Greenhouse gas emission reduction by the selection of efficient lighting systems

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Abstract. Indoor lighting is one of the most important consumer of the energy worldwide, driving to a high GHG emissions. Current state of the lighting system in the classrooms of the Technical University of Ambato (UTA), Tungurahua, Ecuador has been assessed in this work. A sample of classrooms were selected to quantify its illumination levels, with the Luxometer (Sper Scientific 850007), these data were computed by means of DIALUX software, whose generates the light distribution of different lighting systems scenarios and the lamps geometric distribution. Number of luminaires, luminous distribution and the energy efficiency value of the installation (VEEI) were compared among all the different cases, also a luminance analysis and the energy efficiency of installation was performed. First results show an important reduction of around 40% of the energy at present consumed, decreasing the emission of almost 200 tons of CO2 equivalent per year.

1. Introduction
One of the most pressing debates worldwide nowadays is savings in all forms of energy and natural resources conservation [1, 2]. Only the consumption of buildings is around 40% of the energy produced on the planet and its responsible for almost the 30% of greenhouse gas (GHG) emissions [3, 4]. Indoor lighting is the greatest part of the building energy requirement [5]; therefore, in the latest years, new methodologies have been proposed that addresses lamp distribution, to ensure greater illumination [6, 7], as well as several policies that demand the use of better lighting technology.

Regarding to the energy savings by means of luminaries with higher quality, there are, for instance, the use of electroluminescent diodes (LED), which have high energy efficiency standards and are demand in buildings all over the world [8, 9]. LEDs save about 30 and 50% of electricity in buildings due to a remarkable luminous efficiency comparing with fluorescent lamps (LFL) [10, 11]. LFL light is commonly required in Ecuadorian buildings, even though its poor performance; causing visual fatigue and stress after long exposure [12]. These reasons lead to members of the European Union establish the regulations and protocols for energy saving in buildings [13, 14]. Latin-American regulations replicate the good energy saving practices of EU [15], starting by the acquisition and adequate use of low consumption equipment and better technology.

Regarding to the energy savings by rearranging the spatial configuration of the lamp-luminaire assembly, parameters like indoor placement location, work conditions such as: reflectance of ceiling and walls, entry of natural light into the environment, among others [16], are considered, that significantly reduce the electric energy consumption [17]. All the parameters above mentioned contribute to enhance the energy efficiency, whose can be tested based on a modeling analysis of the lighting systems before the construction of buildings [18, 19].
A correct lighting inside classrooms is vital for academic activities. However, this factor represents about 19% of the total amount of energy and 15% of the GHG’s emission all over the world [20]; these are reasons why, before installing lamps, it is essential to consider an exhaustive analysis in terms of lighting requirements and luminary types that minimize the consumption of electricity and GHG’s emission; by means of the DIALUX software (or any else), lighting systems can be performed to appraise the quality of the lamp-luminaire assembly [21].

On the other hand, GHG’s emissions related to electricity consumption depends directly on the type of generation, distribution and use at the destination. Ecuadorian electricity comes largely from hydro power (50.7%), fossil fuels (34.5%) and natural gas (12.6%), however, bio fuels, solar and wind power are not out of the scene.

The main goal of this study is to assess the performance of the current lighting systems of the UTA based on the traditional LFL, versus a most updated system based on the LEDs. Lighting level is the ratio between the luminous flux delivered by the luminaire and the area to be illuminated, for academic activities, the average illumination is between 300 and 700 lux [22]. Lighting level, energy consumption, energy efficiency, homogeneous light distribution, number of luminaries and GHG’s emissions are compare; for having better criteria to install the lighting points in all types of buildings, as specified in the BT25 regulation [23].

2. Methodology
Classroom characteristics were established based on the SLL Code for Lighting 2012. Length, width, height, workplace, spacing, ceiling, wall and floor reflectance of the classrooms and the height of the students’ desk were identified. The reflectance was estimated by utilizing standardized tables [24]. Maximum distance between the measurement points is determined by using equation 1, and the number of points to make the measurements was founded based on the dimensions of the classrooms [25].

\[ p = 0.2 \times 5^{\log(d)} \]  
\[ \text{(1)} \]

Where \( p \) represents maximum distance between point and \( d \) represents longest distance of the classroom.

An observation form designed by Pattini et al [26] was used to collect all the information of the classroom and its lamp luminaire assembly. Once, the parameter \( p \) has been calculated, and the classroom characteristics established, the Sper Scientific 850007 certified luxmeter was used to perform the luminance measurements which provide the needed information to generate the isolines of the selected classrooms. Based on the measurements of the lighting level, the average illumination, maximum and minimum values of the areas presented are estimated, and the installed power of the lighting system is determined. To select the best lamp-luminaire assembly and the analysis of the installed assemblies, equation (2) is used, which corresponds to the energy efficiency value of the installation and installed power in lighting [14].

\[ VEEI = (P \times 100 \text{lux})/(A \times E_m) \]  
\[ \text{(2)} \]

Where \( A \) represents evaluated area of the classroom (\( m^2 \)) and \( E_m \) represents minimum lighting level.

The total amount of electricity consumed was evaluated for one month of operation of the lighting system (MWh/month). Finally, GHG emissions was evaluated by using equation (3), which consider the total energy consumed and emission factor of electricity for generation, distribution and consumption at the destination point.

\[ GHG's \text{ Emissions} = TEC \times (Ef_G + Ef_D) \]  
\[ \text{(3)} \]

Where \( TEC \) represents Total Energy consumed, \( Ef_G \) represents Emission Factor due to electricity generation and \( Ef_D \) represents Emission Factor due to electricity distribution and consumption.
3. Results and discussion
The data has been collected from the UTA’s existing classrooms and based on the current lighting system. Table 1 shows the characteristics of the classrooms and the lamp luminaire assembly used. Considering table 1 and equation (1), measurement points for the current lighting models are obtained and with this data, the behavior of the illuminance in the selected classrooms is determined. The illuminance maintenance factor is the ratio of the luminous flux at a given time to the initial flow, and is estimated based on [23,27].

Table 1. Current characteristics of classroom and lamp luminaire assembly.

| Characteristics                        | Current classroom |
|----------------------------------------|-------------------|
| Length                                 | 9.9 m             |
| Width                                  | 5.8 m             |
| Height                                 | 2.9 m             |
| Plane space work                       | 0.8 m             |
| Reflectance of ceiling and wall        | 79%               |
| Number of luminaires                   | 8                 |
| Number of fluorescent lamps            | 16                |
| Type of lamp                           | 32W LFL           |
| Maintenance factor                     | 0.89              |

Figure 1 shows the average illumination levels measured in the classrooms, the variation of illumination is shown in matrix by using different colors that represent the measured light values. It is observed a low lighting value at the edges of the classroom, the maximum values are below the luminaires. In the center of the classroom, high lighting values are shown, refer to the yellow color, where the luminaires are located, the minimum values are represented by green and cream colors which are located near to the walls due to the luminaries are not available to supply lumens of light properly.

Figure 2 presents the photometric diagram of the LFL SMARTFORM TPS460 luminaire used in classrooms, which expresses the maximum angles of light opening allowed by the lamp housing (90°), lumens emitted by LFL are distributed in a diffuse general form, although, the housing directs this luminous flux to the area to be illuminated, the use of housings with LFL produces a luminous...
efficiency of 70%, losing 30% due to the use of low quality luminaires.

Once the current state of the illumination of the classrooms was analyzed, the selection of several lamp-luminaire sets for the analysis with the DIALux software is considered. Table 2 indicates the characteristics of the proposed sets, 1 type using LED technology and 1 type using LFL technology; the final selection is made based on performance and luminous efficiency.

| Characteristics of the luminaire | LED | LFL |
|----------------------------------|-----|-----|
| Luminaire power [W]              | ENDO RAD706N | TBS318 3xTLD |
| φ luminaire [lm]                 | 39,3 | 108 |
| φ lamps [lm]                     | 5717 | 7204 |
| Luminous efficiency              | 5743 | 9750 |
| Luminous performance [lm/W]      | 100,45% | 73,89% |
|                                  | 145,5 | 66,7 |

Assemblies based on LED technology have a superior performance and luminous efficiency compared to the fluorescent ones, the RAD706N set possesses the highest values of luminous efficiency since it delivers the highest luminous flux using lower power.

Figure 3 illustrates the 2-simulation model performed, DiaLUX software calculates and generates isolines of the lighting levels based on the number of luminaires selected for the simulation, the luminaires are automatically located being adjusted to the lighting parameters recommended for academic activities, in addition, the distribution of luminaires must meet with a minimum number of installation points over an area [23]. In simulation results presented in figure 3, the luminous distribution is shown; minimum points of illumination located at the edges and corners of the work plane, maximum points of illumination located below the luminaires because they are direct points of incidence of the luminous flux. Figure 3(a) shows a more homogeneous or uniform luminous distribution of the model (b), which, on the contrary, there are more variations in its distribution.

![Figure 3](image)

**Figure 3.** Scenarios generated by the DIALux software for luminaires (a) RAD706N (b) TBS318x3.

Table 3 compares the energy efficiency and lighting levels of the current model Ac_1 and the 2 proposed models (a, b). The Ac_1 model has a higher VEEI, this efficiency value is higher than models TBS318x3 based on LFL, on the other hand, LED models RAD706N, denote low values, in addition, the specific power of connection or power relation of the system and the area to be illuminated in LED systems is much lower. Of the proposed models, the average lighting is within the accepted range, except for the Ac_1 model, with values below the recommended one.

In order to select the efficient lighting system, four variables are analyzed (table 4): number of luminaires, light distribution, recommended lighting and relative VEEI; its respective weighting will allow to make an adequate selection, each variable is weighted according to the valuation on the group
of luminaires. There are 3 ways to consider the weighting of each variable: 5% when it does not meet the requirements, 15% when it meets the requirements and 25% when it stands out among the group of luminaires analyzed.

Table 3. Comparison of VEEI parameters and averages of lighting levels.

| Parameters                  | Ac_1 (a) | RAD706N (b) | TBS318x3 |
|-----------------------------|----------|-------------|----------|
| Number of luminaires installed | 8        | 8           | 8        |
| VEEI                        | 3.36     | 1.03        | 2.12     |
| Total power of the classroom [W] | 512      | 314.4       | 864      |
| Specific power of the connection [W/m²] | 8.91     | 5.53        | 15.2     |
| Average level of lighting [lux] | 265      | 536         | 714      |
| Minimum level of illumination [lux] | 142      | 280         | 347      |
| Maximum level of illumination [lux] | 414      | 670         | 929      |

Table 4. Weighting of variables that contribute to the outcome of a scenario.

| Variable                     | Weighting                        | 5%  | 15% | 25% |
|------------------------------|----------------------------------|-----|-----|-----|
| Number                       | High                             | High| Average | Low |  |
| Luminous distribution        | Heterogeneous                    | Heterogeneous | Average | Homogeneous |
| Lighting within the range    | Do not meet                      | Do not meet | Partially meet | Homogeneous |
| Relative VEEI                | High                             | High| Normal | Low |  |

Based on the recommendations stated on table 5, the best scenario (100%) would be a classroom with a small number of luminaires, homogeneous light distribution, compliance with the range of illuminance, and a low relative VEEI value.

Table 5. Evaluation of the selection results of the luminaire models.

| Variable                      | RAD706N | TBS318x3 |
|-------------------------------|---------|----------|
| Number of luminaires          | 15      | 15       |
| Light distribution            | 15      | 15       |
| Lighting within the range     | 25      | 15       |
| Relative VEEI                 | 25      | 15       |
| TOTAL                         | 80%     | 60%      |

Table 5 indicates the evaluation of the selected models according to the sum of the weighted variables, model RAD706N shows the best performance (80%) for its use within the proposed classroom, due to it has the lowest number of luminaries, homogeneous lighting distribution, higher average recommended illuminance and relative energy efficiency value lower than TBS318x3 model.

Table 6 shows the estimate GHG emissions produced by: the model AC_1, which represents the current state of the classrooms, and model RAD706N, which represents the highest lighting efficiency model simulation. It is determined that there is a reduction of around 25% of GHG emissions, which signifies 17.40 tons CO₂e per month and 220 tons CO₂e per year.

In this study, a lighting selection methodology is proposed based mainly on the energy efficiency of the installation, and with several parameters proposed by the lamp luminaire assemble. A correct selection will be the one that meets at least 60% (which means that all its parameters are at least found with average values, according to table 6) of the rating; in case of uncertainty, select the one with the lowest specific connection power.
R would avoid the emission of about 200 tons of CO₂ equivalent each year [29].

4. Conclusions
The selection of efficient lighting system reduces considerably GHG´s emissions. It is estimated that by replacing the LFL luminaires with LEDs, (model RAD760), 0.2 kW of electrical energy will be consumed per classroom, 100 kW in the entire university campus, which means a monthly savings of 25 MWh/month compared to the current status of the lighting systems (close to 105 MW/h) [28], this would avoid the emission of about 200 tons of CO₂ equivalent each year [29].

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Table 6. GHG’s emissions – AC_1 vs. RAD706N.

| Type of Generation | Installed Power | Electric Consumption (KWh/month) | GHG Emissions (tons CO₂e / month) | CO₂e Reduction |
|--------------------|-----------------|---------------------------------|----------------------------------|----------------|
| Hydro power        | 50,70%          | 53235                           | 32,13                            | 7,65           |
| Oil                | 34,50%          | 36225                           | 30,99                            | 7,38           |
| Gas                | 12,60%          | 13230                           | 8,56                             | 2,04           |
| Bio fuels          | 1,50%           | 1575                            | 1,30                             | 0,31           |
| Solar + Wind       | 0,70%           | 546                             | 0,08                             | 0,02           |
| TOTAL:             | 100,00%         | 104811                          | 73,06                            | 17,40          |

**Table 6. GHG’s emissions – AC_1 vs. RAD706N.**
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