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2nd International Electronic Conference on Sensors and Applications
15–30 November 2015

www.mdpi.com/journal/sensors

Conference Proceedings Paper – Sensors and Applications

A Methodology for Daylight Optimization of Buildings

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Published: 5 November 2015

Abstract: Recently, several illuminance studies are being done focusing on the construction field due to the trend of saving energy and the design of sustainable buildings. Nevertheless, studies that match outside daylight measurements with building inside illumination measurement or with building scale models measurement are not found. The aim of this work is to obtain the number of luminaires and electricity consumption that allows determining the illuminances in a projected building, based on a scale model and daylight measurements. This way, it is possible to optimize some building parameters as orientation, numbers and sizes of the windows, etc…, to obtain the best conditions for the maximum use of natural light with the consistently energy saving. To do this, the global illuminance on horizontal surfaces within a room and in its scale model for different distances from the façade windows has been measured with photometric sensors previously calibrated and connected to dataloggers. Also, one photometric sensor is placed outside the model to known the global exterior horizontal illuminance. From these measures a ratio between global horizontal illuminance in the real space and in the scale model has been obtained. This ratio depends on the global horizontal exterior illuminance and the facade distance.

Keywords: illuminance measurements; scale model; daylighting; photometric sensors

1. Introduction

Now a day there is a need of meeting the requirements of European energy strategy and policy for reducing energy consumption in 2020 [1]. In industrialized countries, lighting constitutes about 5%–15% of the total electric energy consumption [2], and in office buildings this increases up to 25%–35% of the total energy consumed [3]. In order to reduce these costs many researches [4–6], have been carried out, studding cost-effective technology and proposing solutions for this energy saving problem.

In order to optimise the use of daylight to save energy by limiting the use of artificial light, many factors should be taken into account: the type of sky, daylight hours, orientation, location, *etc.* In the present paper, a comparison between measures taken through photometric sensors inside a real classroom and a scale model of this classroom have been done, in order to be able to determine the illuminance inside a real location through its scale model.

2. Description and Data Record

In this work, a comparative study between illuminance measures taken inside real building (the classroom 2S2 at the Architecture School of the Technical University of Madrid (ETSAM) and a 1:15 scale model of this classroom has been made. To take the illuminance measurements, 23 photometric sensors LI-COR Li-210 (Figure 1) with their corresponding datalogger Li-1000 were used.

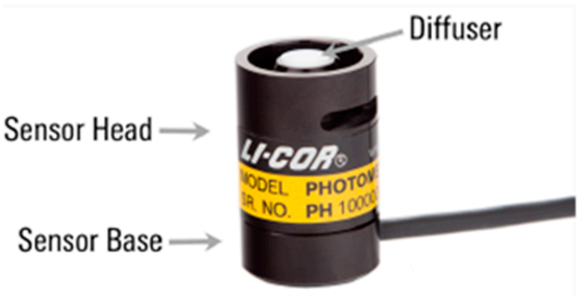

Figure 1. LI-COR Li-210 photometric sensor Source: Photometric sensors LI-COR Li-210 manual [7].

The Li-210 sensors consist of a sensor head attached to a removable base and cable assembly. It measures the light as perceived by the human eye (visible radiation) with a silicon photodiode mounted under a cosine-corrected acrylic diffuser. The sensor output is a current (μA) signal, which is converted into units of radiation (klux) through a multiplier.

These sensors have the following characteristic: a typical error of ± 5% traceable to the U.S. National Institute of Standards and Technology (NIST), an azimuth error less than ± 1% over 360° at 45° elevation 30 μA per 100 klux sensitivity, 2.36 cm diameter x 3.63 cm dimensions, a ± 0.15% per °C maximum temperature dependence and a response time of less than 1 μs (2 m cable terminated into a 604 Ω load).

From the 23 photometric sensors used, 11 Sensors were placed in the classroom, 11 within the scale model and 1 on the roof outside the scale model .The sensors inside the classroom were placed on a working level (0.85m, according to Spanish ergonomic laws), aligned with one of the windows, 0.5m separated from each other (Figure 2) The scale model (fig3) and the sensor for the external global illuminance measurement were placed on the north wing roof of the ETSAM (40º 25’ N, 3º 41’ W) which is situated two floors above the classroom with the same orientation.

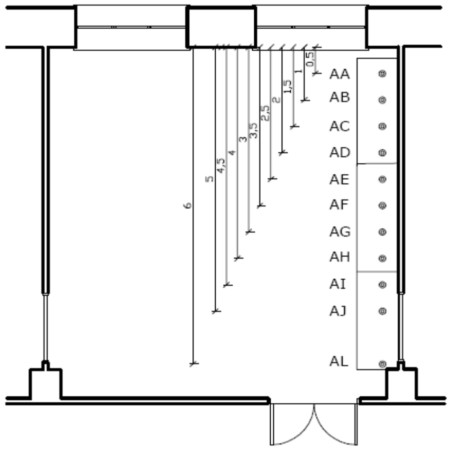

Figure 2. 2S2 classroom E:1/100 (m).

Figure 3. Scale model (1:15).

Measures have been taken under a clear sky during the month of July when there were no classes at the university. Although the recorded measures are not the same every day, the relationship between illuminances of the classroom and the scale model in relation to the exterior illuminance may have an error of ±2%. Therefore, in this paper only the graphics and calculations corresponding to one day (19th of July 2014) are shown.

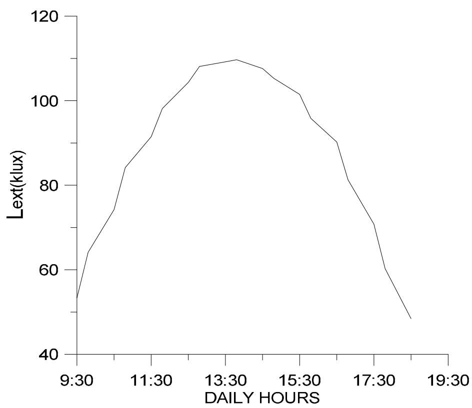

Figure 4. Exterior daily global horizontal illuminance evolution.

3. Illuminance Level Analysis

Daily global horizontal illuminance measurements made by the external photometric sensor from 10:00 until 19:00 are shown in Figure 4.

The daily global horizontal illuminance evolutions at different distances from the window inside the classroom (L_c) are shown on Figure 5. The same evolution of 11 sensors placed in the scale model (L_m) is shown on Figure 6.

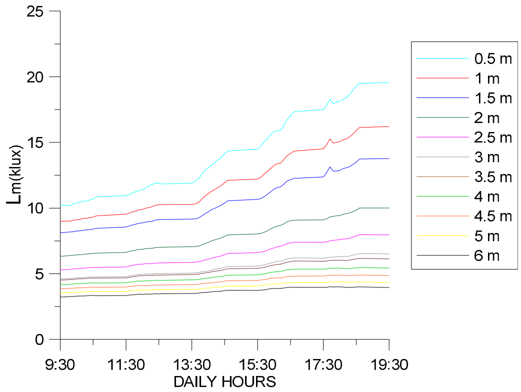

Figure 5. Classroom illuminance.

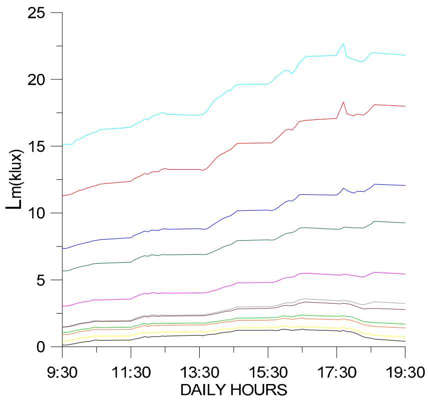

Figure 6. Model illuminance.

As expected, both Figs. 3 and 4 show how the illuminance decreases as we move away from the window. Comparing the results of these two graphs, it can be appreciated that, for all distances, illuminances are always higher in the model than in the classroom because, among other things, there is no glass, only holes in the windows of the scale model.

4. Results and Discussion

Since the illuminances of both classroom and scale model, come from the light outside, we have checked if this relationship is linear. On the base of the global horizontal illuminance data from classroom, scale model and roof, the ratio between classroom and scale model illuminance (L_c/L_m) *vs.* exterior illuminance (L_{ext}) has been analyzed using the 11 pairs of sensors. As exterior illuminance increases from sunrise until noon and decreases from noon until sunset, the analysis of only the afternoon behavior will do. The obtained results from each sensor are shown in Figure 5. A linear fit was made from each. These fits are shown in Figure 6.

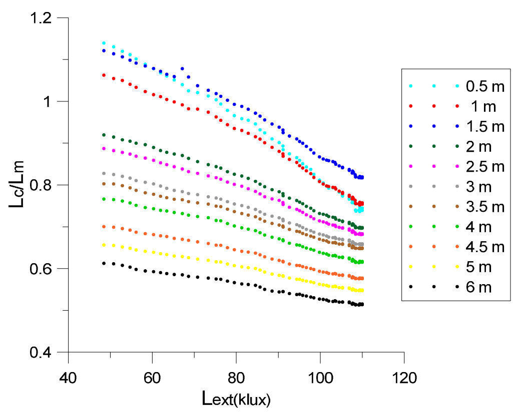

Figure 5. Ratio between classroom (L_c) and model (L_m) illuminances vs. the exterior illuminances (L_{ext}) at different distances from the window.

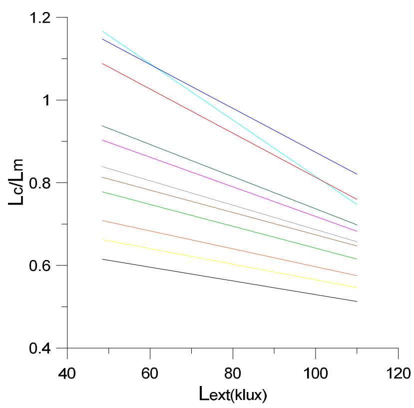

Figure 6. Fitted lines of the ratio between classroom (L_c) and scale model (L_m) illuminances vs. the exterior illuminances (L_{ext}).

The equations of these fitted lines depend on their distance to the window. Taking as generic adjustment next equation:

$$L_c/L_m = a\,L_{ext} + b \qquad (1)$$

The slope (a), the intercept (b) and the correlation coefficient (r^2) for different distances from the façade are shown in Table 1.

Table 1. The a, b parameters and the correlation coefficient "r^2" for different distances from the façade (d).

d	a	b	r^2
0.5	$8.312\text{x}10^{-3}$	0.407	0.963
1.0	$6.818\text{x}10^{-3}$	0.556	0.966
1.5	$5.920\ \text{x}10^{-3}$	0.558	0.973
2.0	$6.201\ \text{x}10^{-3}$	0.742	0.979
2.5	$6.053\ \text{x}10^{-3}$	0.791	0.980
3.0	$5.543\text{x}10^{-3}$	0.906	0.984
3.5	$5.299\ \text{x}10^{-3}$	0.957	0.985
4.0	$5.711\ \text{x}10^{-3}$	0.991	0.983
4.5	$5.480\ \text{x}10^{-3}$	1.131	0.9885
5.0	$5.344\ \text{x}10^{-3}$	1.238	0.990
6.0	$5.391\ \text{x}10^{-3}$	1.353	0.991

From these equations, a model that allows determining illuminances in the classroom from model and external illuminances at 0.5m from the wall (Figure 2) depending on the distance to the window is obtained. The statistical study of the slope (a) variation *versus* the distance to the window (d) shows that data follow a positively sloped linear distribution. Most of the data lays between the confidence limits at 95% and all data are within the limits of prediction and no atypical values are seen. This implies that the relationship between the two variables is a linear model whose equation is:

$$a= (8.976x10^{-4}\ d - 6.273x10^{-3})\ ;\ r^2 = 0.895 \quad (2)$$

The statistical study of the intercept (b) variation based on its distance to the window (d) is shows that data follow a linear distribution with negative slope. Most of the data is within the confidence limits at 95%, all data are among the prediction limits and no atypical values are seen. This implies that the relationship between the two variables is a linear model whose equation is:

$$b= (-0.150\ d + 1.507)\ ;\ r^2 = 0.939 \quad (3)$$

These two models have a p-value of 0.0000<0.5 which indicates that there is a significant statistical relationship between the two variables with a confidence level of 95%. The subsequent diagnosis of residues proves that the analysis is correct. Consequently, the equation that shows the global illuminance on a horizontal plane in the classroom (L_c) at 0.5m from de wall, from its scale model (L_m), depending on the exterior illuminance (L_e) and the distance to the window (d), in the afternoon, is:

$$L_c = [(0.898\ d - 6.273) x\ 10^{-3} L_{ext} - 0.150\ d + 1.507\ ] L_m \quad (4)$$

5. Conclusions

This paper introduces a new way to determine global horizontal illuminances inside of buildings. A general equation to obtain global horizontal illuminance values in a real enclosure from measurements of global horizontal illuminances taken in and outside an exterior scale model of this enclosure is obtained.

Global horizontal illuminance measurements have been taken simultaneously on a clear sky day within a building as well as in and outside a scale model. From these measurements, the ratio between illuminances in real space and in scale model has been obtained.

It can be seen as the illuminance measurements taken by the photometric sensors Li-210, are logical as they decreases the further away they are from the façade window.

It has been observed that there is a linear dependence between the distance to the façade and the ratio between de global horizontal measures of the classroom and its scale model with the outside global horizontal measuremets.

Acknowledgments

This work has been supported by Universidad Politécnica de Madrid.

Conflicts of Interest

"The authors declare no conflict of interest".

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