DAYLIGHTING SUFFICIENCY AND DAYLIGHT NON-VISUAL EFFECTS IN RESIDENCES LOCATED IN TROPICS

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ABSTRACT

Daylight has been considered, in recent years, a proper strategy to favor energy efficiency in buildings if it is controlled glare probability associated to high illuminance levels. However, currently daylight is also being valued according its capacity to suppress melatonin in people located in indoor environments, and, therefore, to contribute to people's alertness throughout the day, that is, to favor the rhythm of circadian cycles. This paper aims to evaluate the daylighting performance of a housing room from the double perspective: light sufficiency on the workplane and considerations of the non-visual effects of daylight on people. That evaluation was done on the desk and on the bedroom of a typical colombian bedroom in different cities. Computational simulations were carried out in specialized computer programs on a hypothetical space with different facade configurations. The following metrics were considered in the simulations: EML and Lux. Simulation results allow a broader view and favor discussion on the criteria for evaluating indoor environments according to lighting performance..

Key words: Daylighting, illuminance, computational simulation.

1. INTRODUCTION

Daylighting has traditionally been considered as a fundamental strategy to favour the optimisation of the bioclimatic performance of indoor spaces, both from the point of view of energy efficiency and visual comfort (X. Yu and Y. Su, 2015), (Y. Al Horr, et al,2016). For this, it has been estimated that the proper integration of daylighting in indoor environments refers to maximising the use of daylight and controlling the risks of glare associated with it (Bellia, Fragliasso, and Stefanizzi, 2017), (Carlucci, Causone, De Rosa, and L. Pagliano, 2015), that is, to naturally illuminate as much of the indoor environment area as possible with sufficient, not excessive, light for as much of the time as possible. For this purpose, various dynamic metrics have been developed for the estimation of daylight utilization using climate files.: Dayligth Authonomy – DA,(C. F. Reinhart, J. Mardaljevic, y Z. Rogers,2006), Useful Daylight Illuminance – UDI, (Reinhart, C.F, Mardaljevic,J and Rogers, Z, 2006), (Mardaljevic, J, Andersen,M Roy, N and Christoffersen, J, 2012), Spatial Daylight Authonomy - sDA y Annual Sunlight Exposure – ASE, IESNA - The Daylight Metric Committee (2012), among others.

From the perspective of visual comfort, which could be defined as "the subjective condition of visual well-being induced by the visual environment" UNE-EN-12665 (2012), both ensuring sufficient light levels on the workplane and minimising the probability of glare are essential conditions to guarantee occupants' satisfaction with the visual environment ISO/ INTERNATIONAL STANDARD (2006). Daylight research in recent years has focused on the study of issues related to glare and visual field(J. Wienold, 2010),(Yong, J, Schiler, M and Kensek , K2017).

From an energy efficiency point of view, daylighting could imply decreasing the energy consumption associated with artificial lighting IESNA (2000),(Gago, E. J, Muneer, T, Knez, M and Köster, H, 2015), if that the artificial lighting system is coordinated with the light availability (X. Yu and Y. Su, 2015), (D. H. W. Li, 2010). Reductions of up to 60% of energy consumption associated with artificial lighting and up to 30% of overall consumption have recently been found, (N. T. Al-Ashwal and A. S. Hassan,2017). Despite this, in the face of advances in technological developments and highly efficient LED luminaires, in recent years attention has been drawn to the need to advance research on the benefits of daylighting beyond energy savings and focus on aspects associated with people's preferences and health, (Pearl Kurian,C, 2020).

In relation to people's health, based on recent scientific findings related to photosensitive ganglion cells (ipRGCs) which contain a photopigment called melanopsin, responsible for regulating biological effects, several authors have advanced research related to the non-visual effects of natural light and how exposure to light levels can affect the suppression of melatonin (sleep hormone), the secretion of serotonin (responsible for alertness) and, therefore, people's circadian cycles(Konis,K 2017),(Konis, K. 2019). Equivalent Melanopic Lux, or EML, are the unit of measurement of circadian illuminance and are equivalent to vertical illuminance (lux) within the circadian-efficient light spectrum.

The International Well Building Institute developed a certification system with circadian lighting assessment standards applying the EML metric proposed by Robert J. Lucas and other authors, in which they propose a minimum of 250 MLE for people between 25 and 65 years for 4 hours each day of the year between 12 m and 4 pm, measured on the vertical surface of the observer's height, (1.20 m from the floor) complying with a melatonin suppression of 98.5 %. However, a recent study proposes 3 minimum ranges of EML for different ages, 25 years needs 314 EML, 55 years 342 EML and 65 years 342 EML (Giraldo.V, 2020).

Despite these diverse views on daylighting, there is little evidence of research that simultaneously addresses lighting sufficiency, glare probability and circadian lighting. With the aim of promoting a broader assessment of the lighting performance of indoor spaces, It was conducted a triple lighting assessment in offices and proposed a graphical system that allowed the results to be visualised in an integrated manner. In addition to this lack of integrated assessments, it is also observed that the main advances and findings on daylighting issues are made in work or academic environments, but not in residential ones.

2. OBJECTIVE

The objective of this paper is to evaluate the lighting performance of a housing room to four cities located in tropics from the double perspective: light sufficiency on the work plane and considerations of the non-visual effects of daylight on people.

3. METHOD

Medellin(Long: -75.56 , Lat: 6.25), Cali (Long: -76.52 , Lat: 3.42), Barranquilla(Long: -74.78 , Lat: 10.98), and Bogotá(Long: -74.08 , Lat: 4.60), in Colombia were the cities analyzed in this research. The following sections describe the processes that were carried out to evaluate the lighting performance of a room within different tropical locations, considering two points of view, light sufficiency over the workplane and circadian illumination in terms of melanopic lux.

3.1. Spatial considerations and observer position

The room geometry and project orientation were modelled in the 3D modelling software Rhinoceros with the Grasshopper plugin. The model was based on a hypothetical space of a typical high-rise residential room with a window orientation towards the south façade. For this space, although no furniture was modelled, its positions within the room were considered to locate the mesh of points on the working plane and the eye point. Table 1 shows the specifications of the geometric model.

Table 1 - Model Properties

Property	Value
Floor length (N-S)	3.0 meters
Floor width (E-W)	2.75 meters
Ceiling height	2.4 meters
Window area	1.44 m²
Floor reflectance	0.5
Wall reflectance	0.5
Ceiling reflectance	0.5
Light transmittance glass	0.88

The simulations carried out in the room were divided into two parts. The first consisted of placing two different grids for the spaces where the body is most likely to be performing an activity for a longer period of time, considering a selected area on the bed (6-point grid) and the desk (10-point grid), both with a separation between them of 0.3 metres and at a height of 0.7 m from the floor. The second consisted of placing a point at the position of the eyes to perform a lighting simulation on the vertical plane with a forward gaze direction. Table 2 shows the specifications of the simulation areas.

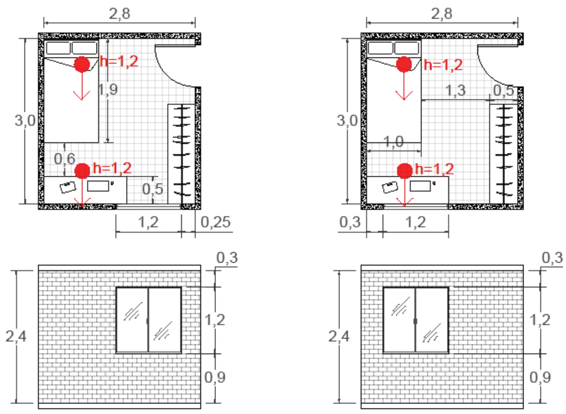


Figure 1: Simulated scenes. Setting 0: room with window located on the west side of the south facade. Setting 1: room with window located on the east side of the south facade.

3.2. Simulation period

Colombia is located with respect to the equator, between 4°N and 10°N, with 80% of its territory in the northern hemisphere and 20% (Meta and Amazonas) in the south. For this reason it has a high availability of outdoor light throughout the year. However, in indoor environment it is not reflected in the same way, due to different reasons, one of them is the position of the window in relation with the sun position and the second is the solar inclination throughout the year, which, although in the tropics is not very high, causes monthly interior light differences, therefore it is decided to initially simulate a city month by month, and review the months with less variability to choose one and perform the analysis for the 4 cities.

3.3. Tool

The model was performed from the grasshopper plugin of the 3d modelling program Rhinoceros where 2 algorithms were generated. The first produced vertical illumination and horizontal illumination data measured in lux. The second calculated the "circadian factor" (from 1 to 1.1) (Konis,2019), which multiplied the vertical illumination simulation result to obtain the melanopic lux, as shown in equation 1 below:

$$EML = Lux * Circadian\ factor \quad (Equation\ 1)$$

Although there is an existing ALFA Adaptative Lighting For Alterness programme, that evaluates circadian lighting in open plan spaces based on a homogeneous evaluation of various points in the space, this measurement method was proposed to consider how furniture conditions the position of the body and the direction of the gaze.

3.3. Balance of computational simulations

To find out the performance of a typical room in Colombia in terms of circadian stimulus and illuminance, 300 EML data were obtained from the simulation for bed position, 300 EML data for desk position, for both façade configurations with window on the west side and window on the east side for a total of 1200 MLE data during the month of June from 8:00 am to 5:00 pm. On the other hand, 3600 illuminance data were obtained for the work plane at the bed and 6000 Lux data for the work plane at the desk, this was repeated for each of the four cities to be studied.

For the analysis of the data, 314 EML was considered as the minimum acceptable value from a circadian point of view and illuminances between 300-3000lux as suitable for reading and writing activities. The results were evaluated on the basis of the simultaneous fulfilment of both criteria, and then the percentage of time per day during a month in which this condition was maintained was counted.

In order to show the results simultaneously, a scatter plot was made with the respective limits mentioned as shown in figure 2.

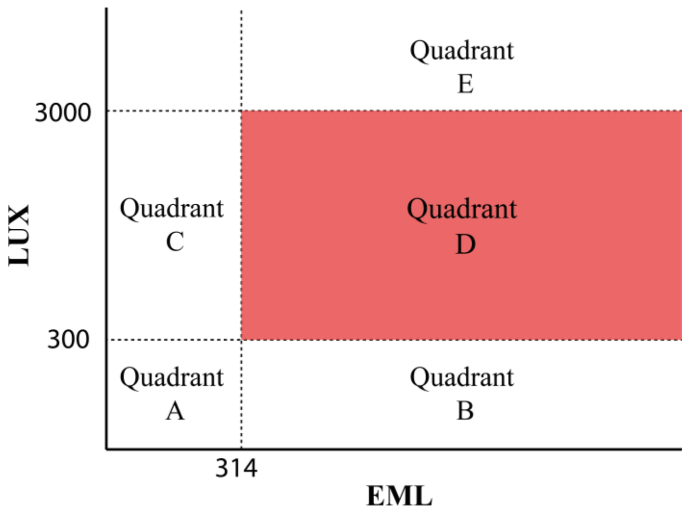


Figure 2. Diagram of the relationship between MLE and Lux for the cases to be studied.

Quadrant A: Does not meet any condition, Worst case below limits.
Quadrant B: Metabolically sufficient, but insufficient to perform visual tasks.
Quadrant C: Sufficient to perform visual tasks but metabolically insufficient.
Quadrant D: (red) Ideal condition.
Quadrant E: Metabolically sufficient, but exceeds the glare level.

4. RESULTS

Initially, a monthly comparison (daily data from 8:00 am to 5:00 pm) of horizontal lighting at a point inside the room (on the desk) in the city of Medellín was made, to define the temporal range of evaluation to study. In Figure 3, it is realized that for the initial and final months of the year, there is a greater light variability reaching up to more than 60,000 lux inside the room at the evaluated point, corresponding to direct light on the workplane, allowing the room in these seasons provide sufficient lighting. The mid-year months (June and July) presented less variability in the data, with a mean of 210.59 lux, For this, June was the month analyzed.

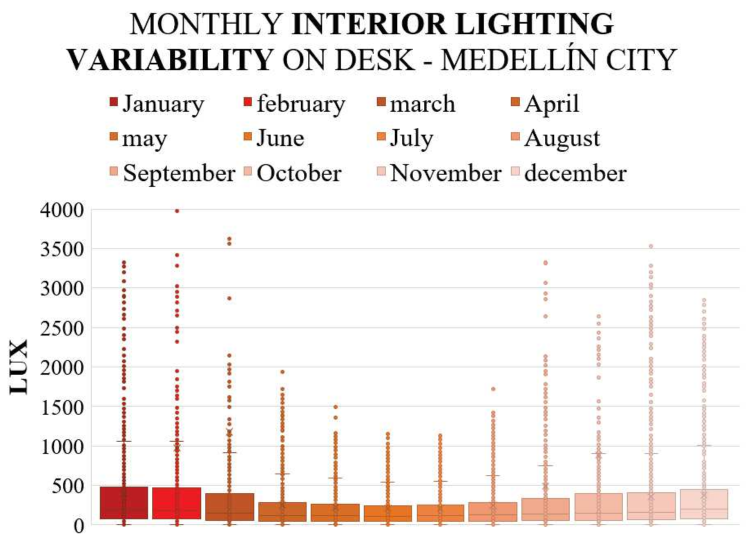


Figure 3. Monthly interior lighting variability is evaluated at a point on the desk in front of the window.

The results of the monthly average per hour in lux for both configurations are shown in figure 4, and it shows different degrees of variability between each one. Firstly, in Setting 0, the hours of the day are identified in which lux exceeds the limit to be sufficient (approximately 10 am to 3:00 pm), while in Setting 1 they are always within the recommended range. It is also identified that Cali, compared to other cities, is within the range established in both window cases, however, Medellín, Barranquilla, and Bogotá do not present the recommended lux for the position of the bed in the setting 0.

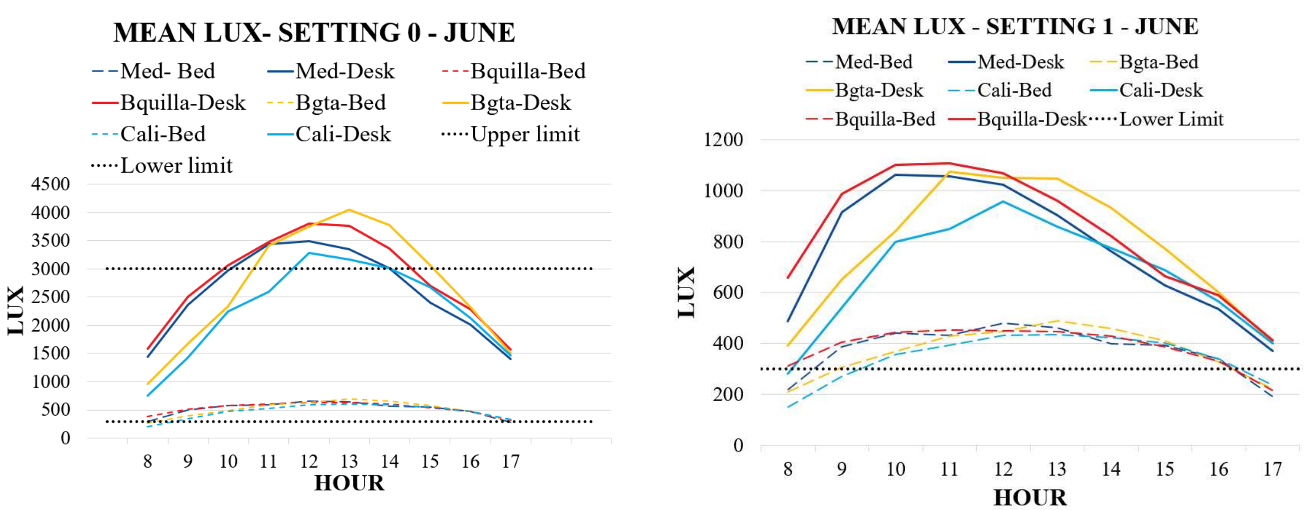
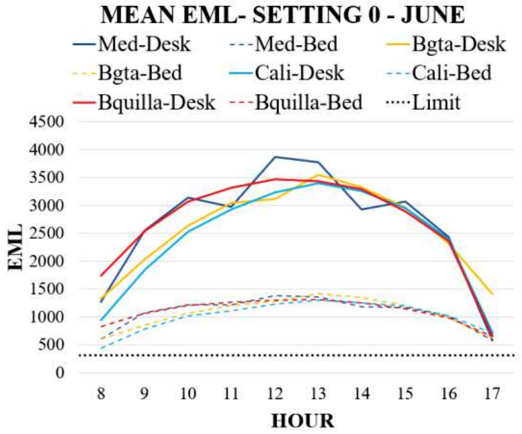


Figure 4. left: Average hours with lux behavior on bed and desk for configuration 0. Right: Average hours with lux behavior on bed and desk for configuration 1

In figure 5, the variability achieved in both results is similar, however in the case of setting 1, the desktop eml's are 100% below the recommended, this is due to the position of the window that is on the opposite side of the desk position.



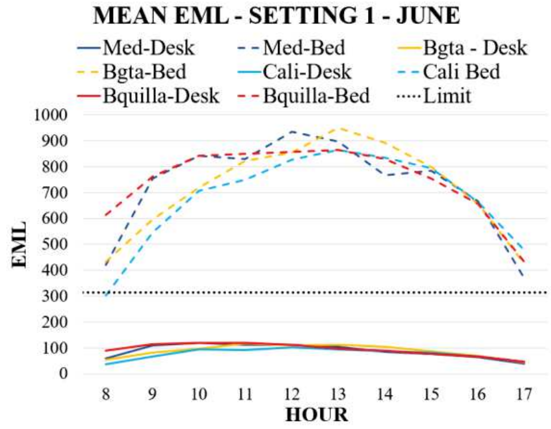
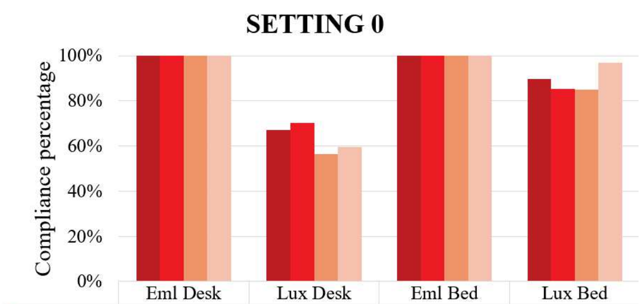


Figure 5. Left: Average of the hours with the behavior of melanopic lux in bed and desk for window 0. Right: Average of the hours with the behavior of lux in bed and desk for window 1.

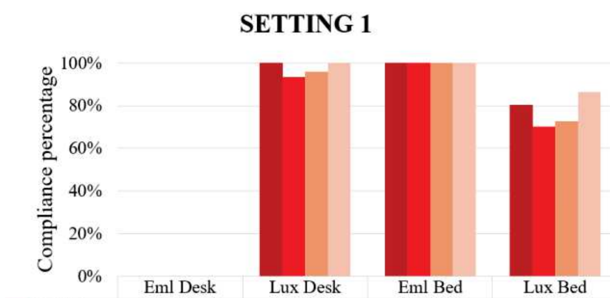
The results of the difference between the four cities in terms of EML and Lux are summarized in figure 6, which shows as a percentage the individual performance of each city and in comparison, to the others. The percentage results were obtained from the data previously analyzed, with compliance ranges; for the circadian stimulus, it was defined that at least 4 hours a day the EML should be equal to or greater than 314, to define that the point was able to complete a true circadian stimulus. For the Lux, it had to be fulfilled that for each hour during the day the illuminance should be between 300 and 3000 lux.

The figures show that for the 4 cities in the setting 0, the circadian stimulus is 100% fulfilled in the position of the desk, however, the range of daylight sufficiency on workplane varies up to 14% between cities, with Cali being the one with the best performance and Bogota the lowest compliance with 56.33%. Although it appears that the desk in front of the window will provide better lighting conditions, it exceeds the threshold and generates glare sensations and reducing the compliance percentage. On the other hand, the 4 cities also comply 100% with the circadian stimulus for this facade configuration and Barranquilla is the city with the best daylight sufficiency on the workplane with up to 97% compliance.

After Analyzing Setting 1, it is evident that the circadian stimulus condition required to suppress melatonin during the day was not met for any of the 4 cities, this is because the gaze is directed towards the opposite side of the light access, near the wall. However, the lighting sufficiency on the desktop is quite acceptable, with Cali being the city that performs the lowest percentage with 93% compliance. Between the 4 cities, there is only a difference of up to 7%. On the other hand, the position of the bed if it achieves 100% fulfillment of the circadian stimulus criterion for the 4 tropical cities, and the light sufficiency on the bed has a percentage difference between cities of up to 16%, with Cali being the lowest percentage and upper Barranquilla.



	Eml Desk	Lux Desk	Eml Bed	Lux Bed
Medellín	100%	67,00%	100%	89,67%
Cali	100%	70,33%	100%	85,33%
Bogotá	100%	56,33%	100%	85,00%
Barranquilla	100%	59,67%	100%	97,00%



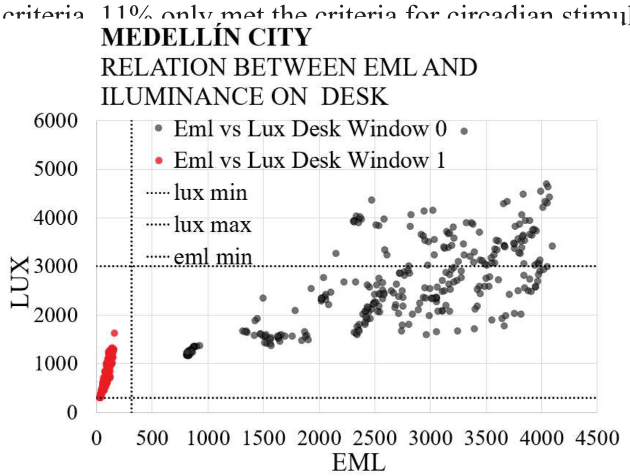
	Eml Desk	Lux Desk	Eml Bed	Lux Bed
Medellín	0%	100%	100%	80%
Cali	0%	93%	100%	70%
Bogotá	0%	96%	100%	73%
Barranquilla	0%	100%	100%	86%

Figure 6. Left: Comparison between Medellín, Cali, Bogotá, and Barranquilla for configuration 0 in terms of EML and Lux. Right: Comparison between Medellín, Cali, Bogotá, and Barranquilla for the facade configuration with window 1 in terms of EML and Lux.

Finally, a scatter diagram was made that related EML and Lux, considering the two locations to study within the room (bed and desk) and the 4 cities (Medellín, Cali, Bogotá, Barranquilla). To obtain the total illuminance data, an average of the mesh of points of each work plane was carried out.

Figure 7 (Left) shows that for Setting 1 in the desk position, 100% of the data are below the lower limit of the circadian stimulus and light sufficiency on the work plane. Setting 0 reflects more dispersed data, of which 67% of them are within the optimal threshold for both criteria to be met. Although 33% of the data for this configuration meet the required circadian stimulus, they exceed the maximum light level proposed, so glare could be generated.

In Figure 7 (Right), a positive linear trend was observed for both bed position facade configurations, the higher the luminance, the higher the circadian stimulus. For Setting 0, only 19.7% of the data obtained does not comply with sufficient lighting, although the circadian stimulus is fulfilled, oscillating between 314 and 600 melanopic Lux. The 80.3% of the data meet both criteria. Setting 1 turned out not to be as problematic for the position in bed as it was for the desk, only 8.7% of the data did not meet any of the criteria. 11% only met the criteria for circadian stimulation and 80.3 % met both criteria.



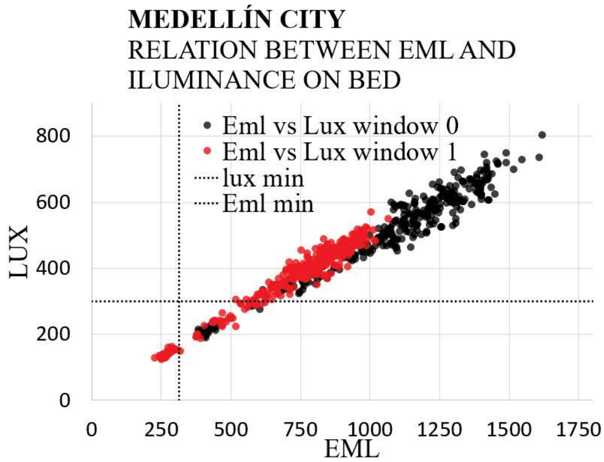
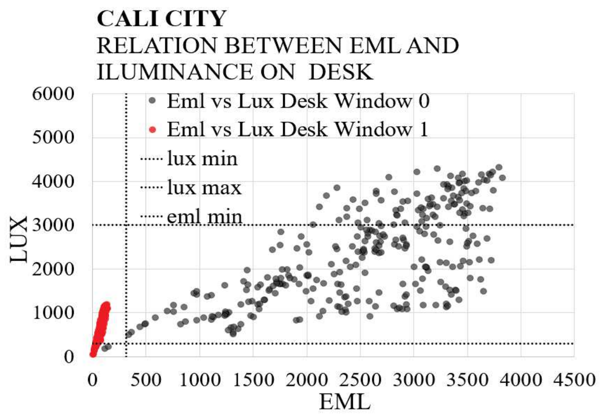


Figure 7. Left: Relationship between EML (circadian stimulus) and illuminance (lux) on the desk for the city of Medellín. With minimum and maximum compliance thresholds. Lux min: 300, Lux max: 3000; Eml min: 314. Right: Relationship between EML (circadian stimulus) and illuminance (lux) on the bed for the city of Medellín. With minimum and maximum compliance thresholds. Lux min: 300, Lux max: 3000; Eml min: 314.

The simulated data from Cali yielded for setting 0 on the desktop, 0.7% of the data do not meet any of the criteria, 29% exceed the criteria of circadian stimulation but generate glare for those who work in this place, and 70.3% meet both conditions, on the other hand in the position of the bed it is observed that 3% of the data do not meet any criteria, 24.7% are between 314 and 780 melanopic lux but below 300 lux and 70% meet both criteria.

To analyze setting 1, it was observed on the desktop that 6.7% of the data does not meet any conditions while 93.3% only meets being above 300 lux, this position and configuration being inadequate to work for more than 4 hours during the day as the melatonin required for alertness will not be suppressed. On the other hand, the position of the bed (figure 8 Right) shows that 5.3% of the data is below both criteria, 24.7% exceed the threshold of the minimum required of melanopic lux and finally 70% meet both terms.



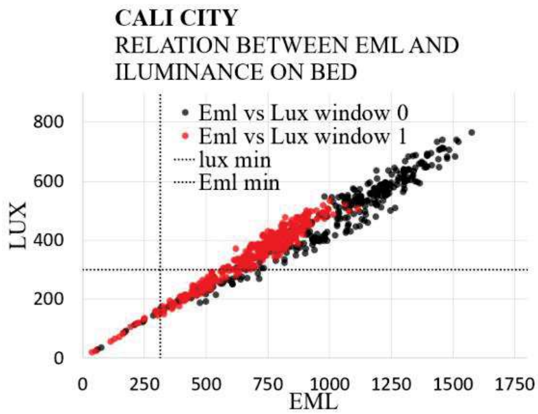
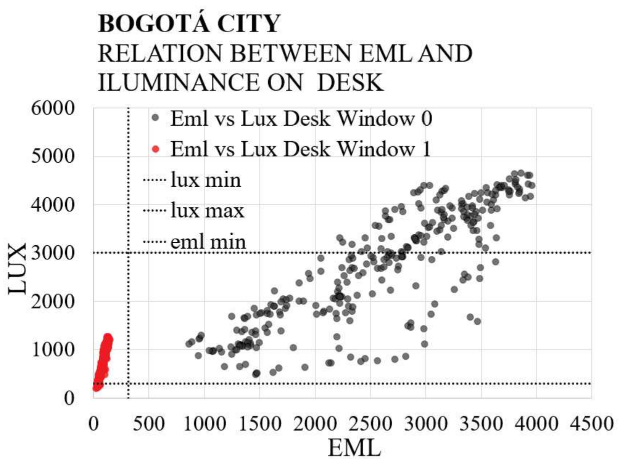


Figure 8. Left: Relationship between EML (circadian stimulus) and illuminance (lux) on the desk for the city of Cali. With minimum and maximum compliance thresholds. Lux min: 300, Lux max: 3000; Eml min: 314. Right: Relationship between EML (circadian stimulus) and illuminance (lux) on the bed for the city of Cali. With minimum and maximum compliance thresholds. Lux min: 300, Lux max: 3000; Min Eml: 314

For the city of Bogota a performance similar to that of Medellín and Cali was observed with small percentage differences. In figure 5 left, it was evidenced that for the facade configuration with window 0, the data have a more accurate behavior for the two criteria to be evaluated. In the desk position, 56.3% of the data are in quadrant D, that is, they meet both criteria, on the other hand, 43.7% of the data exceed the glare threshold although they meet the circadian criterion. The position of the bed also has a similar behavior, although the data is not so dispersed, 15% of the data is below the lower limit of luminance required to perform visual tasks, while 85% of the data complies with the two criteria.

The window facade setting 1 is the least favored in all cities, concerning the desk position. In figure 9 Left, it is evident that 96% of the data are below the lower limit of the circadian stimulus, although it achieves daylight sufficiency to perform visual work for short periods, in the position of the bed it happens differently, 72.7 % of the data meet both criteria.



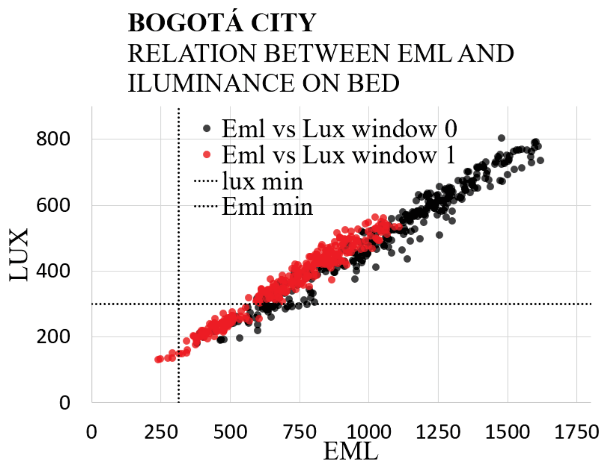
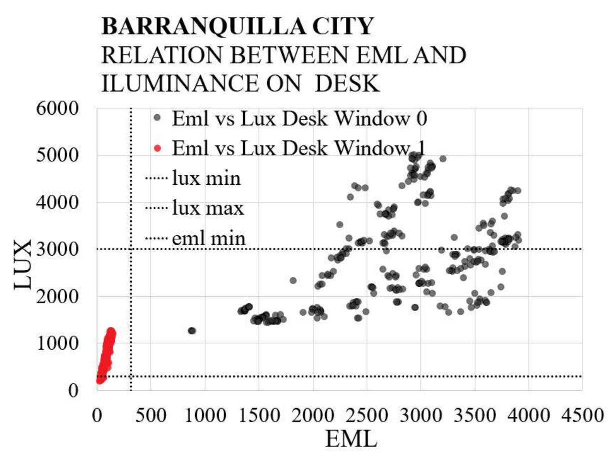


Figure 9. Left: Relationship between EML (circadian stimulus) and illuminance (lux) on the desk for the city of Bogotá. With minimum and maximum compliance thresholds. Lux min: 300, Lux max: 3000; Eml min: 314. Right: Relationship between EML (circadian stimulus) and illuminance (lux) on the bed for the city of Bogotá. With minimum and maximum compliance thresholds. Lux min: 300, Lux max: 3000; Min Eml: 314.

Finally, the same analysis was carried out for the city of Barranquilla, and although it continues to have a similar Performance to the rest of the cities, it tends to respond to the circadian stimulus 200 melanopic lux above Bogota and Cali. In figure 10 left, it was observed that for configuration 0 59.7% of the data are within the threshold required to meet both conditions in the position of the desk and 40.3% of the data although they meet the stimulus condition The circadian stage passed to the glare stage, while in figure 10 right, it was observed that for the position of the bed, 97% of the data meet both criteria, luminous and circadian.

For configuration 1, it was observed in figure 8 that on the desk 100% of the data only met the illuminance condition, while in the bed position 86% met both conditions.



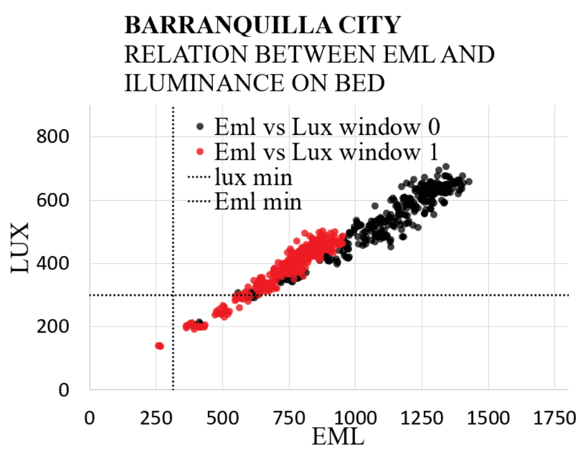


Figure 10. Left: Relationship between EML (circadian stimulus) and illuminance (lux) on the desk for the city of Barranquilla. With minimum and maximum compliance thresholds. Lux min: 300, Lux max: 3000; Eml min: 314. Right: Relationship between EML (circadian stimulus) and illuminance (lux) on the bed for the city of Barranquilla. With minimum and maximum compliance thresholds. Lux min: 300, Lux max: 3000; Min Eml: 314

5. CONCLUSIONS

The cities studied are located at very different altitudes and with their own cloud conditions, and therefore have significant climatic variations between them. Despite this, the daylight availability in the simulated areas was very similar, with annual variations of up to 16%. This allowed us to conclude that these variations between different locations do not have a high incidence on the results of daylight sufficiency or circadian stimulation and that in all cases it will be feasible to ensure the correct conditions of circadian stimulation and daylight sufficiency on the working plane in dwellings. It is important to note: that this will be possible as long as the architectural design ensures a good correspondence between the arrangement of the furniture and the location of the window.

The analyses were only carried out for the month of June and the results were very similar with minimal variations. This was done because one month of insufficient circadian stimulus is enough to generate metabolic alterations. However, for future research, comparisons should be made for the whole year or at least for months with opposite solar conditions in order to provide additional elements about the behavior of the localities in terms of light and circadian conditions.

The development of work and study activities in bedrooms is becoming more and more frequent and it is therefore essential to consider a good position and location of objects inside the room. In this study it was possible to conclude that when working sitting on the bed, the position of the bed provides sufficient lighting conditions, both in circadian and luminous terms. However, it was also observed that when working on the desk, and despite the fact that the illuminance conditions in all cities meet the levels required by the national standard between 95% and 100% of the time, in none of the cases would the circadian stimulus conditions for this configuration be sufficient. It is concluded that the layout of furniture is crucial in circadian terms but there is still no greater sensitivity about it and no mention of it in the current regulations in the country.

Finally, illuminance analyses on the work plane can give erroneous information, qualifying as well-lit sectors of the room that are poorly lit because they can end up affecting the health of the occupants. Certainly, a lighting analysis that exclusively uses illuminance metrics on the work plane can lead to design errors.

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