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Assessing the performance of led lighting in a classroom - simulations versus experiments

Tiberiu Catalina[1], Alexandra Ene[2], Andrei Marian Istrate[3]

[1,2,3] Technical University of Civil Engineering Bucharest, Faculty of Building Services
Adress: Bulevardul Lacul Tei 124,sector 2, București 020396, Romania

E-mails: tiberiu.catalina@gmail.com; alexandra.angelescu@gmail.com ; andreiistrate85@gmail.com

Rezumat. *Iluminatul interior poate avea un impact imens asupra consumului de energie și asupra confortului vizual. Scopul acestei lucrări este de a determina impactul utilizării unor noi soluții de iluminat într-o clasă. În acest scop, sursele de iluminat fluorescente au fost înlocuite cu surse noi de iluminat tip LED și au fost efectuate măsurători ale nivelului de iluminare înainte și după modificare. Pe de altă parte, aceeași cameră a fost simulată utilizând un software de iluminat specializat. Rezultatele au arătat corelația dintre cele două abordări și de asemenea, calculele financiare au subliniat impactul asupra consumului de energie și timpul de rambursare a investiției. A fost măsurată o îmbunătățire a confortului vizual de 42%, în timp ce reducerea costurilor a fost de 250 de euro / an, ceea ce a condus la un timp redus de returnare (mai puțin de 5 ani).*

Keywords: *LED lighting, energy savings, illuminance levels, numerical simulations, experimental measurements*

Abstract. *Interior lighting has a huge impact on energy consumption and visual comfort. The aim of this paper is to determine the impact of using new lighting solutions in a classroom. For this purpose, fluorescent lighting sources were replaced with new LED lighting sources and illuminance level measurements were conducted before and after the modification. On the other hand, the same room was simulated using specialized lighting software. The results showed the correlation between the two approaches and financial calculations highlighted the impact on energy consumption and payback time of the investment. An improvement on the visual comfort of 42% was measured while the cost economy was 250 euros/year resulting in a low payback time (less than 5 years).*

1. Introduction

Indoor air quality represents one of the most important factors in determining the comfort of people inside a building, especially when talking about schools. Thereby, is important to provide a high indoor air quality for a good performance and productivity of students and teachers [1]. Based on a survey, it was found a highly correlation between indoor air quality and the activity of the population in a college building level in Korea [2]. However, indoor air quality is only one parameter used to evaluate the environmental quality of an enclosed space. For example, noise pollution or bad lighting can decrease greatly the occupants' perception of the chamber. Therefore, there are several factors which determine the environmental comfort of a chamber, and visual comfort represents key criteria when evaluating a classroom. According to NP06-2002 the maintained illuminance for a classroom is 300 lux [3], where the maintained illuminance refers to the average illuminance measured on a specified surface and it is not allowed to have lower values. Studies showed that the best performance in reading is under normal illumination intensity of 600 lux, because high illumination intensity can cause screen images to fade and many reflections of the surrounding surfaces [4]. The illuminance in a classroom is required to be right in order to conduct activities like reading and writing on desks and board [5]. Nevertheless, lighting installation should perform the visual aspect of a space without wasting energy and, at the same time, it is required not to compromise the lighting requirements just to reduce the energy consumption [6].

Therefore, windows can have a huge impact on visual aspect and energy consumption. Studies also showed that natural or artificial light have a huge impact on people and in the quality of sleep at home, after they have been subjected to this environmental condition at work [7]. Michael and Heraclous conducted a study on typical classroom in Cyprus and showed that an intense glare appeared on the west and east oriented classrooms on the working surfaces because of the inappropriate shading devices. Also, the study highlighted that the curtains were kept closed through the day to control the over lighting problems [8].

A study carried out in an experimental room where it was compared the comfort ratings and the changing of the clothing levels of the subjects under different color light temperature of 2700K (“warm”) and 6500K (“cold”) showed that participants tend to put on an extra clothing item when using 6500K then the 2700K light bulbs. Furthermore, the same study showed that females tended to put on more clothing objects than men [9]. Another study held in a test room chamber showed an interesting approach for saving energy by underlining the importance of the pre-set environmental conditions of a room. Therefore, study showed that pre-setting higher values of illuminance requires higher level of adjusting the illuminance on desk by the worker [10].

Nowadays, LEDs are used worldwide in both interior and exterior lighting systems due to the low energy consumption, high light-flux efficiency and also to their ability to maintain the light-flux constant value for a long period of time [11]. LEDs are formed from a semiconductor material doped with impurities in order to create a p-n junction and the current flows only from the “p” side which represents the anode, to the “n” side which is the cathode. When applying a suitable voltage, electrons can recombine with electron holes and releases energy in form of a photon. The band gap energy of the materials forming the p-n junction determines the color of the light emitted by the LEDs [12]. Significant energy consumption can be made by using LEDs with a fuzzy logic controller and also for a constant illumination on a surface even when the amount of daylight is constantly changing [13]. Hence, we aim to determine the difference between fluorescent and LED lighting sources and the impact on visual comfort and energy consumption. Iacomussi showed in 2015 that if the intensity and luminance distribution of the LEDs is not different from the fluorescent light sources, it can be applied to LEDs the available metrics for discomfort glare. The study highlighted that an improving performance of the LEDs' lighting can be made by equipping the SSL luminaires with diffusers or by designing lighting so that it is hidden from a direct view of the occupant's eyes [14]. When designing a classroom before installing LED luminaire a correct decision is to use numerical simulations that can help us decide the number and positions of the luminaires. In this article we aim to show how accurate can be lighting simulations by comparing the data with experimental measurements.

2. Description of the classroom

Both numerical simulations and experimental campaign were made for a classroom situated in "Mihai Viteazul" college from Bucharest, Romania. The college has a good tradition from the students' performance point of view and also being more than 100 years old. The investigated classroom presents non-insulated brick walls with a width of about 1m. It also presents three identical double wood pane windows with a west orientation. The classroom presents a total volume of 300 m^3 with the following dimensions: 9 m length, 6 m width and 4.9 m height. The classroom presents 9 lamps with 2 florescent lighting sources of 36 W and a total consumption of the lamp of 84 Wh. They were replaced by 9 lamps type LED GEWISS GWS 3236P SMART with a total consumption of a lamp of 43 Wh.

Fig. 1 – 3D representation of the classroom

Fig. 2 – The real classroom

3. Numerical simulations

The numerical simulations were performed by means of DIALux EVO. This software that can design, calculate and visualize professionally lighting systems by using the catalogs of the world's leading luminaire manufacturers, making simulations meet reality as far as possible.

This investigation presents the aim of highlighting the impact on the illuminance levels and the energy consumption of a classroom by changing the actual fluorescent lighting luminaires with new LED sources. Using the exact geometrical characteristics of the investigated room the LED GEWISS GWS 3236P SMART luminaire were placed and simulations were performed. On the Figure 3 it was pointed out the nine points used for comparison with the experimental measurements.

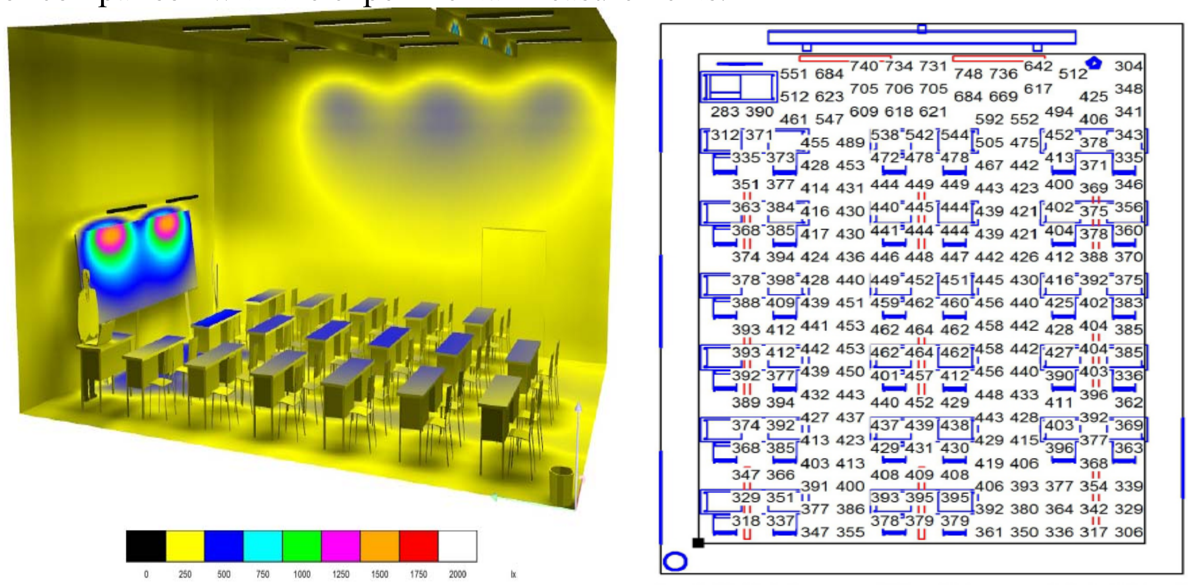

Fig. 3 – Illuminance levels (3D view and plane view) from simulations

The simulations showed that the new LED lighting sources produce around 250 lux on the interior surfaces of the classroom and around 500 lux on board and working surfaces of the investigated classroom. The software showed that the average illuminance at a height of 1.2 m from the room's floor is 426 lux which represents a very good value that meets the European standards. A calculation on the economic impact of the luminaires replacement with LED technology was also conducted (see Table 1).

Table 1

Financial impact of the new lighting system

Fluorescent lighting sources						
Lamp's type	Nb. Lamp [units]	Annual consumption lamp [kWh]	Annual consumption [kWh]	Annual cost consumption [euro]	Annual maintenance cost [euro]	Total annual cost [euro]
Classic luminaire 2x36 W	9	149.7	1646.6	192.19	143	335.19
LED lighting sources						
Lamp's type	Nb. Lamp [units]	Annual consumption lamp [kWh]	Annual consumption [kWh]	Annual cost consumption [euro]	Annual maintenance cost [euro]	Total annual cost [euro]
LED Gewiss GWS3236 P Smart	9	69.93	769.3	84.66	0	84.66

The table 1 shows that by using fluorescent lighting sources, a total consumption of 1646.6 kWh/year can result, meaning 336 euro in a year for energy and maintenance costs, while the same number of LED lighting sources can lead to 769.3 kWh, meaning 84.66 euro in a year. This represents an energy saving of 55.95% that can be paid off in 3 years (770 euros initial investment) and can have a benefit of about 3300 euro for the entire lifetime of the lighting sources. The calculations were made taking into consideration that the lifetime of a LED lighting source is 50.000 h and the price of energy of 0.11 euro/kWh. It was considered a functioning time of the lighting sources of 8 hours a day and 260 days in a year. It should also be mentioned that the financial discussion was done in euro and it does not implies VAT taxes.

3. Experimental campaign

The experimental campaign took place in the classroom presented in the paragraphs above. The illuminance level was measured in 9 different points inside the investigated chamber by means of the Light meter LX – 1102 which has a wide range of measuring possibilities from 40 lux to 400.000 lux and an accuracy of 3% of the measured value. The Light meter was placed on the students' working desks, in different parts of the room as shown in Figure 3. The measuring campaign was conducted for the same points before and after replacing the lighting sources.
The experimental campaign showed that the fluorescent lighting sources produce around 300 lux for most of the measured points while the new LED lighting sources raised the illuminance values up to 524 lux. It can be seen that for the first three points measured, the illuminance level is lower than any other points in the classroom. This could be due to the fact that no source of light is found above the desks. On the other hand, it can be also highlighted that the middle part of the classroom benefits of more visual comfort for both lighting solutions. The average illuminance value of the

measurement points was 274 lux for the fluorescent lighting sources, while for the LED sources reached the average value of 421 lux. This represents an important improvement of the visual comfort of the occupants. Furthermore, the second graphic from Figure 5 shows that the highest level of visual comfort was obtained for point 9, an illuminance level higher with about 40 %.

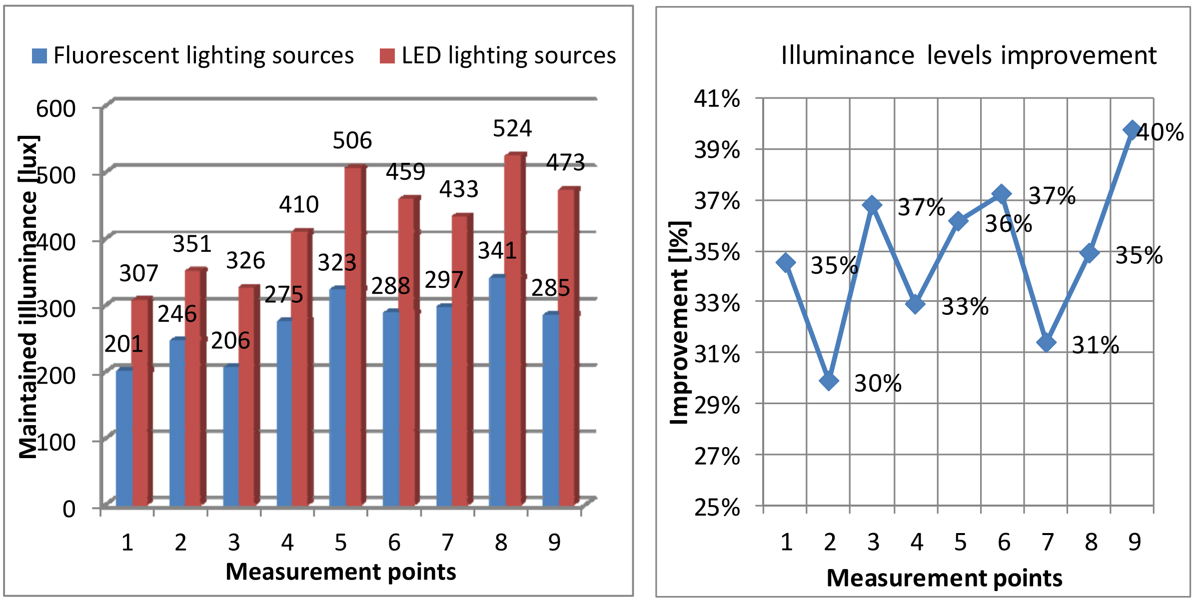

Fig. 5 – Illuminance levels and the visual comfort improvement for the measurement points

4. Correlation between numerical simulations and experimental approach

Figure 6 shows the results obtained by numerical simulations and experimental measurements for the 9 points. It can be observed that the relative error rises significantly from negative values for the first three points up to 15 % for the last two points. Furthermore, it can be highlighted that for the first three measurement points, the absolute error between numerical simulations and experiment is negative and never exceeded more than 50 lux. On the other hand, absolute error rises drastically to positive values up to 85 lux, representing a relative error of 16 %, which represents the most significant one. At the opposite pole, in the middle points (4 and 5) the numerical simulations results are very close to the experimental measurements with absolute errors of 6 lux, meaning only 1% relative error. Another reason for the differences could be the fact that the absorption coefficients of the walls may have been influencing the illuminance level in the experiment due to all the existing posters hanged on the walls.

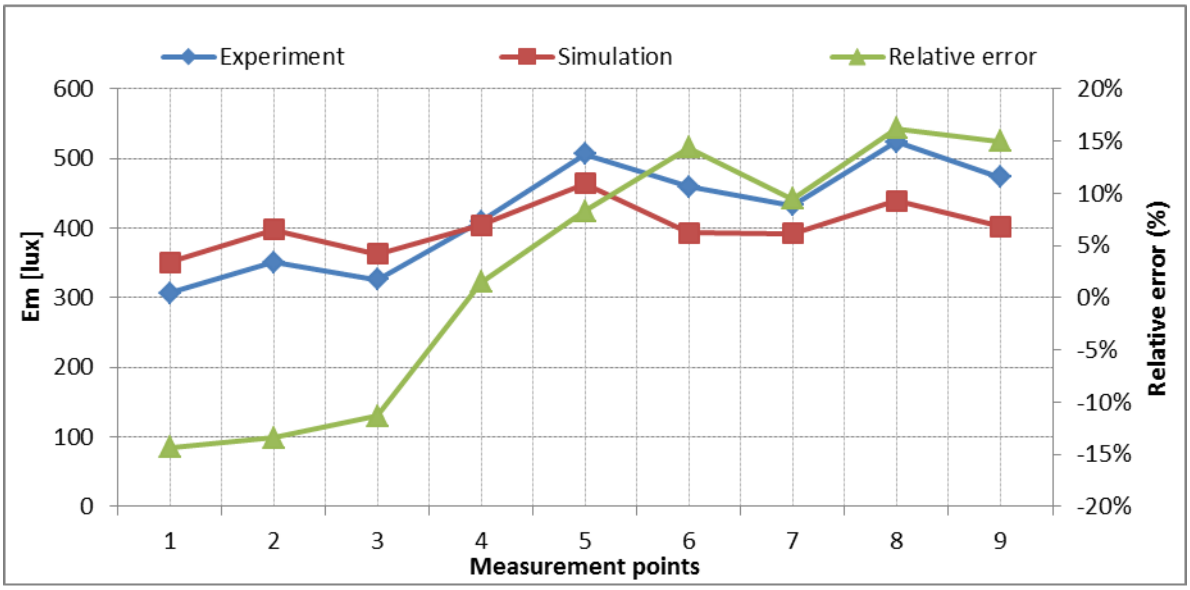

Figure 6 – Comparison between numerical simulations and experimental measurements

5. Conclusions

This paper presents the importance on both, visual comfort and energy savings on a classroom by changing the lighting sources from fluorescent types to LEDs. Using the same number of lamps as the fluorescent lighting sources, but only containing LED lighting sources, it was found a huge improvement in visual comfort of up to 40%. Further on, the financial costs of the investment were determined, showing that the payback time would be within three years and the energy consumption with 55% less than traditions lighting.
By measuring the illuminance level to 9 different points in the classroom and then simulating the same chamber by means of 3D DIALux EVO software, the results showed that maximum relative errors of 16% (average error 11%) while the maximum absolute errors are up to 85 lux. Despite an initial investment of 770 euros the payback time is low, therefore this solution is recommended to be implemented in all schools.

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