Characterization of hybrid lighting systems of the Electrical Engineering Building in the Industrial University of Santander

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Abstract. This paper presents an analysis of hybrid lighting systems of Electrical Engineering Building in the Industrial University of Santander, which is a pilot of green building for warm-tropical conditions. Analysis of lighting performance of inner spaces is based on lighting curves obtained from characterization of daylighting systems of these spaces. A computation tool was made in Excel-Visual Basic to simulate the behaviour of artificial lighting system considering artificial control system, user behaviour and solar condition. Also, this tool allows to estimate the electrical energy consumption of the lighting system for a day, a month and a year.

1. Introduction

Hybrid lighting systems – HLS combine daylight and artificial light. Its operation is focused on control of artificial lighting in response to natural illuminance for a given time [1], [2]. Currently, it is evident that there is a significant range of devices for implementing such systems. However, the number of studies about the detailed operation is reduced, particularly about daylighting scenarios.

Therefore, it is necessary to carry out several analysis of the daylighting behavior in inner spaces. This can be performed by means of Daylight Factor - DF, which is one percentage indicator calculated as the ratio between the illuminance at a point inside and the outside illuminance.

This paper presents the lighting characterization for some inner spaces of the Electrical Engineering Building (EEB) by calculating DF and artificial lighting measurements. EEB is a green building pilot of the Industrial University of Santander (Bucaramanga, Colombia), and works as a laboratory for studying systems aimed at reducing energy consumption in buildings for warm tropical climate.

The lighting curves for each space is based on the artificial lighting level for nights, the set point of operation of the photocells and the contribution of natural light (DF). Additionally, a study was conducted for selecting the outer reference for DF calculation, outdoor terrace (horizontal) and front (vertical) was performed. To display the information collected a computational tool in Excel (ALE3T) was made, with which can be estimated the lighting performance and energy consumption according to space, time, date, level of solar radiation incident.

This study is presented in this document as follows: Section II describes general considerations, Section III exposes the methodology and results, and finally, Section IV presents the Conclusions.
2. General considerations

2.1. Hybrid lighting systems
Daylight is really potent by itself, and it is possible to improve it using smart architecture as an aesthetic method and technical tool, guaranteeing excellent luminance levels and comfort [3]. But, even so, it can get better using hybrid lighting system concept. HLS are groups of techniques and equipment that respond to the natural lighting contribution by artificial lighting. These are configured to respond to the contribution of natural light. Because of this, design should consider that incident solar radiation on windows depends on the type of sky; additionally, the daylighting distribution is as a function of technical characteristic of the inner space. However, this study is not done in detail. Figure 1 shows a typical HLS.

These systems provide benefits such as cost savings in billing for lower energy consumption, and reduction of the carbon footprint in constructions. For example, Chow *et al.* [4] tested a daylight harvesting system with T5 fluorescent lamps for individual offices adjoining the atrium in Hong Kong, achieving an energy saving from 59% to 75%. These good practices improve the level of sustainability in buildings while maintaining comfort and facility of use [5].

In Colombia, the technical regulation about lighting is called “Reglamento Técnico de Iluminación y Alumbrado Público” – RETILAP. Its Section 450 demands that new nonresidential buildings (>500m²) must have lighting control systems, specifically use of natural lighting and control artificial lighting [6].

2.2. Daylight factor
The integration of hybrid lighting systems is based on natural lighting. The measurable parameters regarding lighting can be dimensional (illuminance), dimensionless factor (uniformity) and percentage ($Df$ and glare) [6]. Daylight Factor ($Df$) is the term applied to the percentage of the division between internal illuminance produced by natural light up to the working plane ($E_{int}$) and the illuminance on the outside ($E_{ext}$), determined in the same instant with a uniformly overcast sky without obstructions [6]. In this particular case (classroom) talking about Colombia, $Df$ value must be minimum 2% [6]. $Df$ calculus can be so easy as equation (1) or can considering a lot of parameters like the relative air mass or the luminous turbidity as show in [7], [8]. For this paper was taken standard equation:

$$Df = \frac{E_{int}}{E_{ext}} \times 100\%$$ (1)
\( E_{\text{ext}} \) is typically attributed to the horizontal illuminance measured in terrace, such as shown in [7], [9]; however, it is not reliable for tropical zone due to the sun movement. Specifically, it is possible to evidence that if the horizontal solar radiation is the same for two different dates in the year, the \( D_f \) will be different. This is because the solar height can be significantly different, and therefore varies the amount of solar radiation that may enter through the openings. Therefore, the \( D_f \) was considered with reference to the facade.

### 3. Methodology

This research is conducted in three stages: (i) the illuminance measurement of natural and artificial lighting in selected areas, (ii) the construction of the virtual model of the EEB in DIALux, and (iii) the creation of the virtual tool to estimate illuminance and energy consumption.

The study was performed in Electrical Engineering Building from the Industrial University of Santander, which is located in the city of Bucaramanga (Lat. 7.1°N and Long. 71.3°W). This building is 969 meters above sea level in a tropical zone. It has an average hours of sunlight 12.1 and solar radiation of 4.8 kWh/m²/day [10]. Integrated hybrid lighting strategies in EEB are presented in Table 1.

| Table 1. Current hybrid lighting strategies in EEB. |
|---------------------------------------------------|
| **Strategy** | **Luminaries** | **Control** |
|--------------|----------------|-------------|
| Type I       | Fluorescent On/Off | Occupancy sensor with ON/OFF photocell |
| Type II      | Fluorescent On/Off | Occupancy sensor and ON/OFF photocell |
| Type III     | Dimming fluorescent | Occupancy sensor and dimming photocell |
| Smart hybrid I | Dimming fluorescent | Occupancy sensor and dimming photocell, controlled by BAS (Building Automation System) |
| Smart hybrid II | Dimming fluorescent and solar tubes | Occupancy sensor, dimming photocell and solar tubes, controlled by BAS (Building Automation System) |

### 3.1. Light metering

The measurement step consisted of meshing of spaces, daylighting measurement, data collection, \( D_f \) estimation, artificial illuminance measurement and estimation of the set point in spaces. The measurement was performed with lux meters. Meshing is the location of points according to the sizes of the spaces. Figure 2 depicts an example of meshing for a space.

![Figure 2](image-url)
Daylight is monitored from 08:00 until 18:00 according to the mesh for a height of 75 cm; simultaneously, the incident illuminance on façade was measured. The incident illuminance on the terrace was obtained by measuring the horizontal global solar radiation obtained from the weather station and using a conversion factor (115 lux/W/m$^2$). Later, the $Df$ was calculated for the two references, terrace and facade.

Figure 3 shows the results obtained for the classroom 206. Figure 3. (a) illustrates the high variability $Df$ when is calculated according to the illuminance on the terrace. Conversely, Figure 3. (b) shows a tendency uniform for $Df$ calculated according to the illuminance on the façade, being the best option. Figure 4 shows a 3D representation of $Df$ for the classroom 206 mesh.

Measurement of artificial lighting was performed during evening time (after sunset) (> 6:00 pm) considering the established meshing. Next, the operating set point of the photocells is estimated, which is the minimum value of daylighting contribution that can exist without the need to turn on the lamps.

3.2. Virtual building development

The virtual model of the building was made with the DIALux software (v4.12). The data from simulations describes similar results to analysis based on measurements. The variables analyzed were artificial illuminance and $Df$. The virtual model allows to study several scenarios in order to predict lighting behavior. These information is considered by ALE3T to estimate the energy consumption of the lighting system.

![Figure 3](image1.png)

**Figure 3.** Hourly $Df$ in classroom 206 according to distance to window for two references: (a) $Df$ regard to terrace; (b) $Df$ regard to facade.

![Figure 4](image2.png)

**Figure 4.** Performance of $Df$-facade in classroom 206 (8:00 am).
3.3. **Computational tool ALE3T**

There are some techniques or programs to determinate Daylight, such as shown in [11], [12]. For this tool, Daylight is determined by *DF*. It means, it takes a reference *DF* (Measured), and this is multiplied by horizontal illuminance measured in terrace.

ALE3T is a computational tool developed in Microsoft Excel through Visual Basic Editor. This aims to estimate the power consumption by artificial lighting in specific spaces of Electrical Engineering Building. Also, it can display demand curves, hybrid illuminance and *Df*. The Figure 5.(a) presents the main menu of the tool, where is possible to define the variables, such as space, occupancy, set point for photocells, month and horizontal solar radiation. While Figure 5.(b) is a snapshot of the graphical results.

The first graph ("Average illuminance by source for each hour of the day") shows the artificial illuminance (green line), which is activated when there is occupancy (black line) and average natural illuminance (red dots) is below set point level (orange line). Also, the minimum natural lighting in the space (celestial points) and combined illuminance (purple line) is shown. The second graph allows to know the energy performance, through the power curve (red line) and energy consumption (blue line).

![Figure 5. ALE3T: (a) Main Menu; (b) Some graphical results.](image)

4. **Conclusions**

From the comparison of the *Df* for the two references analyzed (terrace and façade), it was possible to conclude that the method of calculating the *Df* with reference to the radiation collected on the terrace is not the recommendable method for tropical places, mainly due to the apparent solar movement in these areas. Therefore, it is suggested using *Df* – façade.

According to the performance curves of artificial lighting, it was possible to deduce that the illuminance of space is not uniform and varies depending on the configuration the luminaire system and the degree of reflection from the walls and windows.

The computational tool ALE3T fulfills its main objective that is to estimate the energy consumption of the lighting system, and exposes the lighting curves for inner spaces of EEB. The tool should be improved considering aspect such as: time analysis of 5 minutes (currently the analysis is hourly), presentation scenario where the curtain is used and the lamps are partially turned off, and including of the sun tubes (zenithal light).
Comparing the five hybrid lighting strategies in EEB, it found the major power savings between them. This corresponds to labeled in this article Smart hybrid II, because in the same scenario this one consumes less energy, obtaining saves near to 50% respect to worse strategy (Type I), because the consumption are around 2,4 kWh/day and 4,8 kWh/day, respectively.

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