Effect of light distribution in a scale model due to different light shelves

Efecto de la distribución de la luz en una maqueta debido a diferentes bandejas de luz

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Keywords

Light-shelf; classroom illumination; scale models; glare; daylight; tropics.

Abstract

The aim of this experiment is to study the effect of light distribution in scale models of a real classroom due to different light shelves.

The construction of scale models of a classroom of the TEC´s Campus Tecnológico Local San José was carried out with taking the color of the ceiling as variable and maintaining its shape. For the cases of study, the performance of light shelves was analyzed to measure distribution of natural lighting coming from the window to the farthest spaces of the classroom, as well as their effectiveness as solar protection.

Three time slots were analyzed, morning, noon and afternoon, during December 2018 to January 2019, taking lighting measurements outside and within the scale model. The analyzed variables can be summarized as: color of the ceiling, shape of the light trays, and color applied to the walls and surfaces of the classroom.

From the results obtained, it is concluded that there are still large gaps in the understanding of how to achieve a uniform distribution of lighting inside a room, avoiding high visual contrasts, this is especially important in a classroom where there must be a priority in the visual comfort of its users. The specific use of flat light shelves showed effective both as a sunscreen element and to redirect light to spaces far away from the window.

Palabras clave

Bandeja de luz; iluminación de aula; maquetas; deslumbramiento; luz diurna; trópico.

Resumen

El objetivo de este experimento es estudiar el efecto de la distribución de la luz en modelos a escala de un aula real debido a diferentes bandejas de luz.

La construcción de maquetas de un aula del TEC Campus Tecnológico Local San José se llevó a cabo tomando como variable de control el color del techo y manteniendo su forma. Para los casos de estudio, se analizó el comportamiento de las bandejas de luz para medir la distribución de la luz natural proveniente de la ventana hacia los espacios más alejados de la misma, así como su efectividad como protección solar.

Se analizaron tres franjas horarias, mañana, mediodía y tarde, de diciembre de 2018 a enero de 2019, tomando medidas de iluminación fuera y dentro de la maqueta. Las variables analizadas se pueden resumir en: color del techo, forma de las bandejas de luz y color aplicado a las paredes y superficies del aula.

De los resultados obtenidos se concluye que aún existen grandes lagunas en el entendimiento de cómo lograr una distribución uniforme de la iluminación dentro de una sala, evitando altos contrastes visuales, esto es especialmente importante en un aula donde se debe dar una prioridad en el comodidad visual de sus usuarios. El uso específico de bandejas de luz plana se mostró efectivo tanto como elemento de protección solar como para redirigir la luz a espacios alejados de la ventana.

Introduction

Costa Rica is located 10 degrees north of the equator, which makes it have warm temperatures all year long (average temperature of 24° C) [1]. As a result, Costa Rica only has two climatic seasons, the dry and rainy seasons, with up to 10 months of rain per year. This level of cloudiness that is, typical of this tropical zone of the planet turns the climate unstable, predominately cover with clouds the majority of the day [2]. Consequently, the population becomes dependent of the use of artificial illumination during the whole day.

The educational buildings of our country respond to what is established by the Public Education Ministry [3]. According to the regulations and dimensions established for educational architecture, the classrooms have to contain the internal dimensions of 6 m x 9 m. Additionally, each classroom had to be located ideally from north to south, with crossed ventilation and with bright colored that can contribute to refresh the humidity and high temperatures from the classroom while reflecting natural light in the whole space.

At global scale for more than a decade the teaching methods has evolved. Now teachers seek better methods of teaching as a more creative, fun and interactive way where the whole space of the classrooms now contribute a different role than before being a place where the students share and discuss ideas and talk each other and discuss ideas, not only a room to hear the teacher [4, 5]. Nevertheless, despite that all the teaching methods have evolved, our architectural spaces for these classrooms haven't changed at all and continues to be the same (figure 1).

The classroom studied from the Campus Tecnológico Local San José, of Instituto Tecnológico de Costa Rica, TEC, fulfills the dimensión regulations of 6 m x 9 m, but it presents an important variation in the form of the internal ceiling. It utilizes rectangular stripes in the gypsum ceiling that contain artificial light bulbs, leaving exposed the concrete slab black colored. The colors of the walls, mostly white have high reflective levels (figure 2).

Figure 1. Traditional classroom since 1950 [6].

According to the international recommendations, the rage of illumination that should exist in a classroom to keep visual comfort should be at 300-500 lux [7]. And for tropical climates such as the case of Costa Rica, it is recommendable the utilization of surfaces highly reflective in the biggest surfaces of a space, like the ceiling, walls and the floor; to be able to contribute to reflect the majority of natural light in the classroom area. "Natural lighting is a vital resource for well-being within the school and must be designed so that tasks can be carried out in the most effective way, in an appropriate psychological and physical context " [8].

Figure 2. Clasroom of Campus Tecnológico Local San José, TEC.

The use of shading and solar internal or external protection has been a present resource since the vernacular architecture of our country to the present day [9]. These functions are elemental in the window facades, to contribute to minimize the high levels of solar radiation that goes through windows and even walls. Light shelves specifically are used as an element of redirection of natural light to far spaces from window opening, being used a more frequently used in latitudes north and south tropics [10] [11].

Light shelves are flat or curved elements located in the window opening. They can be external, internal, or a combination of both [12]. The literature about light shelves generally does not include experiments conducted with all desirable scientific rigor. Perhaps as a consequence of this, Steemers points out that they have a potential to increase lighting levels in the back of the room, although this is difficult to achieve [13].

The interior light shelves have been studied in some detail in the Building Research Establishment [14] for other latitudes, using scale models, however it is considered that for our geographical location there are large gaps waiting to be explored to determine what are the most recommended materials, shape and position in window.

The Lawrence Berkeley Laboratory has designed and used innovatively and highly efficient light shelves in public buildings [15]. Examples of buildings incorporating light shelves include: La Vanoise College, Moderne Training Center, Agriculture Bank, Athens, Tennessee Valley Authority Offices, Chattanooga, etc.

In developing countries such as Costa Rica, highly sophisticated technology is not available to all users, but the implementation of passive solutions solar protections that shade and protect the window openings and eliminate the direct incidence of the Sun's rays are economically more viable solutions and feasible to achieve. They effectively will contribute to the well-being of people and decrease energy consumption in buildings. In this direction light shelves have been tested in many countries, achieving positive results in improving the use of natural light, for example have shown an increase in useful natural light up to 6 m from a window [16].

This investigation aims the use of this devices as an element that accomplish a double function, in such way that it contributes to decrease the problems of concentration of light that generates the areas closer to windows specifically of 1 m to 3 m. It also shall carryout the natural light to far spaces (beyond 3 m from window), where according to the investigation results, exist nowadays a clear dependence of the use of artificial lighting. This generates serious problems of the uniformity of the levels of light inside the classroom, which creates problems in comfort visuals in students.

Methods

Study of lighting in the scale- model.

In this research, methodologically based on the general systems theory, was proposed: “a systemic approach, understood as the process in which all factors contribute, directly or indirectly, to optimization in the conception of the research objective” [12].

Action-research is a form of self-reflective inquiry developed by participants in social situations (including educational ones) in order to improve the rationality and justice of: a) their own social or pedagogical practices, b) their understanding of these practices and c) the situations in which they are carried out [17]. Action-research is clearly an applied approach that can also be described as experimental. Its design closely links the research process with its context and is based on the idea that research is undertaken for a practical purpose intended for change. It also adapts to the idea of the research process conceived as a spiral activity that goes through repeated cycles that change at all times [18].

A scale model was built, see figure 3. It is scale model of a classroom on the third floor at the TEC Academic Center, located in San Jose, the capital of Costa Rica. The structure of classrooms, recently constructed has contiguous buildings, they all lower, so nothing shadows the sun light to its windows. This building has 3 levels and one basement. The chosen classroom is on the second level, approximately 3.5 meters above ground level and its main window faces north.

Figure 3. Scale model.

The classroom has a dimension of 9 by 6 meters; in 6 meters the wall is the only window, whose orientation towards the north. The wall has an approximate area of 21 m^2 and the window represents approximately one third of its area. The exact size of the window is 4 m wide by 1.7 m high.

The luminosity data within the model was taken at three different points measured from the windows, in the real classroom would correspond to 1m, 3m and 5m.

A luxometer was used for the data collection and measurements were made twice a week for a period of 4 weeks, two in December 2018 and two in January 2019 at approximately 9:00 a.m. and 3:00 pm (see figure 4). The values were averaged, and then plotted.

Figure 4. Measuring using the scale model.

Each measurement was done with black and white ceiling and 4 types of scale light shelves were used: flat horizontal, and with inclinations of 23° and 45° and a curve, as control measurement naked window was used.

During this experiment, a second scale model was built at 1:20 scale where it was proposed to use a completely flat and white, opposed to the black sky of the original classroom. In this second model all the surfaces of walls and sky were painted in white with the intention of maximizing the reflection of natural light inside the space. Tests were also performed with the same light shelves described in last paragraph.

Results

The results of lighting measurements in the models are presented in the figures 5 to 8:

Direct measurements of lighting were taken, great areas with luminosity over 500 lx and under 300 lx allowed us to document the lighting conditions and the problems currently detected: areas of glare and lack of light for comfortably read that shows there is no uniformity of light distribution in the architectural space.

In all cases the flat light shelf made the best shielding to avoid glare next to the window.

The light shelves have a slight effect on the interior lighting of the model space.

The situation of having the ceiling painted black diminishes the internal illumination of the space (compare figure 5 with figure 6 and figure 7 with figure 8).

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At 9 am they have a screening effect of the lighting next to the window but almost no effect beyond 3 m from it (see figure 5 and 6). At 3 pm all but the inclined one in 45° maintain the effect of shielding, the latter equals its effect to the absence of a tray (figure 6) where the ceiling is white and the lighting increases, especially near the window in the case of the black ceiling (figure 7).

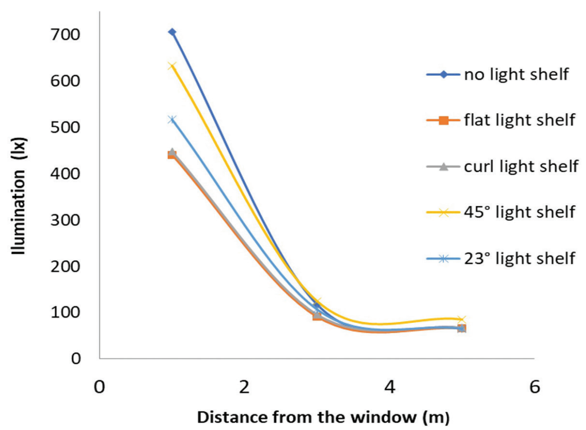

Figure 5. Illumination in the model. White ceiling. 9:00 a.m. Outdoor lighting 7921 lx.

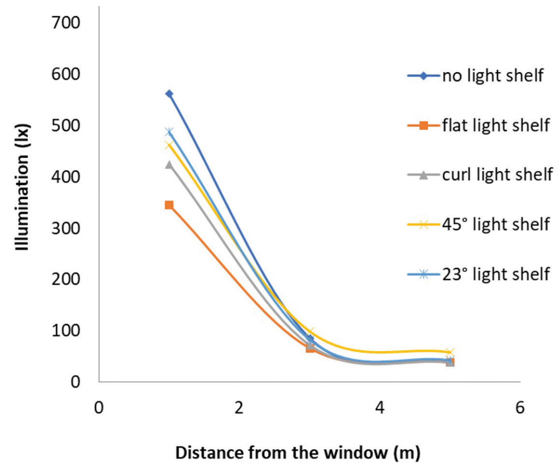

Figure 6. Illumination in the model. Black ceiling. 9:00 a.m. Outdoor lighting 7921 lx.

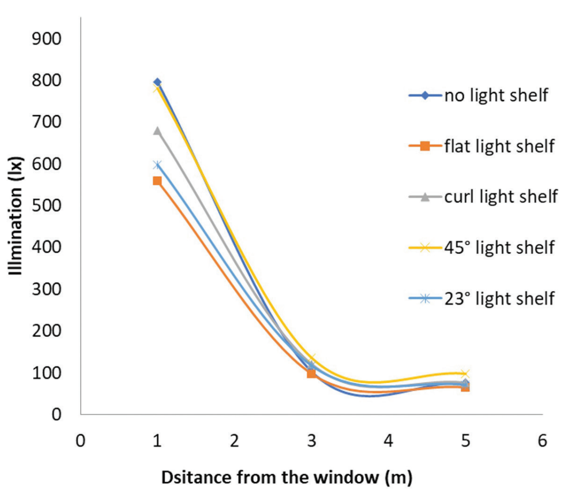

Figure 7. Illumination of the model. White ceiling. 3:00 p.m. Outdoor lighting 8942 lx.

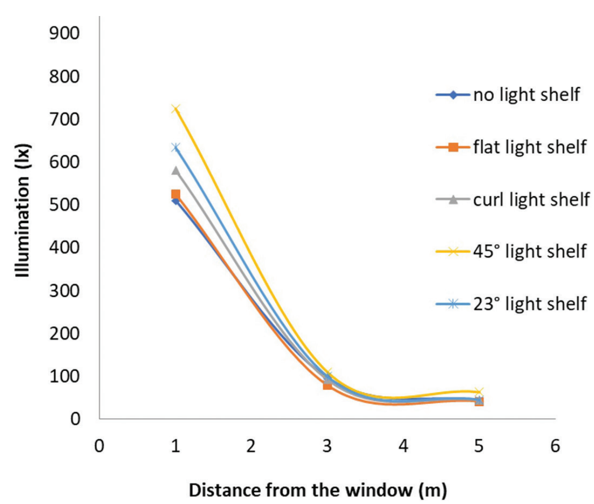

Figure 8. Illumination of the model. Black ceiling. 3:00 p.m. Outdoor lighting 8942 lx.

Conclusions

The above justifies and concludes that although the use for this north orientation has given good results, of internal surfaces with a higher index of light reflectivity, specifically white, there are still problems of lack of light in the farthest points of the window opening.

It is confirmed that the ceiling painted in black, instead of being favorable for the use of natural light in the classroom, becomes an element that is absorbing the lighting.

From the results obtained, it is extracted that even with the use of light shelves and the variation of the color on the internal surfaces, there are still large gaps that determine how to achieve a better distribution of the illuminance to avoid high visual contrasts. The use of light shelves showed greater effectiveness as a solar protection in its flat shape and as elements to redirect the light to the opposite end of the window, its use was more effective with the angle at 45°.

As future lines of research, it would seem indispensable to analyze the behavior of these shelves and their effectiveness in the Costa Rican tropics applied to other orientations such as the east and west, they might contribute to improve the distribution of light within the classroom, which seems to be a new challenge to face.

The light shelf device that manages to work with a double objective, both to redirect natural light and a sun protection element could be a combination of elements that fulfill this double function having a part of the flat surface and another inclined at 45° for the north facade in question. However, this solution still indicates that it will require other devices that minimize the high visual contracts that still remain in the classroom space.

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