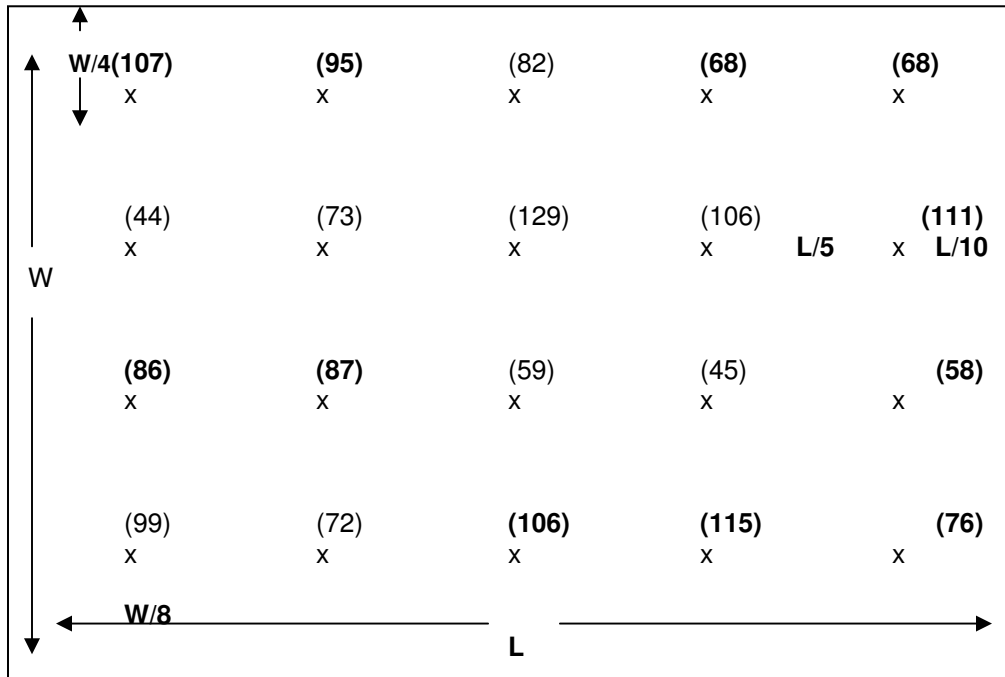


Figure 5-1: Grid for illuminance measurements

Table 5-4: estimation of ILER and Diversity Ratio

	A	B	C	D
		Equation to be used in column C	Value	Unit
14	Average room illuminance		84	lux
15	Measured/estimated circuit power		350	W
16	Installed Lighting Efficacy	$C14 * C10 / C15$	9.0	lm/W
17	Target Lighting efficacy	Take value from table 5.1	43	lm/W
18	<b>Installed Lighting efficacy ratio</b>	$C16 / C17$	<b>0.22</b>	
19				
20	Average illuminance on task areas		96.7	
21	Average illuminance on non- task areas		77.1	
22	<b>Diversity ratio</b>	$C20 / C21$	<b>1.25</b>	

The ILER for this installation is only 0.22. Referring to table 5.2, it can be seen that this lighting installation requires urgent review to improve energy efficiency.

Measures to improve ILER in this case would be:

1. Provide mirror optics luminaires for lamps. Many lamps do not have reflectors
2. Replace existing 36 W lamps and electromagnetic ballast by more efficient T5 tube lights having electronic ballasts.
3. Reduce mounting height of lamps to 1.5 metres from the working plane. This can increase illuminance on work plane without spending more power. This helps in improving ILER.
4. Improve reflectance of walls & ceiling by providing light coloured, preferably white, painted surface.

Measures to improve task lighting effectiveness:

1. Proper relocation of light sources to improve task lighting and increase diversity ratio to 3:1.
2. Reduce the mounting height from existing 2.0 metre to 1.5 metre

## 6 FORMAT OF TEST RESULTS

### 6.1 Format of measurements & calculations

A format of data collection and calculations for estimating ILER is given below.

**Name of Industry:**

**Test Date:**

**Time**

#### Details of instruments used

Sl.No	Description	Measured parameter	Description of accuracy
1	Electrical Power Analyser	Voltage, current, p.f, power input, frequency	0.5% 0.5% 1.0% 0.01Hz
2	Lux meter	Illuminance	5%

Sl. No.	Date:		29//09/2005
1	Time of measurement		16:30 to 17:30
2	Room identification		Office area
3	Type of activity		Reading , writing
4	Number of lamps		4
5	Length of room	m	7.5
6	Width of room	m	4
7	Number of illuminance measurement points taken		18
8	Average room illuminance, F	lux	80
9	Measured/estimated circuit power, P	W	52
10	Installed Lighting Efficacy	lm/W	46
11	Target Lighting efficacy	lm/W	52
<b>12</b>	<b>Installed Lighting efficacy ratio</b>	p.u.	<b>0.89</b>
<b>13</b>	<b>Uncertainty</b>	%	<b>5.1%</b>
14	Average illuminance on task areas	Lux	96.7
15	Average illuminance on non- task areas	Lux	77.1
<b>16</b>	<b>Diversity ratio</b>	p.u	<b>1.25</b>

Test conducted by:  
(Energy Auditing Firm)

Test witnessed by:  
(Energy Manager)

## 7 UNCERTAINTY ANALYSIS

### 7.1 Introduction

Uncertainty denotes the range of error, i.e. the region in which one guesses the error to be. The purpose of uncertainty analysis is to use information in order to quantify the amount of confidence in the result. The uncertainty analysis tells us how confident one should be in the results obtained from a test.

*Guide to the Expression of Uncertainty in Measurement* (or GUM as it is now often called) was published in 1993 (corrected and reprinted in 1995) by ISO. The focus of the ISO *Guide* or GUM is the establishment of "general rules for evaluating and expressing uncertainty in measurement that can be followed at various levels of accuracy".

The following methodology is a simplified version of estimating combined uncertainty at field conditions, based on GUM.

### 7.2 Methodology

Uncertainty is expressed as  $X \pm y$  where  $X$  is the calculated result and  $y$  is the estimated standard deviation. As instrument accuracies are increased,  $y$  decreases thus increasing the confidence in the results.

A calculated result,  $r$ , which is a function of measured variables  $X_1, X_2, X_3, \dots, X_n$  can be expressed as follows:

$$r = f(X_1, X_2, X_3, \dots, X_n)$$

The uncertainty for the calculated result,  $r$ , is expressed as

$$\partial_r = \left[ \left( \frac{\partial r}{\partial X_1} \times \delta x_1 \right)^2 + \left( \frac{\partial r}{\partial X_2} \times \delta x_2 \right)^2 + \left( \frac{\partial r}{\partial X_3} \times \delta x_3 \right)^2 + \dots \right]^{0.5} \quad \text{----(1)}$$

Where:

$$\begin{aligned} \partial_r &= \text{Uncertainty in the result} \\ \delta x_i &= \text{Uncertainties in the measured variable } X_i \\ \frac{\partial r}{\partial X_i} &= \text{Absolute sensitivity coefficient} \end{aligned}$$

In order to simplify the uncertainty analysis, so that it can be done on simple spreadsheet applications, each term on RHS of the equation-(1) can be approximated by:

$$\frac{\partial r}{\partial X_1} \times \delta X_1 = r(X_1 + \delta X_1) - r(X_1) \quad \text{----(2)}$$

The basic spreadsheet is set up as follows, assuming that the result  $r$  is a function of the four parameters  $X_1, X_2, X_3$  &  $X_4$ . Enter the values of  $X_1, X_2, X_3$  &  $X_4$  and the formula for calculating  $r$  in column A of the spreadsheet. Copy column A across the following columns once for every variable in  $r$  (see table 7.1). It is convenient to place the values of the uncertainties  $\partial(X_1), \partial(X_2)$  and so on in row 1 as shown.



Table 7-1: Uncertainty evaluation sheet-1

	A	B	C	D	E
1		$\partial X_1$	$\partial X_2$	$\partial X_3$	$\partial X_4$
2					
3	$X_1$	$X_1$	$X_1$	$X_1$	$X_1$
4	$X_2$	$X_2$	$X_2$	$X_2$	$X_2$
5	$X_3$	$X_3$	$X_3$	$X_3$	$X_3$
6	$X_4$	$X_4$	$X_4$	$X_4$	$X_4$
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1, X_2, X_3, X_4)$

Add  $\partial X_1$  to  $X_1$  in cell B3 and  $\partial X_2$  to  $X_2$  in cell C4 etc., as in Table 7.2. On recalculating the spreadsheet, the cell B8 becomes  $f(X_1 + \partial X_1, X_2, X_3, X_4)$ .

Table 7-2: Uncertainty evaluation sheet-2

	A	B	C	D	E
1		$\partial X_1$	$\partial X_2$	$\partial X_3$	$\partial X_4$
2					
3	$X_1$	$X_1 + \partial X_1$	$X_1$	$X_1$	$X_1$
4	$X_2$	$X_2$	$X_2 + \partial X_2$	$X_2$	$X_2$
5	$X_3$	$X_3$	$X_3$	$X_3 + \partial X_3$	$X_3$
6	$X_4$	$X_4$	$X_4$	$X_4$	$X_4 + \partial X_4$
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1', X_2, X_3, X_4)$	$r=f(X_1, X_2', X_3, X_4)$	$r=f(X_1, X_2, X_3', X_4)$	$r=f(X_1, X_2, X_3, X_4')$

In row 9 enter row 8 minus A8 (for example, cell B9 becomes B8-A8). This gives the values of  $\partial (r, X_i)$  as shown in table 7.3.

$$\partial (r, X_1) = f(X_1 + \partial X_1, X_2, X_3, \dots) - f(X_1, X_2, X_3, \dots) \text{ etc.}$$

To obtain the standard uncertainty on  $y$ , these individual contributions are squared, added together and then the square root taken, by entering  $\partial (r, X_i)^2$  in row 10 (Figure 7.3) and putting the square root of their sum in A10. That is, cell A10 is set to the formula,  $\text{SQRT}(\text{SUM}(\text{B10}+\text{C10}+\text{D10}+\text{E10}))$  which gives the standard uncertainty on  $r$ ,  $\partial (r)$

Table 7-3: Uncertainty evaluation sheet-3

	A	B	C	D	E
1		$\partial X_1$	$\partial X_2$	$\partial X_3$	$\partial X_4$
2					
3	$X_1$	$X_1 + \partial X_1$	$X_1$	$X_1$	$X_1$
4	$X_2$	$X_2$	$X_2 + \partial X_2$	$X_2$	$X_2$
5	$X_3$	$X_3$	$X_3$	$X_3 + \partial X_3$	$X_3$
6	$X_4$	$X_4$	$X_4$	$X_4$	$X_4 + \partial X_4$
7					
8	$r=f(X_1, X_2, X_3, X_4)$	$r=f(X_1', X_2, X_3, X_4)$	$r=f(X_1, X_2', X_3, X_4)$	$r=f(X_1, X_2, X_3', X_4)$	$r=f(X_1, X_2, X_3, X_4')$
9		$\partial (r, X_1)$	$\partial (r, X_2)$	$\partial (r, X_3)$	$\partial (r, X_4)$
10	$\partial (r)$	$\partial (r, X_1)^2$	$\partial (r, X_2)^2$	$\partial (r, X_3)^2$	$\partial (r, X_4)^2$

### 7.3 Uncertainty evaluation

The error in illuminance measurement methodology as explained in section 3.4 is given to be 5% or 10% depending on the number of measurement points chosen.

For the sample calculation given in section 5.4, an instrument accuracy table can be prepared as given in table 7.4, based on instrument specified accuracies and calibration certificates.

*Table 7-4: Instrument accuracy table*

Description	Power	Illuminance
% error	1%	5%
Absolute error	3.5	4.2

In Table 7.5, each uncertainty term from the instrument accuracy table is added to the corresponding measured value, one parameter at a time.

*Table 7-5: Uncertainty estimation*

Area, m2	37.5	37.5	37.5
Illuminance, lux	84	88.2	84.0
Power, watts	350	350	353.5
ILE	9.00	9.45	8.91
Target ILE	43	43	43
ILER	0.21	0.22	0.21
Delta		-0.010	0.002
Delta <sup>2</sup>		0.0001095	4.29E-06
		0.0106683	
% uncertainty		5.1%	

## **8 GUIDELINES FOR IDENTIFYING ENERGY SAVING OPPORTNITIES**

- Use as much natural day light as possible by use of translucent roofing sheets.
- Use day lighting effectively by locating work stations requiring good illuminance near the windows.
- Minimise illuminance in non- task areas by reducing the wattage of lamps or number of fittings
- Avoid use of incandescent/tungsten filament lamps. The power consumed by these lamps is 80% more than the fluorescent lamps (discharge) for same lumen output.
- Use electronic ballasts in place of conventional ballast for fluorescent lamps.
- Task lighting saves energy, utilize it whenever possible.
- All surfaces absorb light to some degree and lower their reflectance. Light colored surfaces are more efficient and need to be regularly painted or washed in order to ensure economical use of light.
- Maintenance is very important factor. Evaluate present lighting maintenance program and revise it as necessary to provide the most efficient use of lighting system.
- Clean luminaries, ceilings, walls, lamps etc. on a regular basis.
- Controls are very effective for reducing lighting cost. Provide separate controls for large ratings.
- Install switching or dimmer controls to provide flexibility when spaces are used for multiple purpose and require different amounts of illumination for various activities.
- Switching arrangements should permit luminaries or rows of luminaires near natural light sources like windows or roof lights to be controlled separately.
- Separate lighting feeder and maintain the feeder at permissible voltages by using transformers.
- Install occupancy sensors for indoor cabin light controls

## ANNEXURE-1: RECOMMENDED ILLUMINANCE LEVELS

INDUSTRIAL BUILDINGS & PROCESSES	Average Illuminance
<b>i) General Factory Areas</b>	
a) Canteens	150
b) Clock-rooms	100
c) Entrances, corridors, stairs	100
<b>ii) Factory Outdoor Areas</b>	
Stockyards, main entrances and exit roads, car parks, internal factory roads	20
<b>iii) Aircraft Factories and Maintenance Hangars</b>	
a) Stock parts productions	450
b) Drilling, riveting, screw fastening sheet aluminium layout and template work, wing sections, cowling welding, sub-assembly, final assembly and inspection	300
c) Maintenance and repair (bangars)	300
<b>iv) Assemble Shops</b>	
a) Rough work, for example, frame assembly and assembly of heavy machinery	150
b) Medium work, for example, machine parts, engine assembly, vehicle body assembly.	300
c) Fine work, for example, radio and telephone equipment, typewriter and office machinery assembly	700
d) Very fine work, for example, assembly of very small precision mechanisms and instrument	1500
<b>vi) Boiler House (Industrial)</b>	
a) Coal and ash handling	100
b) Boiler rooms :	
1) Boiler fronts and operating areas	100+
2) Other areas	20 to 50
c) Outdoor plants :	
1) Cat-walks	20
2) Platforms	50
<b>vii) Breweries and Distilleries</b>	
a) General working areas	150
b) Brewhouse, bottling and canning plants	200
c) Bottle inspection	Special lighting
<b>viii) Chemical Works</b>	
a) Hand furnaces, boiling tanks stationery driers, stationery or gravity crystallizers, mechanical driers, evaporators, filtration plants, mechanical crystallizing, bleaching, extractors, percolators nitrators and electrolytic cells	150
b) Controls, guages, valves, etc	100

c) Control rooms :	
1) Vertical control panels	200 to 300
2) Control desks	300
ix) Chocolate and Confectionery Factories	
a) Mixing , blending and boiling	150
b) Chocolate husking, winnowing, fat extraction, crushing and refining, feeding, bean cleaning, sorting, milling and cream making	200
c) Hand decorating, inspection wrapping and packing	300
<b>XI) GLASS WORKS AND PROCESSES</b>	
a) Furnace rooms, bending, annealing lehrs	100
b) Mixing rooms, forming (blowing, drawing, pressing and rolling)	150
c) Cutting to size, grinding, polishing and roughening	200
d) Finishing (beveling, decorating, etching and silvering)	300
e) Brilliant cutting	700
f) Inspection:	
1) General	200
2) Fine	700
<b>XII) INSPECTION SHOPS (ENGINEERING)</b>	
a) Rough work, for example, counting and rough checking of stock parts, etc.	150
b) Medium work, for example, 'go' and 'no go' gauges and sub-assemblies	300
c) Fine work, for example, radio and telecommunication equipment, calibrated scales, precision mechanisms and instruments	700
d) Very fine work, for example, gauging and inspection of small intricate parts	1500
e) Minute work, for example, very small instruments	3000*
<b>Iron and Steel Works</b>	
a) Marshalling and outdoor stockyards	10to 20
b) Stairs, gangways, basements, quarries and loading docks	100
c) Slabyards, melting shops, ingot stripping, soaking pits, blast-furnace working areas picking and cleaning lines, mechanical plant and pump houses	100
d) Mould preparation, rolling and wire mills, mill motor rooms, power and blower houses	150
e) Slab inspection and conditioning cold strip mills, sheet and plate finishing, tinning, galvanizing, machine and roll shops	200
f) Plate inspection	300
g) Tinplate inspection	Special lighting

<b>xiii) Laboratories and Test Rooms</b>	
a) General laboratories and balance rooms	300
b) Electrical and instrument laboratories	450
<b>Lundries and Drycleaning Works</b>	
a) Receiving, sorting, washing, drying, ironing (calendering) and despatch	200
b) Drycleaning and bulk machine work	200
c) Fine hand ironing, pressing, inspection, mending and spotting	300
<b>Leather Dressing</b>	
a) Vats, cleaning, tanning, stretching, cutting, fleshing and stuffing	150
b) Finishing, staking, splitting and scarfing	200
<b>XIV) MACHINE AND FITTING SHOPS</b>	
a) Rough bench and machine work	150
b) Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing and polishing	300
c) Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing	700
<b>XV) MOTOR VEHICLE PLANTS</b>	
a) General sub-assemblies, chassis assembly and car assembly	300
b) Final inspection	450
c) Trim shops, body sub-assemblies and body assembly	300
d) Sprey booths	450
<b>Paint Works</b>	
a) General, automatic processes	200
b) Special batch mixing	450
c) Colour matching	700*
<b>Paint Shops and Spraying Booths</b>	
a) Dipping, firing and rough spraying	150
b) Rubbing, ordinary painting, spraying and finishing	300
c) Fine painting, spraying and finishing	450
d) retouching and matching	700*
<b>XVI) PAPERS WORKS</b>	
a) Paper and board making :	
1) Machine houses, calendering, pulp mills, preparation plants, cutting, finishing and trimming	200
2) Inspection and sorting (over hauling)	300
b) Paper converting processes :	
1) Corrugated board, cartons, containers and paper sack manufacturer, coating and laminated processes	200

2) Associated printing	300
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<b>XVII) PHARMACEUTICALS AND FINE CHEMICAL WORKS</b>	
a) Raw material storage	200
b) Control laboratories and testing	300
c) Pharmaceuticals manufacturing :	
1) Grinding, granulating, mixing and drying, tableting, sterilizing and washing, preparation of solutions and filling, labelling, capping, cartoning and wrapping and inspection	300
d) Fine chemical manufacture :	
1) Plant processing	200
2) Fine chemical finishing	300
<b>XVIII) PLASTIC WORKS</b>	
a) Manufacture (see Chemical Works)	
b) Processing :	
1) calendering and extrusion	300
2) Moulding- compression and injection	200
3) Sheet fabrication :	
I) Shaping	200
II) Trimming, machining, polishing	300
iii) Cementing	200
<b>XIX) ELECTROPLATING SHOPS</b>	
a) vat and baths, buffing, polishing and burnishing	150
b) Final buffing and polishing	Special lighting
Pottery and Clay Products	
a) Grinding, filter pressing, kiln rooms, moulding, pressing, cleaning, trimming, glazing and firing	150
b) Enamelling, colouring, decorating	450
<b>XX) SHEET METAL WORKS</b>	
a) Bench work, scribing, pressing, punching, shearing, stamping, spinning and folding	200
b) Sheet inspection	Special lighting
<b>XXI) TEXTILE MILLS (COTTON OR LINEN)</b>	
a) Bale breaking, blowing, carding, roving, slubbing, spinning (ordinary counts), winding, heckling, spreading and cabling	150
b) Warping, slashing, dressing and dyeing, doubling (fancy) and spinning (fine counts)	200
c) Healding (drawing-in)	700
d) weaving :	

1) Patterned cloths and fine counts, dark	700
2) Patterned cloths and fine counts, light	300
3) Plain grey cloth	200
e) Cloth inspection	700

<b>XXII) TEXTILE MILLS (SILK OR SYNTHETICS)</b>	
a) Soaking, fugitive tinting, conditioning or setting or twist.	200
b) Spinning	450
c) Winding, twisting, rewinding and coining, quilting and slashing :	
1) Light thread	200
2) Dark thread	300
d) Warping	300
e) Healding (drawing-in)	700
f) Weaving	700
g) Inspection	1000
<b>XXIII) TEXTILE MILLS (WOOLEN)</b>	
a) Scouring, carbonizing, teasing, preparing, raising, brushing, pressing, back-washing, gilling, crabbing and blowing	150
b) Blending, carding, combing (white), tentering, drying and cropping	200
c) Spinning, roving, winding, warping, combing (coloured) twisting	450
d) Healding (drawing-in)	700
e) Weaving :	
1) Fine worsted	700
2) Medium worsteds and fine woollens	450
3) Heavy woollens	300
f) Burling and mending	700
g) Perching :	
1) Grey	700
2) Final	2000
<b>XXIV) WAREHOUSES AND BULK STORES</b>	
a) Large material loading bays	100
b) Small material racks	150
c) Packing and dispatch	150
<b>Commercial buildings</b>	
Offices	
General Offices	300



Deep Plan General Offices	500
Computer Works Station	300
Conference Rooms, Executive Offices	300
Computer and Data Preparation Rooms	300
Filing Rooms	200
Drawing Offices	
General	300
Drawing Boards	500
Print Rooms	200
Counter, Office Area	300
Public Area	200
Retailing	
Small Shops with counters	300
Small Self Service Shops with Island Displays	300
Super Markets – Hyper-Markets	300
General	300
Checkout	300
Showrooms for large objects, for example, cars, furniture	300
Shopping precincts and arcades	100
<b>Hospitals</b>	
Anesthetic Rooms	
General	200
Local	750
Consulting Area	
General	200
Examination	750
Corridors	
General	100
Ward Corridors	
Day, Screened from Bays	150
Day, open to nature light	150
Cubicles	
General	200
Treatment	750
Examinations	
General	200
Local Inspection	750
Intensive Therapy	
Bed Head	30
Circulation Between Bed ends	50
Observation	200
Local Observation	750
Staff base (day)	200
Staff base (Night)	30
Laboratories	
General	200
Examination	300
Nurses 's stations	
Morning/Day/evening	200
Night desks	30
Night, Medical Trolleys	50
Operating Theatres	
General	300

Local	10000
<b>Hotels</b>	
Entrance Halls	50
Receptions, Cashiers & Porter's desks	200
Bars, Coffee base, dining rooms, Grill rooms, Restaurants, Lounges	50
Cloak Rooms, Baggage Rooms	50
Bed Room	30
Bath Rooms	50
Food Preparation & Stores, cellars, Lifts and corridors	100
<b>Transport</b>	
Air ports	150
Ticket Counters, Checking, desks and information desks	300
Departure Lounges, other waiting Areas	150
Baggage reclaim	150
Baggage Handling	50
Customers & Immigration halls	300
Concourse	150
<b>Railway Stations</b>	
Ticket Office	300
Information Office	300
General	50
Counter	150
Waiting Rooms	150
Concourse	150
Time Table	150
Ticket Barriers	150
Platforms (Covered)	30
Platforms (Open)	20

## **ANNEXURE-2: REFERENCES**

1. IS 3646: Code of practice for interior illumination- July 1991
2. IS 6665: Code of practice for industrial lighting – May 1997
3. SP: 32 Handbook on functional requirements of Industrial Buildings- 1986 (BIS publication)
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