# Development of energy efficient lighting (EEL) design and savings calculator for commercial application

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ARTICLE INFORMATION

*Article History:*
Received 17 December 2014
Received in revised form 21 March 2015

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ABSTRACT

*The Energy Efficient Lighting (EEL) Design and Savings Calculator (DSC) for Commercial Application is a handy tool intended for project engineers to have a quick reference in the illumination design. This project is specifically focused on selecting energy efficient lamps used notwithstanding its illumination requirement in the given area/task.*

*The EEL-DSC comprises of the rotary disk (inner and outer) and disk jacket. The inner rotary disk shows the various lamps type, lamp wattage, lamp light output, color temperature, color appearance, and color rendering group. Side A of the outer rotary disk displays the Lumen Method formula while side B shows the notations for Color Rendering Group (CRG), Correlated Color Temperature (CCT), and the Lamps type legend.*

*The disk jacket has two parts: the inner disk jacket and the outer disk jacket. The inner disk jacket (IDJ) illustrates the instruction manual and steps in calculation.*

*Table 1 indicates the recommended level of illumination and Table 2 the color rendering index (CRI) with lamp efficacy. The outer disk jacket (ODJ) illustrates the picture from DOE while Table 3 displays the Coefficient of Utilization (CU), the Maintenance Factor (MU) and Terminologies.*

*These parameters were simplified to help the engineers quickly estimate the design of energy efficient lighting system by selecting the lamps type, categories e.g. High-bay, low-bay and 2-Lamps, coefficient of utilization, and maintenance factors. The reflectance for ceiling, walls, and floor cavity were also simplified at 70%, 50% and 30% respectively. Finally, the total number of luminaires was determined.*

*Moreover, EEL-DSC for Commercial Application is one of the contributions of the Technological University of the Philippines (TUP) in the advocacy of the Department of Energy to address the barrier to use energy efficient lighting system in the Philippines and its goal to reduce Greenhouse Gas (GHG) emission in the energy sector. Furthermore, this project was funded by the United Nation Development Programme (UNDP) through the Philippine Efficient Lighting Market Transformation Project (PELMATP) – Department of Energy.*

*Keywords*
Energy Efficiency, Lighting Design Calculator

## Introduction

The world's lighting issues according to Carbon Trust, states that "*Commercial and industrial lighting consumes an estimated 20% of all electricity generated in the UK alone. In most organizations, lighting accounts for up to 40% of total electricity costs.*" It is also supported by the Green Business Light Association which states *"Electric lighting burns up to 25% of the average home energy budget."* Further, the Light Research Center hold that *"Energy Efficient Lighting (EEL) demands less electricity, which reduces polluting power plant emissions."*

In this account, the Philippines was among the first country to prepare a National Action Plan to mitigate the polluting emission that leads to Climate Change. The Department of Energy (DOE) as one of the implementing agencies that moderate, monitor, and evaluate the Greenhouse Gas (GHG) effect in the country. DOE has also received the climate change project with a total funding of US$ 15M through the Philippine Efficient Lighting Market Transformation Project (PELMATP) under the Global Environmental Facility - United Nation Development Programme (GEF-UNDP-DOE).

The PELMATP seeks to address the barriers to widespread use of energy efficient lighting system (EELs) in the Philippines. Also it aims to promote the use and benefits of EEL with simplified tools to calculate savings for new commercial and industrial establishments.

This project Energy Efficient Lighting Design and Savings Calculator (EEL DSC) was developed to provide designers (e.g. engineers, architects, etc.) of lighting system for commercial application a handy tool for a quick comparative estimate on energy consumptions and savings.

It is focused on determining a number of luminaires and the type of lamp to be used in the particular area or task within a recommended illumination and energy efficiency.

## Objectives

The objectives of the project follow:

1. To develop simplified tools that can quickly estimate and calculate of energy consumption using the energy efficient lighting (EEL) products.

2. To provide EEL products of comparative parameters as light sources commonly used for commercial applications lighting systems.

3. To prepare an instruction manual for the Energy Efficient Lighting Design & Savings Calculator (EEL-DSC) as guideline of designers (e.g. engineers, architects, practitioners, etc).

4. To determine the level of accuracy of the estimated lighting systems using EEL-Design & Savings Calculator.

## Method

The energy efficient lighting design and savings calculator (EEL-DSC) was created in reference to several calculators in rectangular, triangular and circular format. The initial pattern used was the rectangular form, however, after deliberation with colleagues the circular form was decided to use to give optimum space that carries more information than any other forms.

The light sources were taken from the catalogues of several known manufacturers producing EEL commercially available products. They were arranged according to types, lamp wattage, lamp light output, color temperature, color appearance, and color rendering group. The light sources were arranged according to ascending values of the watts, lumens and Kelvin units. These parameters were printed in the inner rotary disk.

The design calculation used to determine the number of luminaires is the Lumen method from the journal published by the latest edition of the Illumination

Engineering Society of North America (IESNA), the most widely used designing lighting systems by practitioner. Tables were selected, simplified, and adhered to the most frequently used specifications.

The instruction manual was printed to guide the designer-engineer to facilitate calculation. The calculation method was taken from IESNA and all the needed parameters in the formula marked in the disk.

**Results**

After several trials and configurations of the calculators, these results were obtained:

The selected form of the EEL DSC was a circular form that carries more information than others. Figure 1 below shows the inner rotary disk:

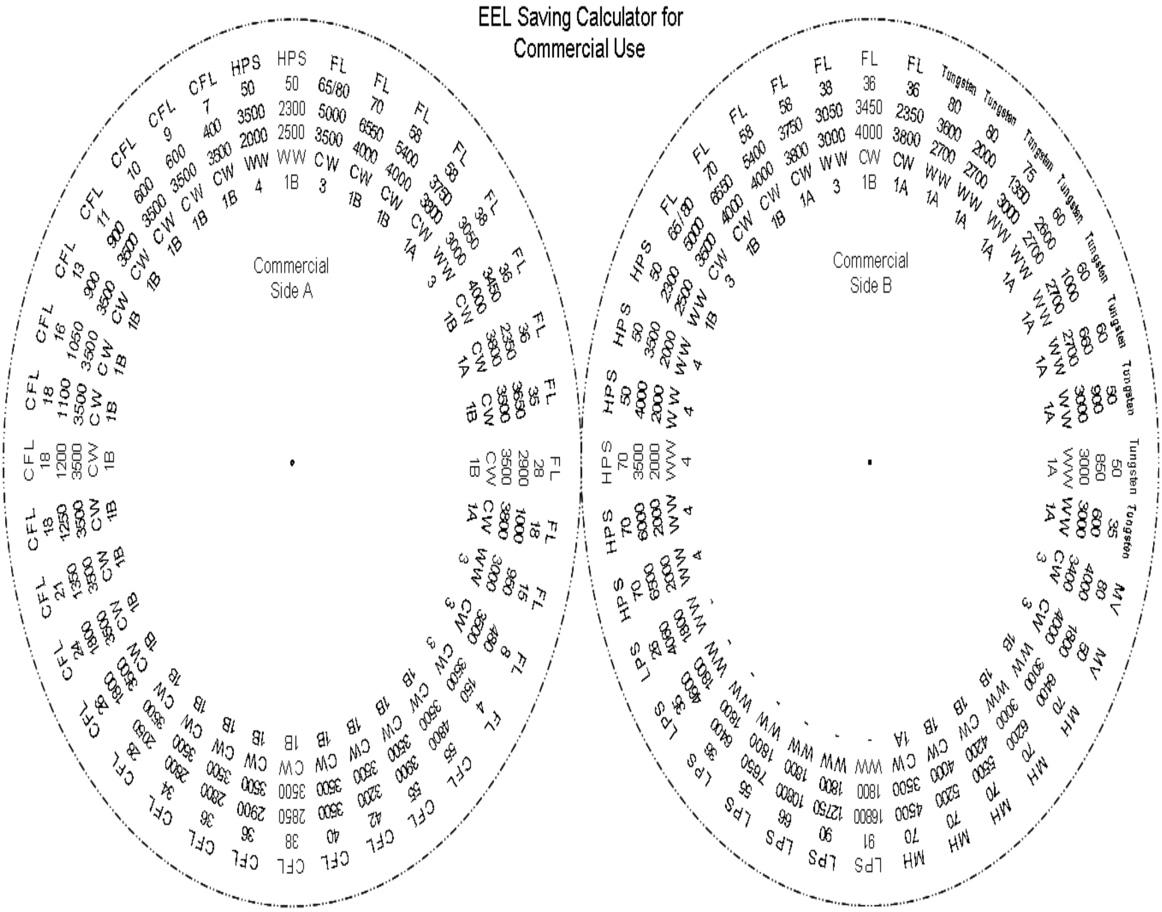



*Figure 1. The Inner Rotating Disk that contains specifications of lighting source e.g. Lamp type, Lamp wattage, Lamp light output, Color temperature, Color appearance, Color rendering group. A single lamp specification is arranged in one column of different levels.*

Figure 1 shows the inner rotary disk of the EEL DSC calculator and the specifications of various light sources. These light sources are commercially available in the market with lighting catalogues of different known lamp manufacturers.

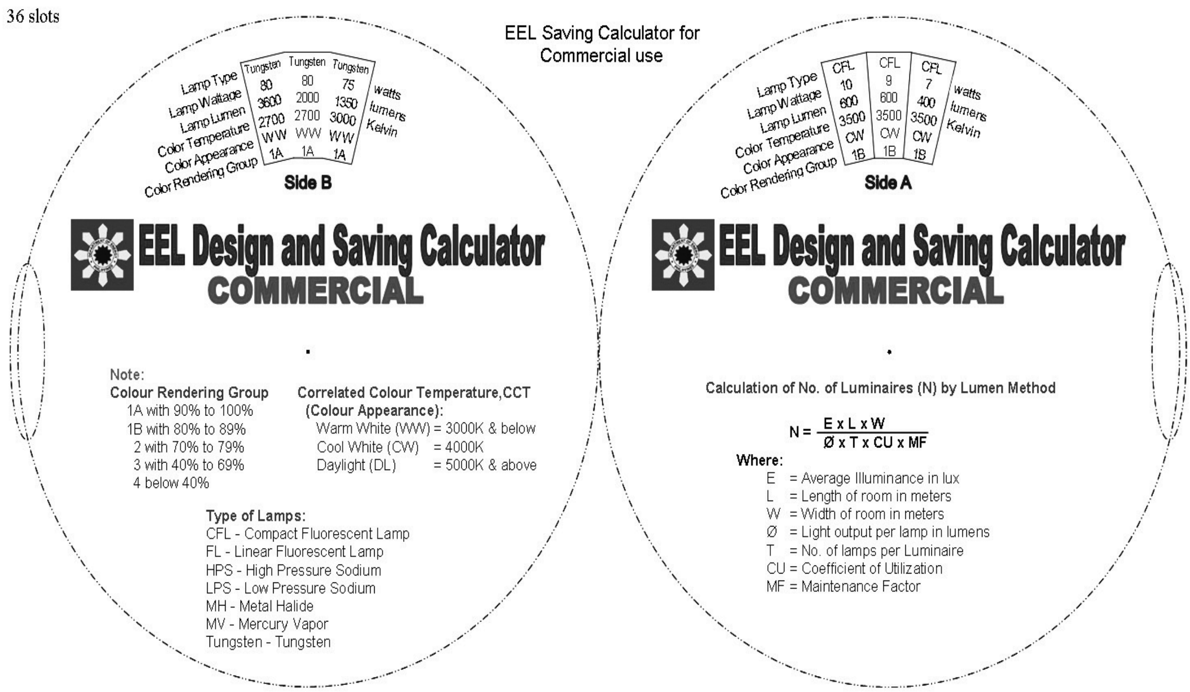



*Figure 2a. The outer disk shows the two sides of the calculator. Side A shows the formula of Lumen method while side B shows lighting parameters. The windows (trapezoidal form) are for viewing the specifications of light sources to select appropriate lighting source.*

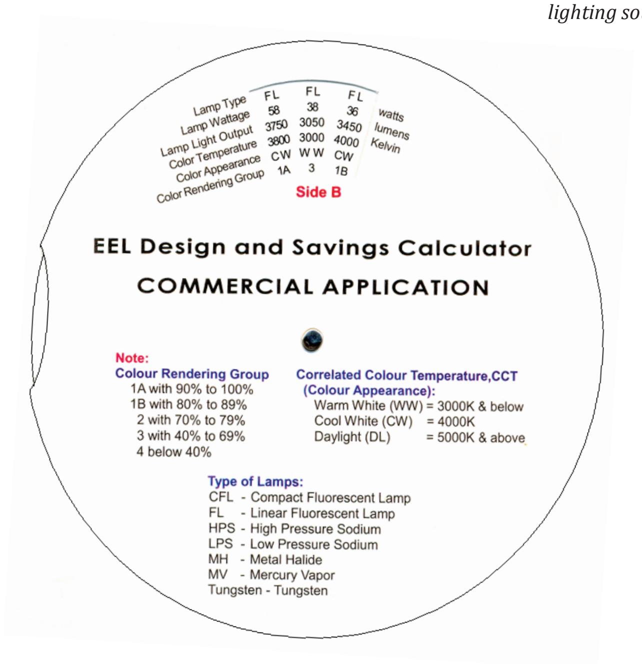



*Figure 2b. The outer disk assembly showing only one side "Side B" with inner rotating disk visible at the left side.*

Figure 2a shows the construction layout of the outer disk. The lumen method formula and lighting parameters are printed in faces of the outer disk Side A and Side B respectively.

Figure 2b illustrates the assembly format of the outer disk. Side A is not visible as it is at the back of side B. The selection of lamp types can be changed by moving the inner rotating disk upward or downward to see the different lamp types and their specification. These will provide the designer flexibility in choosing the appropriate lamp type according to specifications/design, as found in the window at the upper part of the disk.

**Instructions:**

1. Determine the dimension (length, width and height) of the room in meters.
2. Determine the nature of activity or task for the given area or room.
3. Determine the required illumination level (lux) required for the task or activity.
4. Select the type of lamp to be used by turning the tab on the side of the calculator.
5. Calculate the room cavity ratio (RCR) using the formula below and using the values obtain in the item (1) above.
6. Determine the Coefficient of Utilization (CU) based on item (4). Choose from the values given in section 4 of the calculator.
7. Determine the Maintenance Factor (MF). Choose from the values given in section 4.
8. Calculate the number of luminaires (N) using the formula in the calculator.
9. Calculate the total power consumption of the installed luminaires (lamp and ballasts combination).
10. Arrange the luminaire in a suitable grid or install the luminaires symmetrically.
11. Repeat step 5 to 9 using other types of luminaire for the comparison on the cost of operation using other types of luminaire,
12. Compare the total power consumption of the new type of luminaire with luminaire use in the first calculation.
13. Choose the luminaire that provides the lowest energy operating cost.

**Important note:**

Lower consumption type of luminaire shall not compromise or/sacrifice the required illumination level on the given task.

**Steps by step Calculation:**

1. Determine the area (length, width and height) of the working space.
2. Calculate the room cavity ratio (all dimensions are in meters):

$$RCR = \frac{5 \text{ x height (length x width)}}{\text{length x width}}$$

3. Select the reflectances (reflection factor) of ceiling (rc), wall (rw), floor (rf):
4. Select the luminaire and lamp type
5. Choose the Coefficient of Utilization (CU), from table corresponding to the luminaire.
6. Select the Maintenance Factor (MF)
7. Determine the illuminance level required
8. Calculate number of luminaires
9. Arrange the luminaries in a suitable grid.
10. Check the spacing to height ratio in both direction.

Page 2

Section 3

**Table 1. Recommended level of Illumination***

| Type of interior, task or activity | Maintained illuminance level, lux | Type of interior, task or activity | Maintained illuminance level, lux |
|---|---|---|---|
| **Offices** | | **Electrical Equipment Manufacturing** | |
| Drafting room | 2200 | Insulating: coil winding and testing | 1100 |
| Rough layout drafting, accounting offices | 1600 | **Dairy products** | |
| Reading handwriting in ink or medium pencil | 750 | Boiler room, bottle storage, pasteurizer, separators, and storage refrigerator | 320 |
| Conference room (conferring and note taking) | 330 | **Textile mills** | |
| Corridor | 220 | Opening, blending, picking, warping, weaving | 1100 |
| **Hotels** | | **Storage room or Warehouses** | |
| Bathrooms, bedrooms, lobby (gen. lighting) | 320 | Active and inactive | 100 |
| **Stores** (Merchandizing areas) | 1100 | **Shoe manufacturing** | |
| Self-service, showcases, and wall cases | 2200 | Varnishing, vulcanizing, upper and sole cutting | 540 |

** For other level of Illumination please see Manual of Practice on Efficient Lighting, 2007 edition*

**Table 2. Color Rendering Index and Lamp Efficacy for Typical Light Source**

| Lamp Type | Lamp Watts | Mean Lamp Efficacy | Mean Lamp Lumen | CRI |
|---|---|---|---|---|
| Incandescent | 100 | 16 | 1575 | 100 |
| Compact Fluorescent | 26 | 53 | 1370 | 82 |
| Fluorescent(4') - Standard Phosphor | 36 | 68 | 2300 | 62 |
| Mercury Vapor | | | | |
| Clear | 250 | 42 | 10500 | 20 |
| Color Improved | 250 | 43 | 10700 | 45 |
| Metal Halide | | | | |
| Clear | 250 | 68 | 17000 | 65 |
| Color Improved | 250 | 64 | 16000 | 70 |
| Pulse Start | 250 | 84 | 21040 | 65 |
| High Pressure Sodium | | | | |
| Clear | 250 | 102 | 25600 | 21 |
| Color Improved | 250 | 83 | 20700 | 65 |

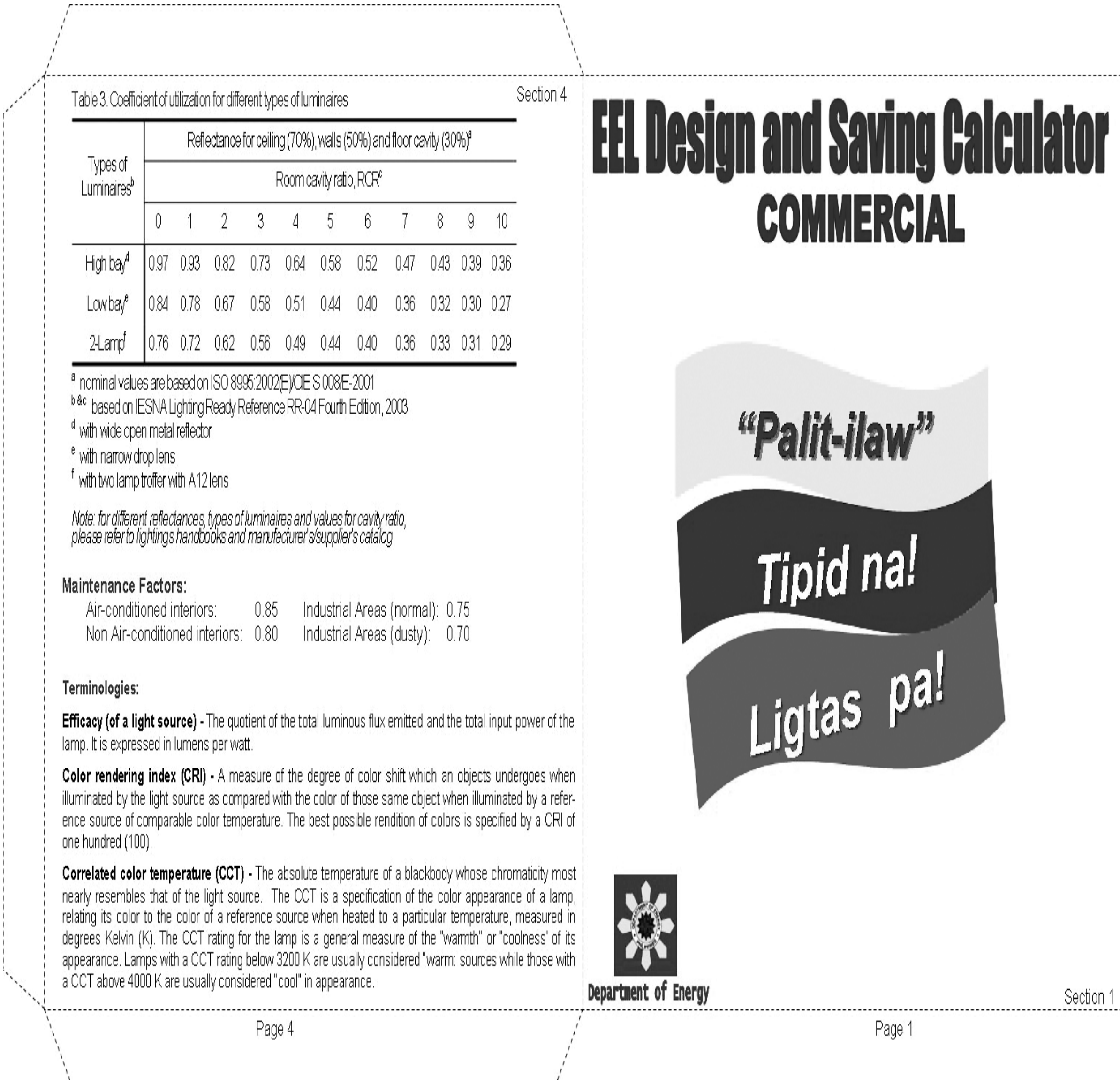
Page 3

*Figure 3. The inner disk jacket (IDJ) shows the instruction manual calculation on page 2 while page 3 displays Table 1 Recommended level of illumination and Table 2 Coloring rendering index and lamp efficacy.*

Figure 3 reveals the inner cover jacket (ICJ) where the outer disk is inserted for protection like the common compact disk (CD) with cover. The printed instruction manual gives direction and steps by step calculation of lighting system to the designer while Table 1 refers to the recommended level of illumination. Table 2 indicates the Color rendering index and Lamp Efficacy of different lamp types.

Table 1 on recommended level of illumination refers to the task of activity that the researcher considered common to a commercial space application. Such type of interior, task or activity chosen must fit offices, hotel, stores, electrical equipment manufacturing, dairy products, textile mills, storage room or warehouse, and shoe manufacturer.

Table 2 on Color rendering index and Lamp efficacy refers to the lamp type and its parameters considered such as incandescent, CFL, fluorescent, mercury vapor, and metal halide.



Section 4

Table 3. Coefficient of utilization for different types of luminaires

| Types of Luminaires[b] | Reflectance for ceiling (70%), walls (50%) and floor cavity (30%)[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Room cavity ratio, RCR[c] | | | | | | | | | | |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| High bay[d] | 0.97 | 0.93 | 0.82 | 0.73 | 0.64 | 0.58 | 0.52 | 0.47 | 0.43 | 0.39 | 0.36 |
| Low bay[e] | 0.84 | 0.78 | 0.67 | 0.58 | 0.51 | 0.44 | 0.40 | 0.36 | 0.32 | 0.30 | 0.27 |
| 2-Lamp[f] | 0.76 | 0.72 | 0.62 | 0.56 | 0.49 | 0.44 | 0.40 | 0.36 | 0.33 | 0.31 | 0.29 |

[a] nominal values are based on ISO 8995:2002(E)/CIE S 008/E-2001
[b &c] based on IESNA Lighting Ready Reference RR-04 Fourth Edition, 2003
[d] with wide open metal reflector
[e] with narrow drop lens
[f] with two lamp troffer with A12 lens

*Note: for different reflectances, types of luminaires and values for cavity ratio, please refer to lightings handbooks and manufacturer's/supplier's catalog*

**Maintenance Factors:**

Air-conditioned interiors: 0.85 Industrial Areas (normal): 0.75
Non Air-conditioned interiors: 0.80 Industrial Areas (dusty): 0.70

**Terminologies:**

**Efficacy (of a light source)** - The quotient of the total luminous flux emitted and the total input power of the lamp. It is expressed in lumens per watt.

**Color rendering index (CRI)** - A measure of the degree of color shift which an objects undergoes when illuminated by the light source as compared with the color of those same object when illuminated by a reference source of comparable color temperature. The best possible rendition of colors is specified by a CRI of one hundred (100).

**Correlated color temperature (CCT)** - The absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source. The CCT is a specification of the color appearance of a lamp, relating its color to the color of a reference source when heated to a particular temperature, measured in degrees Kelvin (K). The CCT rating for the lamp is a general measure of the "warmth" or "coolness' of its appearance. Lamps with a CCT rating below 3200 K are usually considered "warm: sources while those with a CCT above 4000 K are usually considered "cool" in appearance.

Page 4



*Figure 4. The outer cover jacket (OCJ) composed of front page and back page. The front page is the picture from DOE while the back page shows Table 3 on Coefficient of Utilization (CU) including the Maintenance Factor and Terminologies.*

The outer cover jacket (OCJ) shows the initial design of the front page "Palit – ilaw" project of the Department of Energy and was later revised. The back page of the OCJ shows Table 3 on Coefficient of utilization of different type of luminaires. The researcher simplified the table by considering only the high bay, low bay and the 2-lamps types of luminaires. Furthermore, the researcher assumed the percentage of reflectance as follows: 70% of ceiling, 50% walls, and 30% floor cavity reflectance due to its frequent practice combination in the design.

Maintenance factor was considered to be of four types such as, 0.85 air-conditioned interior, 0.80 non air-conditioned interior, 0.75 normal industrial areas, and 0.70 dusty industrial areas.

The terminologies were also included on the last portion of the OCJ.


*Figure 5a. The final layout of the Front Cover Jacket of EEL DSC.*

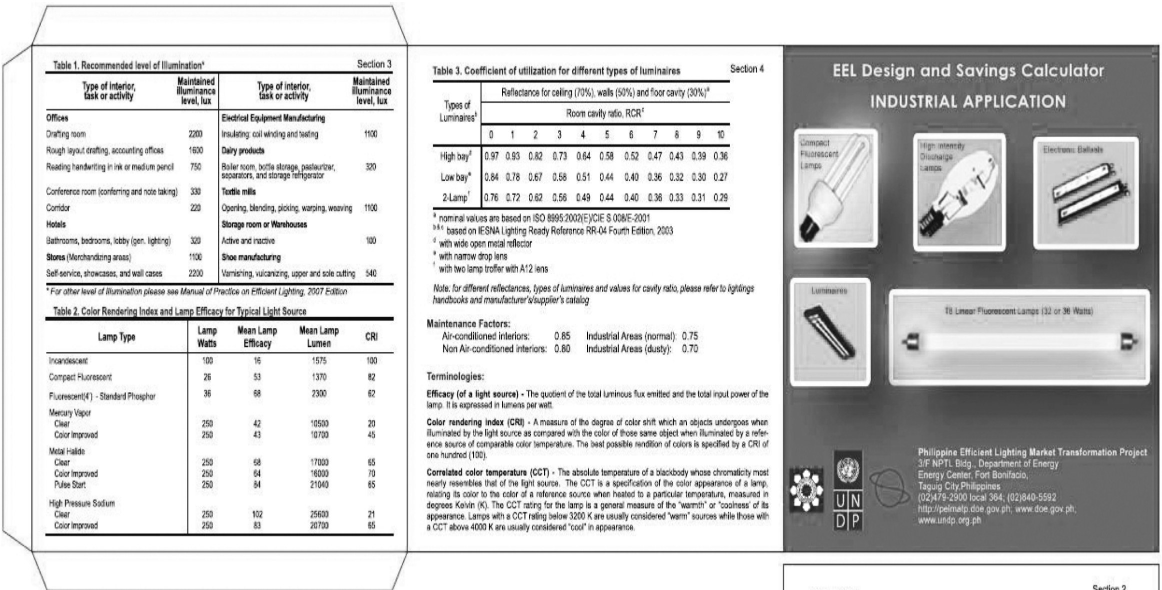


Table 1. Recommended level of Illumination* — Section 3

| Type of interior, task or activity | Maintained illuminance level, lux | Type of interior, task or activity | Maintained illuminance level, lux |
|---|---|---|---|
| **Offices** | | **Electrical Equipment Manufacturing** | |
| Drafting room | 2200 | Insulating: coil winding and testing | 1100 |
| Rough layout drafting, accounting offices | 1600 | **Dairy products** | |
| Reading handwriting in ink or medium pencil | 750 | Boiler room, bottle storage, pasteurizer, separators, and storage refrigerator | 320 |
| Conference room (conferring and note taking) | 330 | **Textile mills** | |
| Corridor | 220 | Opening, blending, picking, warping, weaving | 1100 |
| **Hotels** | | **Storage room or Warehouses** | |
| Bathrooms, bedrooms, lobby (gen. lighting) | 320 | Active and inactive | 100 |
| **Stores** (Merchandizing areas) | 1100 | **Shoe manufacturing** | |
| Self-service, showcases, and wall cases | 2200 | Varnishing, vulcanizing, upper and sole cutting | 540 |

** For other level of illumination please see Manual of Practice on Efficient Lighting, 2007 Edition*

Table 2. Color Rendering Index and Lamp Efficacy for Typical Light Source

| Lamp Type | Lamp Watts | Mean Lamp Efficacy | Mean Lamp Lumen | CRI |
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| Incandescent | 100 | 16 | 1575 | 100 |
| Compact Fluorescent | 26 | 53 | 1370 | 82 |
| Fluorescent(4') - Standard Phosphor | 36 | 68 | 2300 | 62 |
| Mercury Vapor | | | | |
| Clear | 250 | 42 | 10500 | 20 |
| Color Improved | 250 | 43 | 10700 | 45 |
| Metal Halide | | | | |
| Clear | 250 | 68 | 17000 | 65 |
| Color Improved | 250 | 64 | 16000 | 70 |
| Pulse Start | 250 | 84 | 21040 | 65 |
| High Pressure Sodium | | | | |
| Clear | 250 | 102 | 25600 | 21 |
| Color Improved | 250 | 83 | 20700 | 65 |

Table 3. Coefficient of utilization for different types of luminaires — Section 4

| Types of Luminaires[b] | Reflectance for ceiling (70%), walls (50%) and floor cavity (30%)[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Room cavity ratio, RCR[c] | | | | | | | | | | |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| High bay[d] | 0.97 | 0.93 | 0.82 | 0.73 | 0.64 | 0.58 | 0.52 | 0.47 | 0.43 | 0.39 | 0.36 |
| Low bay[e] | 0.84 | 0.78 | 0.67 | 0.56 | 0.51 | 0.44 | 0.40 | 0.36 | 0.32 | 0.30 | 0.27 |
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*Note: for different reflectances, types of luminaires and values for cavity ratio, please refer to lightings handbooks and manufacturer's/supplier's catalog*

**Maintenance Factors:**

| | | | |
|---|---|---|---|
| Air-conditioned interiors: | 0.85 | Industrial Areas (normal): | 0.75 |
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**Terminologies:**

**Efficacy (of a light source)** - The quotient of the total luminous flux emitted and the total input power of the lamp. It is expressed in lumens per watt.

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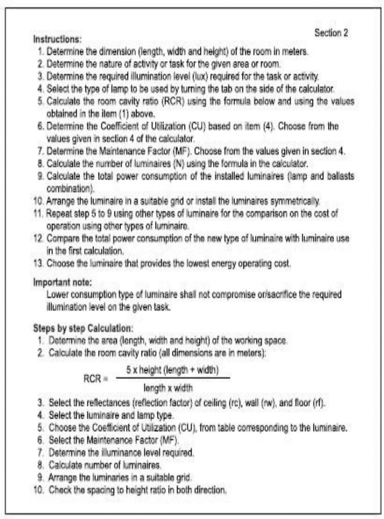

Section 2

**Instructions:**

1. Determine the dimension (length, width and height) of the room in meters.
2. Determine the nature of activity or task for the given area or room.
3. Determine the required illumination level (lux) required for the task or activity.
4. Select the type of lamp to be used by turning the tab on the side of the calculator.
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6. Determine the Coefficient of Utilization (CU) based on item (4). Choose from the values given in section 4 of the calculator.
7. Determine the Maintenance Factor (MF). Choose from the values given in section 4.
8. Calculate the number of luminaires (N) using the formula in the calculator.
9. Calculate the total power consumption of the installed luminaires (lamp and ballasts combination).
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11. Repeat step 5 to 9 using other types of luminaire for the comparison on the cost of operation using other types of luminaire.
12. Compare the total power consumption of the new type of luminaire with luminaire use in the first calculation.
13. Choose the luminaire that provides the lowest energy operating cost.

**Important note:**

Lower consumption type of luminaire shall not compromise or/sacrifice the required illumination level on the given task.

**Steps by step Calculation:**

1. Determine the area (length, width and height) of the working space.
2. Calculate the room cavity ratio (all dimensions are in meters):

$$RCR = \frac{5 \times \text{height (length + width)}}{\text{length} \times \text{width}}$$

3. Select the reflectances (reflection factor) of ceiling (rc), wall (rw), and floor (rf).
4. Select the luminaire and lamp type.
5. Choose the Coefficient of Utilization (CU), from table corresponding to the luminaire.
6. Select the Maintenance Factor (MF).
7. Determine the illuminance level required.
8. Calculate number of luminaires.
9. Arrange the luminaries in a suitable grid.
10. Check the spacing to height ratio in both direction.

Figure 5b. *The final construction layout of the Cover Jacket of EEL DSC ready for printing for mass production.*

Figure 5a shows the final layout of the front page of the Cover Jacket of the EEL DSC while Figure 5b the final layout of the Cover Jacket in one piece for printing and mass production. The Department of Energy through the Philippines Efficient Lighting Market Transformation Project under the United Nation Development Programme (DOE-PELMATP-UNDP-GEF), mass produced the EEL DSC.

## Discussion

The EEL DSC were tested through the simulation of the three (3) different problems from the samples on the Manual of Practice on Efficient Lighting and three (3) actual design problems given by a design practitioner. The six problems were calculated using both the computer software and the EEL-DSC.

Comparing the results of the computer software simulation against EEL DSC calculation, EEL DSC gave an average of 80% level of accuracy. This result can be attributed to the lack of available lamp types of the software that tend to give lower accuracy. However, the results from the estimated calculation of the practitioner against the use of EEL DSC calculation, EEL DSC gave an average of 90% level of accuracy, as attributed to the actual assumption of the practitioner in the lighting system design

The result also provides an average percent accuracy for the EEL DSC that ranges from +/- 10% minimum to +/- 15% maximum of the estimated value. This can be attributed to the assumption made by the design engineer on the flexibility of the coefficient of utilization and the lamp type used in the design.

Finally, the result indicates that EEL DSC can be used as alternative tool to quickly estimate EEL products to attain energy efficient in lighting system.

## Conclusion

In light of the findings, these conclusions can be drawn:

1. Circular format was used for the EEL-DSC. The spaces for printing information in circular form were strategically designed to give more lamps specification. Also the used cover jacket provides useful information such as:

    a. Twelve (13) most common types of interior and activities were considered in Table 1 with recommended level of illumination.
    b. Ten (10) lamps types were considered in the Table 2 with the most common mean lamp lumen used for commercial application.
    c. Only three (3) types of percent reflectance were considered in Table 3. Coefficient of Utilization: ceiling - 70%, walls - 50% and floor cavity - 30%

2. More than 70 luminaires were considered in EEL DSC Calculator Disc with complete specifications.

3. The instruction manual as guide for the designer to facilitate calculation can easily be followed.

4. The EEL-DSC can be used as an alternative tool to readily estimate EEL products with accuracy of about +/- 10% minimum and +/- 15% maximum.

## Recommendations

1. Update the luminaires with the most recent technology of lighting source with LEDs from the different manufacturers' catalog.

2. Reduce the parts of material and cost of EEL-DSC by combining the print of the inner disc and calculator disc back to back.

3. Validate the accuracy of the EEL-DSC calculator by conducting more surveys to engineers and lighting design practitioners.

4. Determine the level of satisfaction as perceived by engineers and lighting design practitioners using EEL-DSC.

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