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Review and Evaluation of Artificial Lighting Systems in Higher Education Classrooms - Case Study

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ABSTRACT

The software and plug-ins designed for the lighting project are designed for making decisions on light comfort and environmental comfort. However, within the scope of the evaluation of lighting in the work environment, such as safety standards, they provide exhaustive procedures that require in-depth technical knowledge. In teaching resources, diagnostic solutions, and lighting solutions for public educational institutions, designed projects, dependent on routine maintenance and investment solutions in elementary education. In this sense, an alternative computer solution objective aimed to evaluate the research room lighting system, as an objective to aid maintenance. The methodology used in the research was aided by a survey, with the use of evaluation strings and techniques based on NHO 1, the qualitative evaluation was aided by a list of and comprehensive analysis of luxury strategies, using the lux meter. The results were integrated by the simulation, using the Relux Desktop software. It was found that the classroom has deficiencies in its lighting system. Despite the need for corrective measures, the present study emphasizes as its main contribution, the use of computer simulation for the evaluation of lighting in the work environment as a quick and easy-to-use means, aimed at public educational institutions, which always have resources and resources poor maintenance management.

1. INTRODUCTION

Adequate lighting enables people to see their surroundings, move about and perform visual tasks safely, efficiently, and accurately without causing eye fatigue and discomfort. Whether natural, artificial, or a combination of both, for lighting to be effective, attention is required to both its quantity and quality. The benefits of good lighting are undeniable, both on the scale of buildings and in cities. The proper lighting not only helps maintain health but also helps promote it (BANDEIRA; SCARAZZZATO, 2018).

According to Choi; Lee; Suk (2015), with the rapid development of lighting technology year after year, the role of artificial lighting is changing, becoming more significant and dependent on the user's environment. In the same context, previous studies have shown that lighting affects the physical and mental conditions of human beings.

For Sholanke*et al.*,(2021), adequate lighting in the indoor environment is a fundamental condition to improve visual performance, visual comfort, and comfort in the work environment. For Kralikova; Wessely (2016), the appropriate level of light at different times of the day can provide an increase in the sense of well-being to users of the environment, improving concentration, motivation, and performance.

Therefore, visual comfort depends on specific conditions, such as intensity, uniformity of light densities, temporal uniformity of light, excessive contrast, and elimination of glare and shading (GRANDJEAN, 2002). In this sense, for the authors, Hemphälä; Eklund (2011), the work environment requires much of the vision and a good visual environment is very important for health and well-being. Thus, the work area should have uniform illuminance while the surrounding areas should not be uniform, and should not even cause glare (VEITCH, 2001).

Boyce (2003) identified three means by which lighting affects human performance: through the visual system, the circadian system, and the perceptual system. The visual system refers to image processing, defined by five parameters: visual size, brightness contrast, color difference, retinal image quality, and retinal illuminance. Therefore, the stimulus and the state of the visual system are determinants for the level of visual performance achieved and contribute to task performance.

The practice of good lighting for workplaces is much more than just providing a good view of the task. The tasks must be performed easily and comfortably (PAIS, 2011). In this sense, artificial lighting has the function not only to represent the space systematically but also to provide safety and comfort for users (MORAES; ALCOLJOR; BITTENCOURT, 2018). For this, with the advancement of technology and the aid of standards, it is possible to simulate environments, in which it can be observed and evaluated in a three-dimensional way, to eliminate risks to users and promote recommendations to the lighting system (MORAES; ALCOLJOR; BITTENCOURT, 2020).

According to Grondzik and Kwok (2013), simulation *software* and *plug-ins* were developed to calculate artificial and natural lighting. For example, in the design phase of the project and/or during the maintenance of the lighting system, the tool contributes as a facilitator, optimizing time and thus facilitating decision-making to meet a series of standards set by the standard.

For Moraes; Alcoljor; Bittencourt, (2020), and Maamari et al. (2006), such simulations can generate guidelines for the environment, which can help designers concerning artificial or natural lighting suitable for the environment.

These tools have an intuitive interface, and most of them refer to software linked to national and international parameters, including *Relux Professional Desktop*, *Dialux*, *Apolux,* and *Softlux*(MAAMARI, et al., 2006). According to Correia, Cabús, and Araújo (2008), *Relux*is based on the *Radiosity* method to evaluate natural and artificial lighting in the architectural space.

Several parameters are used to measure the effectiveness of daylight in any space. One of the parameters is illuminance. It is the amount of sunlight incident on any surface before it is reflected. It is measured in Lux. Similarly, another parameter that measures the effectiveness of daylight is luminance, which is the amount of light reflected from any surface.

However, in Brazil, the parameters for lighting in the workplace come from the NR17 - Ergonomics and NHO 11 - Evaluation of lighting levels in indoor work environments (ZLATAR et al., 2020). NHO 11 presents specifications and reference levels of illuminance for work environments.

For the authors Franco *et al*. (2021) and Farias (2006), the classroom is considered a work environment, since the classroom is a place where teachers work and students learn, and can be considered as a work environment.

In this sense, by equating the classroom environment to the workplace environment, and considering the current conditions of Brazilian public higher education institutions, it was hypothesized that the use of simulation software of easy interoperability would be a quick and easy way to evaluate lighting systems, to assist the maintenance management of the university property.

This research aimed to analyze the effectiveness of computer simulation to evaluate the classroom lighting system, as an alternative means of diagnosis and maintenance aid. To do so, it was used as a reference, the comparison with the results from the evaluation of the lighting under the normative perspective.

2. METHOD

This is quality-quantitative research, which had as methodology an integrative review, and exploratory, descriptive, and explanatory research.

To this end, four steps were developed: literature and document review, characterization of the object studied, field research, and evaluation by computer simulation.

2.2. Bibliographic and Documentary Review

The methodology used for the research had the aid of a research protocol, with the use of search *strings to* collect scientific articles in indexed journals. The research was also conducted in dissertations, books, magazines, regulatory standards, and websites in the sphere of luminous comfort.

To plan the present research, regarding the definitions of the objective, of the aspects to be addressed, and the keywords, was analyzed first, some studies concerning the theme (GRANDJEAN, 2002; BOYCE, 2003; LIMA, 2006; MAAMARI, 2006; PAIS, 2011; NHO 11, 2018). Then, according to this analysis, Table 1 was created with the summary of the research protocol (BICHARRA, 2020).

Table No 1 - Research Protocol

Item	Content
a. Background	The study focused on evaluating the lighting system of the classroom of an educational institution, since it seems to be deficient, and linked to contrasts and glare. The importance of this study is to verify a simple and practical evaluation method, to enable monitoring of the lighting quality routinely, associating it with the maintenance management, with simple solutions.
b. Research Objective	The objective is to evaluate the artificial lighting system of a classroom of a public Brazilian higher education institution, both utilizing normative instructions aimed at working environments and by simulation software.
c. Research Questions	Is the use of simulation software effective for classroom lighting evaluation? Are there divergences between standardized assessment and software simulation? Is software simulation a solution for monitoring the lighting conditions in public educational institutions?
Language	Portuguese, English, and Spanish.
Database	SCOPUS, CAPES, SCIELO AND GOOGLE SCHOLAR
Search Calibration	Web application →Proxy-server application (institutional).
Generic search *string*	*("Ergonomics" AND "illumination") OR ("Lighting" AND "ergonomic analysisatwork") AND ("Lighting" OR "ergonomic analysisat work") OR ("Ergonomics AND ilumination applied to workstation")*
Specific search *string*	*("Bright comfort" OR "work environment") AND ("luminous comfort" AND "classroom") OR ("University" AND ("luminous comfort") AND ("computer lighting simulators "AND " luminous comfor").*

Inclusion criteria	Publication time: 2002 - 2021; Areas of expertise: Architecture, Civil Engineering, and Occupational Health and Safety. Subject: Assessment of the lighting system
Exclusion criteria	Duplicate articles, articles that addressed only daylighting.
Execution of the search	124 found: Relevant: 40Full: 23
Aid Tools	Regulatory Standards →NR 17 (2018); NHO 11 (2018); →Study Phases: Qualitative / Quantitative Evaluation →Area: Occupational Safety and Health Interface: Web. → Google Scholar →Study Phases: Selection of primary studies Area: →Illuminance / Illuminance →Interface: Web. Sites→→ Study phases: Selection of primary studies Area: Natural / artificial lighting →Interface: Web. *Research Gate*→ Study phases Selection of primary studies Area: →Luminotechnical system simulation →Interface: Web.

Source: Bicharra - UNIRIO/CCET (Research methodology), adapted by the authors (2021).

The bibliographic methodology used to conduct this research followed the guidelines of the Preferred Reporting Items for Systematic Reviews (LIBERATI et al., 2009).

2.3. Characterization of the object of study

The object of study was the campus of the Escola Politécnica da Universidade de Pernambuco - POLI/UPE. Equipping the classroom environment to the workplace environment, and through behavioral observations and in the environment, it was raised the primary hypothesis that the lighting system of the classroom building of the campus is deficient to the normative requirements. And as a secondary hypothesis, it was raised the possibility of using simulation tools as an effective, simple, fast, easy visualization, and low-cost way to diagnose the system.

Figure 1 shows the campus of POLI/UPE and highlights the classroom building (in blue). This building is the most recent construction of the institution. The access doors to the classrooms are recessed about the facade, protecting the solar incidence directly from the sunset.

Figure no 1 - Schematic ground plan of POLI/UPE

Source: Authors (2021)

Non-systematic and non-structured visits and observations of exploratory nature were carried out. Considering that the floor plans and furniture of the classrooms are standardized, was chosen a classroom to represent the building, which by the geographical position and is located on the ground floor, presents the most unfavorable lighting conditions.

2.4. Field research

The field research included a quality-quantitative evaluation. First, observations were performed with the help of a checklist, based on the NHO11.

In addition to the field for observations, the checklist included fields for the reference number of the normative item, the description of the normative item and the situation, whether compliant (CO), not compliant (NC), or not applicable (N/A).

The qualitative evaluation consisted in verifying general and specific lighting conditions, such as the types of lamps, which can impair the comfort and perceived sensation; glare, which is the condition of discomfort or reduced ability to differentiate objects; the transition zones between indoor and outdoor environments, which is the difference in illuminance levels of the work area and the outdoor area; the color appearances, which are the color temperatures of the lamps; the existence of flicker, which corresponds to variations in apparent brightness or color of a light source that is perceived visually; and the stroboscopic effect, which is when a pulsating light source illuminates a moving object.

The quantitative analysis covered measurement strategies and the quantification of lux, with the use of a lux meter. The measurement strategy was subdivided into two steps: the measurement of points for the average illuminance of the environment and the point-to-point measurement of the task areas.

According to Setiawan (2021), the environment must be evaluated in its typical condition, so that the evaluation is efficient. Mimoso (2018) also emphasizes that the evaluated object must be in its "worst" condition, since this way, the results can replicate for the entire lighting system of the studied object. In this sense, the measurements were performed during the operating hours of daytime classes, specifically in the morning shift, considered the most unfavorable period, in terms of natural lighting, i.e., in the account of direct solar incidence, leading to increased temperature, and the windows are provided with black film remaining closed.

The measurement of the points for the average illuminance of the environment was based on Figure 2, requiring the use of a tripod to support the lux meter. The grid for identification of the points was drawn in AutoCAD 2D, consisting of 18 measuring points.

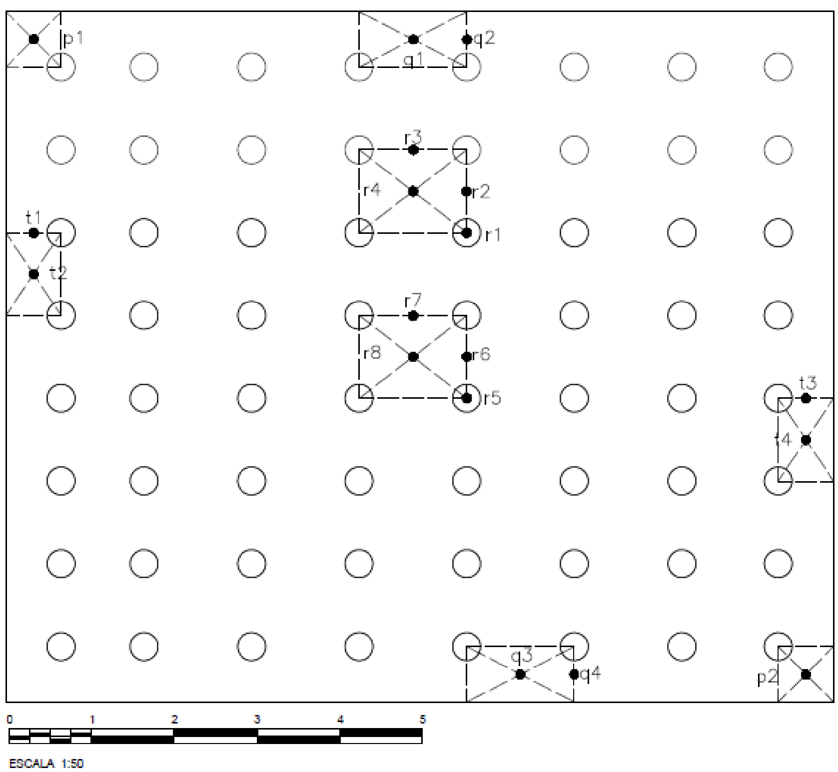

Figure no 2 - Pre-defined measurement strategy for rectangular area work environments, illuminated with regular patterned light sources, symmetrically spaced in two or more rows

Source: Occupational Hygiene Standard - NHO 11, adapted by the authors (2021).

The room studied has a rectangular area work area, with rectangular standard luminaires that are symmetrically spaced over two rows. For this conformation, taking into consideration issues of similarity, NHO11 determines the following form for average illuminance:

$$\bar{I}=\frac{R\ (N-1)(M-1)+Q\ (N-1)+t\ (M-1)+P}{NM}$$

Being:

N = Number of luminaires per row

M = Number of rows.

For the point-to-point measurement strategy, 38 distinct points were defined, corresponding to the task areas. For comparison purposes to the values measured in these 38 points, the NHO11 determines the minimum illuminance values according to the type of environment, task, or activity. For the research, it was considered an educational building area of higher education, adult classrooms, having 500 lux as a reference value.

3. Evaluation by Computational Simulation

For the simulation, *Relux Desktop software* was used. From the *Relux*CAD *plugin*, the floor plan of the institution was exported. The format dwg to be manipulated in *Relux*.

Initially, we entered the ceiling height and the floor plan of the classroom, the quantity and specifications of the light fixtures and lamps, the relationship of the environment with the outside (natural lighting), and the openings (doors and windows) (Figure 3). Based on the input data, the lighting calculation process was initiated, where direct incidence and the contribution of reflections on the work plan were considered, and the results were made available through 2D, 3D, and rendered images.

Figure no 3 - Floor plan image as input data generated in Relux

Source: Authors (2021)

4. RESULTS AND DISCUSSION

4.1. Qualitative analysis

Figure 4 presents the graph with the percentages of items in compliance (CO), non-compliance (NC), and not applicable (N/A) verified with the use of the checklist.

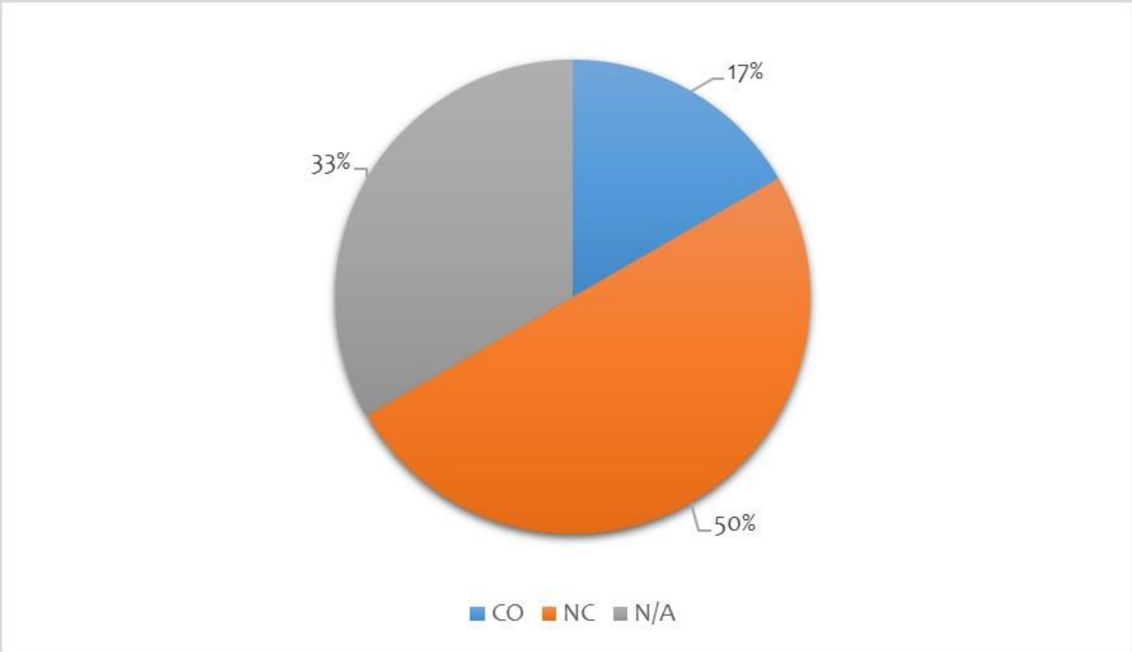

Figure no 4 - Qualitative analysis - Classroom

Source: Authors (2021).

It was verified that 17% of the applied items comply, being possible to identify the inexistence of perceptible flicker in the work environment and the maintenance of cleanliness in the work areas, as well as on the workbenches and floors.

Regarding the items in non-compliance (NC), represented by 50% of the applied items, they refer to the presence of burned-out lamps and the slowness in changing lamps; excessive natural lighting and shadow areas, causing excessive contrast of adjacent areas; and absence of safety signaling.

In this sense, it is important to highlight that these inconsistencies, such as excessive reflection on the furniture, can cause diseases, as well as visual fatigue, headache, and sometimes burning and tearing during reading (SANT'ANNA et al., 2003).

It was also found that the lighting system and the maintenance management of the classrooms should be objects of attention since it directly impacts working conditions and user productivity.

4.2. Quantitative analysis

With 3.00 x 6.95m x 9.09m dimensions, the classroom is presented in Figure 5. Note the student desks, low windows, teacher's desk, whiteboard, light fixtures, and high windows. There is a high incidence of natural light on both sides of the classroom.

The natural lighting incident in the morning shift is usually blocked by partially closing the low windows, which are fitted with black film since the entry of the sun considerably increases the room temperature. In the afternoon shift, the temperature is milder, and the windows are kept open, as seen in Figure 5.

Figure no 5 - Object of study - Classroom

Source: Authors (2021).

Considering the models for determining the average illuminance presented in NHO 11, the classroom environment was analyzed and characterized as a rectangular area, illuminated with rectangular light sources with a regular pattern and symmetrically spaced in two rows. Figure 6 shows the strategy for measuring the average illuminance in the classroom.

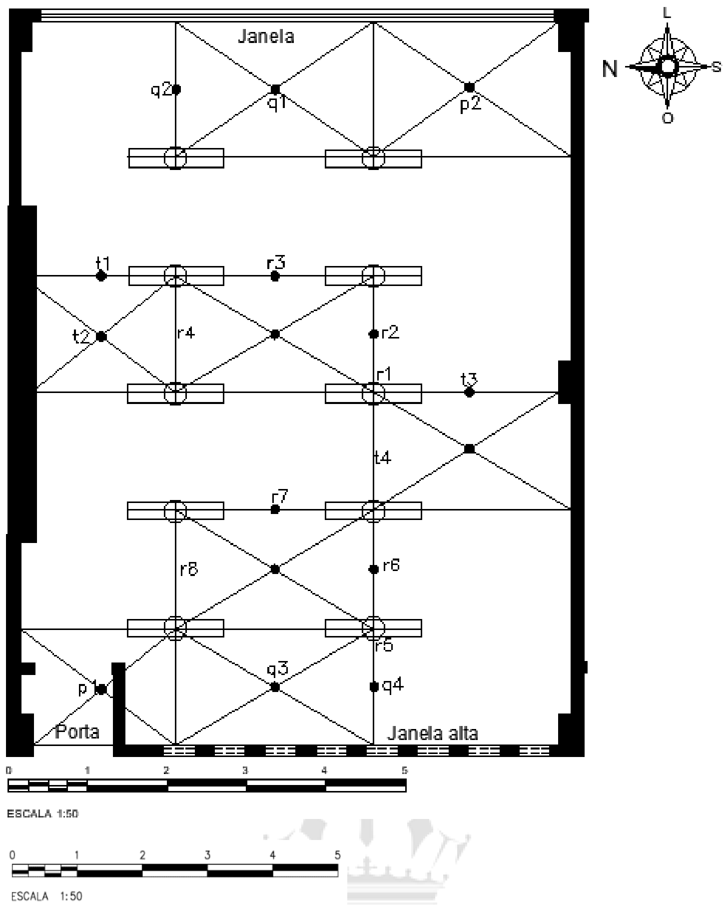

Figure no 6 - Graphic representation of the measurement strategy to obtain the MI

Source: Authors (2021)

Table 2 presents the results obtained at the points indicated in Figure 6.

Table no 2 - Results of the measurements of the points and partial averages

Point	Result (Lux)	Average Arithmetic
p1	1153	*688*
p2	223	
t1	730	
t2	716	*570*
t3	385	
t4	449	
q1	310	
q2	1311	*696,75*
q3	552	
q4	614	
r1	300	
r2	792	
r3	696	
r4	675	*634,5*
r5	300	
r6	791	
r7	700	
r8	522	

Authors (2021)

From the results obtained in Table 2, the average of the illuminance levels of all measured points was calculated, given by:

$$IM = \frac{634.5\ (10 - 1)\ (2 - 1) + 696{,}75\ (10 - 1) + 570\ (2 - 1) + 688}{10.2} = 661{,}97$$

Considering the average found, NHO 11 indicates that the illuminance measured point by point in the task areas should not be less than 70% of the average, to seek a uniform environment and avoid contrasts. Thus, considering that the average illuminance was 661.97 lux, it is known that:

70% of MI = 463.38 lux.

That is, the illuminance values in the task areas, obtained by point-to-point measurements, shall not be less than 463,38 lux.

Figure 7 shows the measurements performed point by point in the task areas, using the lux meter on the desk where users usually use notebooks and notebooks. It was evaluated 34 different points, all located in front of the whiteboard. It is important to emphasize that the measurements were performed in the typical situation and the most unfavorable situation.

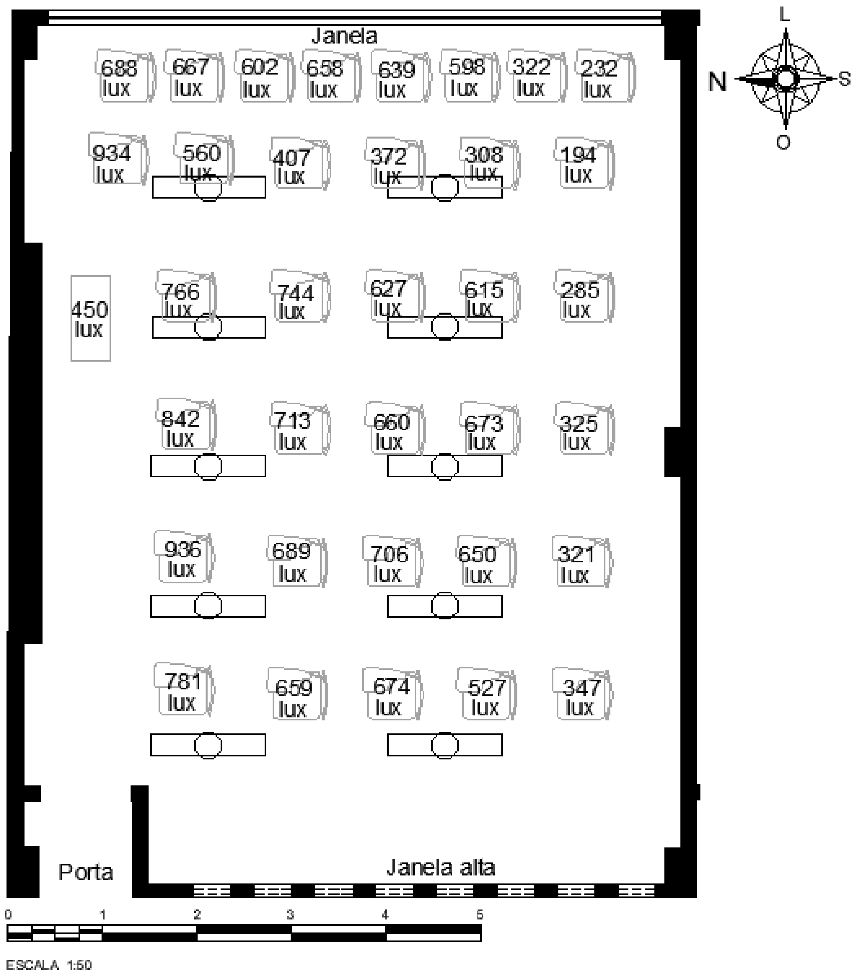

Figure no 7- Point-to-point measurements of task areas

Authors (2021)

Based on Table 2 of NHO 11, for the activity and environment considered, the recommended value is 500 lux and the color rendering index is 80. However, the standard allows a tolerance of up to 10% below this value. In addition, the values of the task areas measured point by point should not be lower than 70% of the MI, equivalent to 463.38 lux. In Figure 7, values below 450 lux are verified, contributing to lighting with poor uniformity and areas with shadows.

Another observation criterion specified in NHO 11 is that the ratio of the highest value measured in the task area to the average ambient illuminance (IM) should not exceed the ratio of 5:1, the result being satisfactory, to avoid excessive contrasts.

5. *Relux Software* Simulation

The simulation of the environment was performed using the *software* Relux Professional, developed by Informatik AG. The *software* is available for free on the internet and is used as a tool to study artificial and natural lighting, simulating the characteristics of light sources and materials. Relux has a quick-to-learn interface, with commands and resources that are easy to absorb for 3D modeling of the environment (LIMA; GARROCHO, 2006).

As a result of the simulations, Figure 8 on the left above, is presented the floor plan with isolux curves, using the solid colors given by the software itself. On the right, is presented the Isolux or PseudoColor with the illuminance values for the selected work plan. On the left below, the illuminance graph in 3D, and on the right below, is presented a three-dimensional plan rendered by the application.

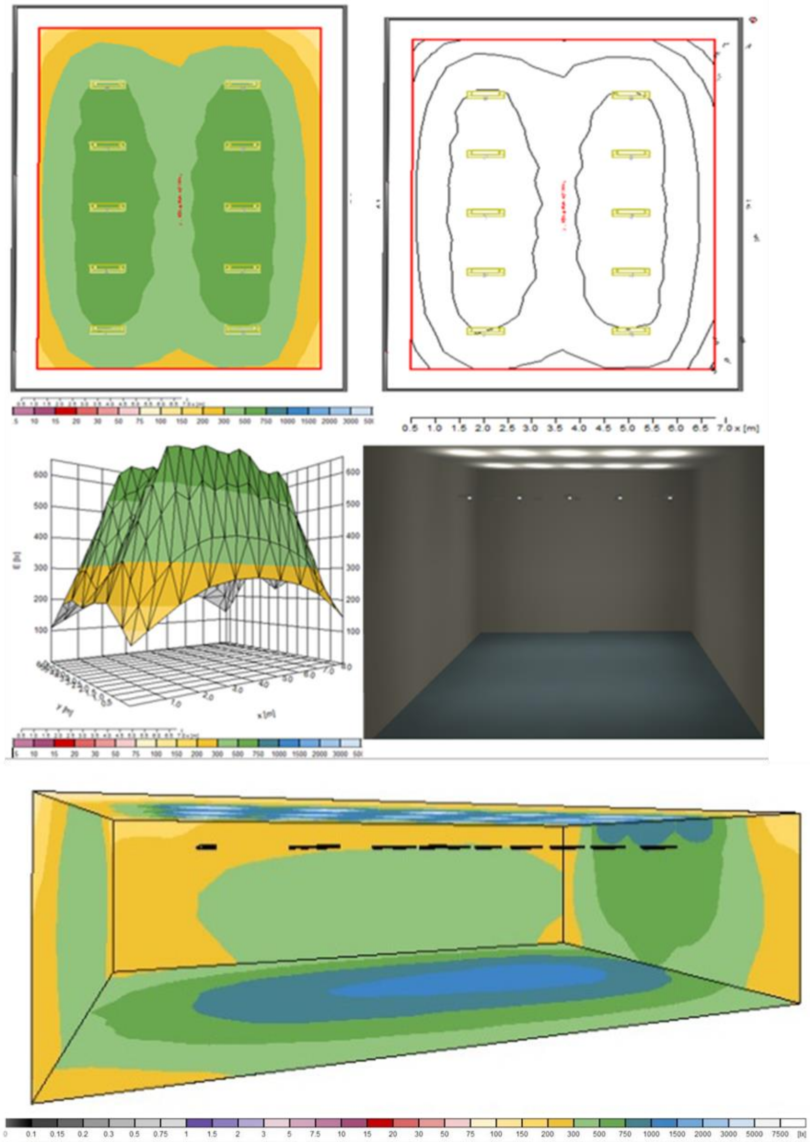

Figure no 8 - Images of the simulation results in Isolux (left above), PeseudoColor (right above), 3D Line Graph (left below), and the rendered 3D Luminance (right below).

Authors (2021)

It is verified that the workstations immediately below the luminaires and in adjacent areas have adequate lighting levels. However, in the peripheral areas, in yellow, there are areas with shadows and lighting levels below the standard requirements.

In addition to the illuminance graph in 3D, isolines of points with the illuminance values for the selected work plan and the floor plan with the representation of the isolux curves, the software also generates a brief report of the calculation performed for the lighting system with information about the luminaires used (luminous flux, useful life, power). The report issued by the *Relux Desktop* software aims to show more clearly how the lighting calculations are made, and to point out the reference values given by the simulation, showing together with the model and type of luminaires.

6. DISCUSSION OF RESULTS

It is known that in the lighting project, it is also essential to make the study with simulation in specific 3D *software*. With the simulation, it is possible to see if the project is by what is expected.

In this sense, the *Relux software* can be considered a necessary tool for decision making and can be used in the process of project design, as it presents potential in the collaboration of artificial lighting design and energy efficiency calculations.

On the other hand, assuming that the classroom is a working environment, in which teachers and students spend the day at posts in the classroom building, there is a need to evaluate the illuminance in the built environment.

Figure 9 shows the image generated by the software and the point-to-point illuminance values in the task areas, measured in the field study. There were differences in the "accuracy" of the reference values, although there were no excessive divergences in the results (Figure 9). This is justified by the fact that the software used did not adopt as a basis, the parameters of the NHO 11.

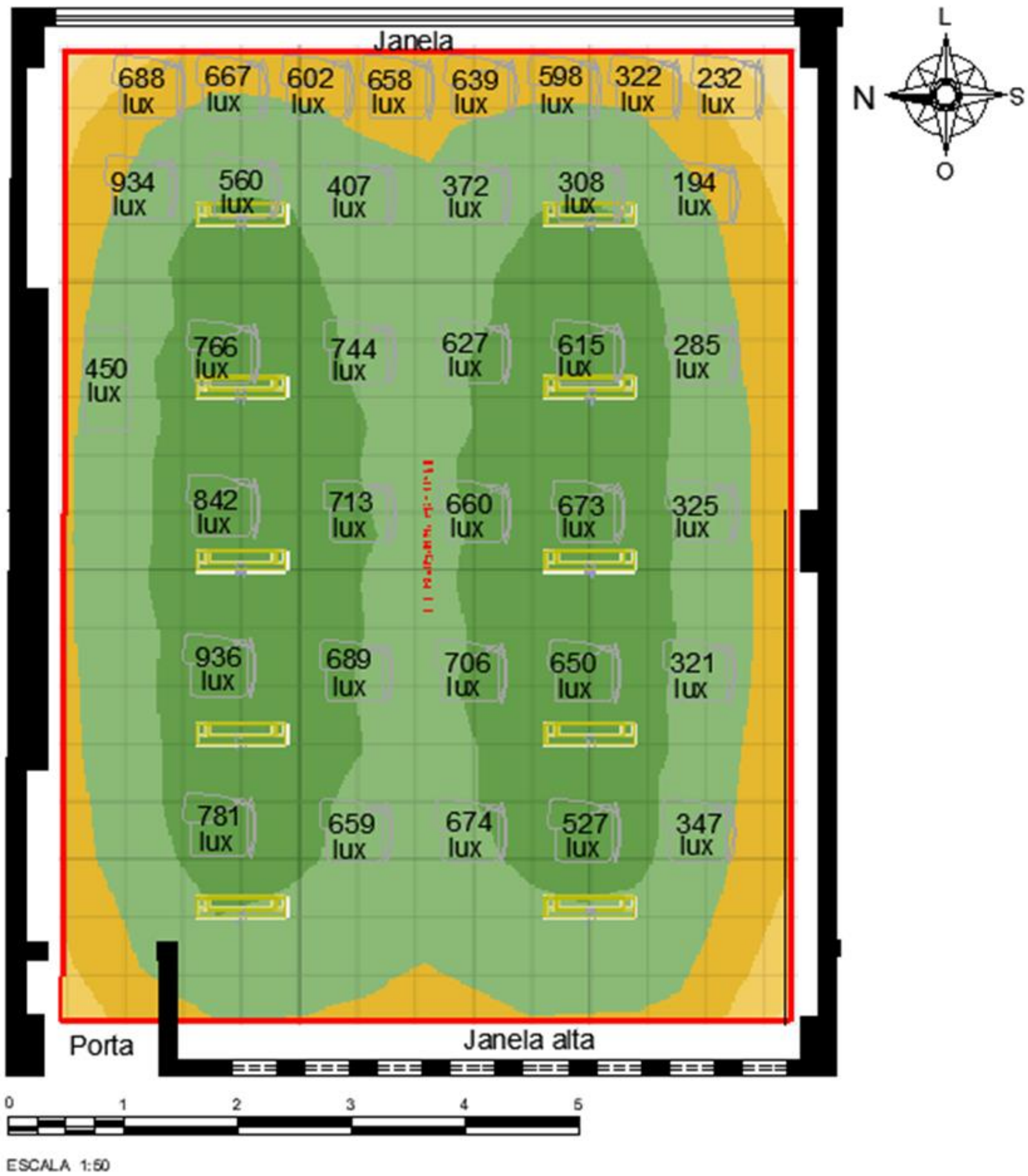

Figure no 9 - Floor plan with the isolux curve and the points of the task area measured with the equipment

Authors (2021)

In addition, despite not requiring in-depth knowledge on the subject and skills in handling the measuring equipment as required for the standardized quality-quantitative evaluation, it was verified the need for a critical eye and with minimum technical knowledge for the interpretations of the simulations, which may be in the undergraduate student in civil engineering, present in the studied institution.

Even with these caveats, the use of *software* simulation was considered effective, corresponding to the initial hypothesis of being characterized as a quick and easy-to-use tool that can be used to evaluate the lighting system of a public educational institution, which has limited resources and poor maintenance management. However, it is worth changing the software reference parameters.

7. FINAL CONSIDERATIONS

This paper presented the evaluation of the lighting system of a classroom of a university campus using computer simulation, confronting it with the results of a standardized quality-quantitative evaluation in the field.

The study showed that the classroom is deficient in its lighting system, and thus can cause occupational, mental, and even physical risks to users. Due to insufficient lighting in the task, it was placed as a priority the replacement of burned-out or defective lamps, cleaning in the fixtures and lamps. In addition, it is indicated the signaling of the arrangement on the floor, since, at some points, the pillars cause shadows impacting on some work areas.

Regarding the blocking by black film, it is indicated the exchange of frames, the double type with micro blinds. However, despite having a long life, it has a high initial cost, difficult for the public institution. In this context, it was considered the maintenance of the film and considered the human behavior, which inevitably closes either by the entrance of the sun, as in the entrance of rain, and opens in the afternoon, to ventilate the environment. For future studies, it is verified the need for a temperature study, being the environment in the morning shift is critical.

Despite the need to correct teaching irregularities, the present study emphasizes, as the main contribution, the computational simulation environment for the evaluation of the lighting of the work environment as a means of rapid implementation and of easy-to-use public systems, which usually have limitations, and poor maintenance management.

Finally, it is worth studying the future to enable an adjustment, in the parameters, of the software used for a new study, since the study room will be compared to a working environment for students and teachers, at all working hours. In this study, there is no intention to substitute technicians for issuing technical reports.

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Note

The equipment used for the luminance measurements is the EXTECH INSTRUMENTS Luxmeter Model LT300, with serial number 150609562. Calibration performed through the Almont Laboratory, 2021. Located at RuaHorácio de Castilho, 284 - Vila Maria Alta, São Paulo - SP, Brazil.

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