# BEE - CODE DEVELOPMENT PROJECT

# SECOND DRAFT CODE

# ON

# LIGHTING

*Prepared by*

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## CONTENTS

# 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 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 Hong kong 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 | W |
| 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 | $m^2$ |

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

**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/m²**

**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/m²

**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/$m^2$ 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 1.05 |
| Fluorescent Lamp | X 0.99 |
| Sodium Lamp | X 1.11 |
| Daylight | X 0.95 |

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

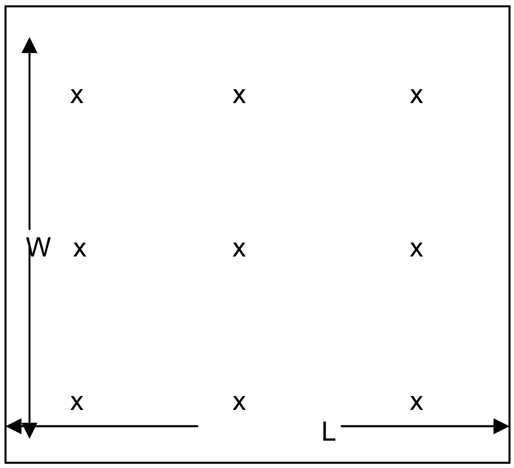
Based on the room index, the minimum number of illuminance measurement points is decided as per the following table 4.2.

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

Where L = Length
W = Width
$H_m$ = 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 ± 5% accuracy | For ± 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= 5m, width W = 5 m and lamp mounting height of 2.6 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 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 a few fittings and estimating the total power consumption.

If power measurement is not possible, from the number of operating fixtures and power consumption/fittings & ballast loss data available from manufacturers, the total circuit watts can be calculated. Note that there can be significant errors in the results, if this method is used.

## 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 for a detailed list of accredited laboratories. Calibration interval suggested for instruments is 6 months.

| 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 '$H_m$'
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 E1, E2,…, En are illuminance measurements at points 1,2,…., n

   Average illuminance, $E_{av} = \frac{E1+E2+E3+\ldots+En}{N}$ X 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.

   Total available lumens on the measurement plane = Average illuminance X (L X W)

   i.e. $\phi_m = E_{av} \times L \times W$

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

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

ILER indicates the efficiency of lighting end use. The following table 3.3 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 = $A_{task}$ and non-task area = $A_{non\text{-}task}$,

The number of illuminance measurements points on task areas

$$= \frac{A_{task}}{(A_{task} + A_{non\text{-}task})} \times \text{Total number of illuminance measurement points as per Table 5.1}$$

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 $E_{av\text{-}task} : E_{av\text{-}non\ task}$ .

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

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

Tabl3 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*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

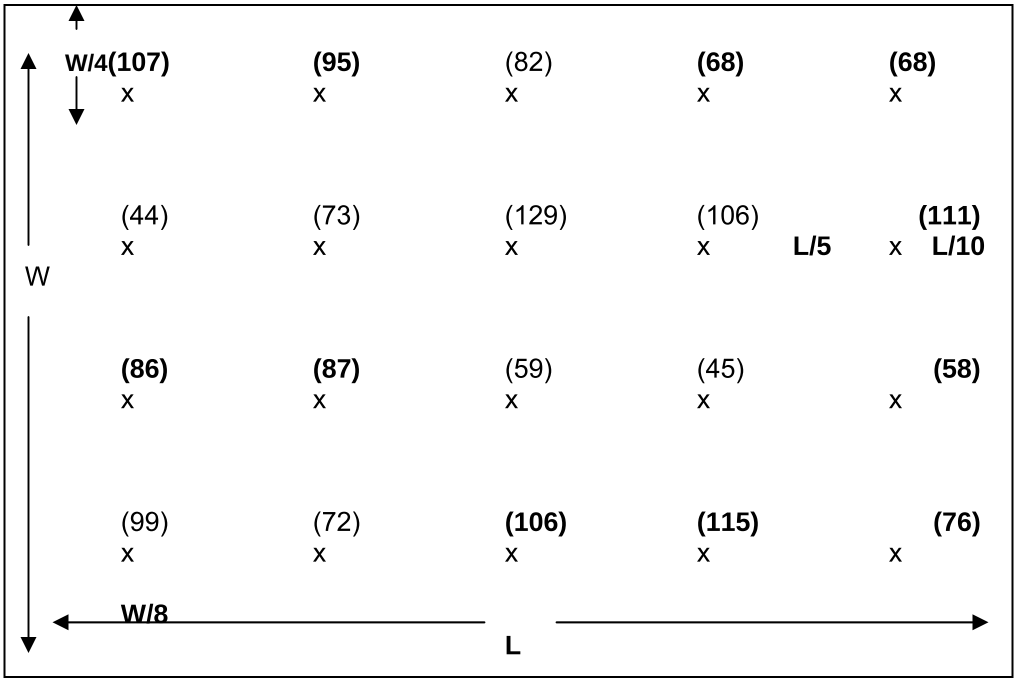



Figure 5-1:Grid for illuminance measurements

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 | **Installed Lighting efficacy ratio** | C16/C17 | **0.22** | |
| 19 | | | | |
| 20 | Average illuminance on task areas | | 96.7 | |
| 21 | Average illuminance on non- task areas | | 77.1 | |
| 22 | **Diversity ratio** | C20/C21 | **1.25:1** | |

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 location 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

3.

# 6 FORMAT OF TEST RESULTS

## 6.1 Format of measurements & calculations

A format of data collection and calculations for estimating ILER is given in table 6.1. This table and equations given can be used in MS Excel spread sheet for calculations.

Table 6.1: Data collection and calculations

| 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*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 | |
| 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 | **Installed Lighting efficacy ratio** | C16/C17 | **0.22** | |
| 19 | | | | |
| 20 | Average illuminance on task areas | | 96.7 | |
| 21 | Average illuminance on non- task areas | | 77.1 | |
| 22 | **Diversity ratio** | C20/C21 | **1.25** | |

# 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 +/- 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 $X_1$, $X_2$, $X_3$,….., $X_n$ can be expressed as follows:

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

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

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

Where:

| | |
|---|---|
| $\partial r$ | = Uncertainty in the result |
| $\delta xi$ | = Uncertainties in the measured variable $X_i$ |
| $\frac{\partial r}{\partial X_i}$ | = Absolute sensitivity coefficient |

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:

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

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 $\partial(r, X_1)$ as shown in table 7.3.

$\partial(r, X_1)=f(X_1+\partial X_1), X_2, X_3\ldots) - f(X_1, X_2, X_3..)$ *etc*.

To obtain the standard uncertainty on *y*, these individual contributions are squared, added together and then the square root taken, by entering $\partial(r, X_1)^2$ 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, SQRT(SUM(B10+C10+D10+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 | $\partial(r)$ | $\partial(r,X_1)^2$ | $\partial(r,X_2)^2$ | $\partial(,X_3)^2$ | $\partial(r,X_4)^2$ |

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

| | | | |
|---|---|---|---|
| Area | 37.5 | 37.5 | 37.5 |
| Illuminance | 84 | 88.2 | 84.0 |
| Power | 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 $^2$ | | 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.
- 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.

## ANNEXURE-1: RECOMMENDED ILLUMINANCE LEVELS

| INDUSTRIAL BUILDINGS & PROCESSES | Average |
|---|---|
| | Illuminance |
| **I) General Factory Areas** | |
| a) Canteens | 150 |
| b) Clock-rooms | 100 |
| c) Entrances, corridors, strairs | 100 |
| **ii) Factory Outdoor Areas** | |
| Stockyards, main entrances and exit roads, car parks, | 20 |
| internal factory roads | |
| **iii) Aircraft Factories and Maintenance Hangars** | |
| a) Stock parts productions | 450 |
| b) Drilling, riveting, screw fastening sheet aluminium layout | 300 |
| and template work, wing sections, cowling welding, | |
| sub-assembly, final assembly and inspection | |
| c) Maintenance and repair (bangars) | 300 |
| **iv) Assemble Shops** | |
| a) Rough work, for example, frame assembly and | 150 |
| assembly of heavy machinery | |
| b) Medium work, for example, machine parts, engine assembly, | 300 |
| vehicle body assembly. | |
| c) Fine work, for example, radio and telephone equipment, typewriter and | 700 |
| office machinery assembly | |
| d) Very fine work, for example, assembly of very small precision | 1500* |
| mechanisms and instrument | |
| **vi) Boiler House (Industrial)** | |
| a) Coal and ash handling | 100 |
| b) Boiler rooms : | |
| 1) Boiler fronts and operating areas | 100+ |
| 2) Other areas | 20 to 50 |
| c) Ourdoor plants : | |
| 1) Cat-walks | 20 |
| 2) Platforms | 50 |
| vii) Breweries and Distrilleries | |
| a) General working areas | 150 |
| b) Brewhouse, bottling and canning plants | 200 |
| c) Bottle inspection | Special lighting |
| viii) Chemical Works | |
| a) Hand furnaces, boiling tanks stationery driers, | 150 |
| stationery or gravity crystallizers, mechanical driers, evaporators, | |
| filtration plants, mechanical crystallizing, bleaching, | |
| extractors, percolators nitrators and electrolytic cells | |
| 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 | 200 |
| and refining, feeding, bean cleaning, sorting, milling | |
| and cream making | |
| c) Hand decorating, inspection wrapping and packing | 300 |
| **xi) Glass Works and Processes** | |
| 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 (bevelling, decorating, etching and silvering) | 300 |
| e) Brilliant cutting | 700 |
| f) Inspection: | |
| 1) General | 200 |
| 2) Fine | 700 |
| **xii) Inspection Shops (Engineering)** | |
| a) Rough work, for example, counting and rough | 150 |
| checking of stock parts, etc. | |
| b) Medium work, for example, 'go' and 'no go' | 300 |
| gauges and sub-assemblies | |
| c) Fine work, for example, radio and telecommunication | 700 |
| equipment, calibrated scales, precision mechanisms | |
| and instruments | |
| d) Very fine work, for example, gauging and | 1500 |
| inspection of small intricate parts | |
| e) Minute work, for example, very small instruments | 3000* |
| Iron and Steel Works | |
| a) Marshalling and outdoor stockyards | 10to 20 |
| b) Stairs, gangways, basements, quarries | 100 |
| and loading docks | |
| c) Slabyards, melting shops, ingot strippling, | 100 |
| soaking pits, blast-furnace working areas | |
| picking and cleaning lines, mechanial plant | |
| and pump houses | |
| d) Mould preparation, rolling and wire mills, mill | 150 |
| motor rooms, power and blower houses | |
| e) Slab inspection and conditioning cold strip mills, | 200 |
| sheet and plate finishing, tinning, galvanizing, | |
| machine and roll shops | |
| f) Plate inspection | 300 |
| g) Tinplate inspection | Special lighitn |

| | |
|---|---|
| **xiii) Laboratories and Test Rooms** | |
| a) General laboratories and balance rooms | 300 |
| b) Electrical and instrument laboratories | 450 |
| Lundries and Drycleaning Works | |
| a) Receiving, sorting, washing, drying, ironing | 200 |
| (calendering) and despatch | |
| b) Drycleaning and bulk machine work | 200 |
| c) Fine hand ironing, pressing, inspection, mending and | 300 |
| spotting | |
| Leather Dressing | |
| a) Vats, cleaning, tanning, stretching, | 150 |
| cutting, fleshing and stuffing | |
| b) Finishing, staking, splitting and scarfing | 200 |
| **xiv) Machine and Fitting Shops** | |
| a) Rough bench and machine work | 150 |
| b) Medium bench and machine work, | 300 |
| ordinary automatic machines, rough | |
| grinding, medium buffing and polishing | |
| c) Fine bench and machine work, fine automatic machines, | 700 |
| medium grinding, fine buffing and polishing | |
| **xv) Motor Vehicle Plants** | |
| 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 |
| Paint Works | |
| a) General, automatic processes | 200 |
| b) Special batch mixing | 450 |
| c) Colour matching | 700* |
| Paint Shops and Spraying Booths | |
| 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* |
| **xvi) Papers Works** | |
| a) Paper and board making : | |
| 1) Machine houses, calendering, pulp mills, preparation | 200 |
| plants, cutting, finishing and trimming | |
| 2) Inspection and sorting (over hauling) | 300 |
| b) Paper converting processes : | |
| 1) Corrugated board, cartons, containers and paper | 200 |
| sack manufacturer, coating and laminated processes | |
| 2) Associated printing | 300 |

| | |
|---|---|
| **xvii) Pharmaceuticals and Fine Chemical Works** | |
| a) Raw material storage | 200 |
| b) Control laboratories and testing | 300 |
| c) Pharmaceuticals manfuacturing : | |
| 1) Grinding, granulating, mixing and drying, tableting, | 300 |
| sterilizing and washing, preparation of solutions and | |
| filling, labelling, capping, cartoning and wrapping and | |
| inspection | |
| d) Fine chemical manufacture : | |
| 1) Plant processing | 200 |
| 2) Fine chemical finishing | 300 |
| **xviii) Plastic Works** | |
| 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 |
| **xix) Electroplating Shops** | |
| a) vat and baths, buffing, polishing and burnishing | 150 |
| b) Final buffing and polishing | Special lighitn |
| Pottery and Clay Products | |
| a) Grinding, filter pressing, kiln rooms, moulding, pressing, | 150 |
| cleaning, trimming, glazing and firing | |
| b) Enamelling, colouring, decorating | 450* |
| **xx) Sheet Metal Works** | |
| a) Bench work, scribing, pressing, punching, | 200 |
| shearing, stamping, spinning and folding | |
| b) Sheet inspection | Special lighitn |
| **xxi) Textile Mills (Cotton or Linen)** | |
| a) Bale breaking, blowing, carding, roving, slubbing, spinning | 150 |
| (ordinary counts), winding, heckling, spreading and cabling | |
| b) Warping, slashing, dressing and dyeing, doubling | 200 |
| (fancy) and spinning (fine counts) | |
| 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* |

| | |
|---|---|
| **xxii) Textile Mills (Silk or Synthetics)** | |
| a) Soaking, fugitive tinting, conditioning or setting | 200 |
| or twist. | |
| 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* |
| **xxiii) Textile Mills (Woolen)** | |
| a) Scouring, carbonizing, teasing, preparing, raising, | 150 |
| brushing, pressing, back-washing, gilling, crabbing | |
| and blowing | |
| b) Blending, carding, combing (white), tentering, drying | 200 |
| and cropping | |
| c) Spinning, roving, winding, warping, combing (coloured) | 450 |
| twisting | |
| 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 |
| **xxiv) Warehouses and Bulk Stores** | |
| a) Large material loading bays | 100 |
| b) Small material racks | 150 |
| c) Packing and dispatch | 150 |

## ANNEXURE-2: REFERENCES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