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Lighting Applied to Textile Industries to Increase the Welfare of Personnel and Business Productivity

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ABSTRACT

Lighting engineering, the science in charge of determining the necessary levels of illumination in the spaces destined to the development of daily activities, considers that in industry, optimal levels of illumination allow activities to develop in an adequate environment, in addition to increasing the well-being of the employees and, consequently, increasing the productivity of the companies; Several studies have been conducted worldwide related to the analysis of lighting in different work activities, showing that it is an aspect to be improved in workplaces, it has also been identified that the lack of lighting has a substantial impact on the psychophysiological processes of vision, so the objective of this study is to develop a systematic proposal to identify the level of lighting in industries engaged in garment manufacturing and propose a scheme to ensure adequate levels of lighting, for this, the procedures provided in the Mexican Official Standard are applied: NOM-025-STPS-2008, for the luminotechnical study and the results are compared with the Spanish Standard: UNE-EN 12464-1:2022, identifying a 50.52% of non-compliance with the expected standard; from the diagnosis a lighting proposal is developed using the software DIALux evo 8. 2 software for design and simulation. From the expected results, it is estimated that with the implementation of the proposal, 100% compliance with the required lighting standards will be achieved, energy productivity will be increased by 462% in the application area and, according to other research, the labor welfare of employees will be improved by 40% thanks to adequate levels of brightness in their workstations, as well as the reduction of visual discomfort.

Keywords: Occupational well-being, Energy efficiency, Lighting, Increased productivity

INTRODUCTION

According to The United Nations Environment Programme (UNEP) (Programa de las Naciones Unidas para el Medio Ambiente, 2016), the Global Environment Facility (GEF) (Fondo del Medio Ambiente Mundial, 2021) and United for Efficiency (U4E, United for Efficiency) (U4E United for Efficiency, 2021) in their document: "Accelerating the Global Adoption of Energy Efficient Lighting" (International Science Council, 2022), lighting accounts for

15% of global energy consumption and 5% of greenhouse gas emissions, generating environmental impacts contributing to current climate change (Saavedra, et al., 2016). In addition to all this, lighting is a priority part of the ergonomic conditioning (Instituto Nacional de Seguridad e Higiene en el Trabajo, 2015) of all workplaces, even though the human being has the ability to adapt, poor lighting environments can cause increased visual fatigue, reduced efficiency associated with performance, increased non-quality, and even occupational accidents.

According to the digital portal Portafolio (EL TIEMPO Casa Editorial, 2021), in their article called "Lighting and design influence work performance", they say that the change of light throughout the day depending on the biorhythm of people, collaborates the motivational aspect of their performance, for example the cold light, which is more intense and blue, at the beginning of the working day, helps in the activation of the organism, For example, cold light, which is more intense and blue, at the beginning of the working day, helps to activate the organism, and at the end of the day, warm light, which is less intense and has a yellowish hue, helps to relax and rest. Philips (2021) affirms that optimal lighting can increase productivity by 10%.

In 2010, the lighting initiative called en. lighten (Programa de las Naciones Unidas para el Medio Ambiente, 2016), with the aim of incorporating new and more efficient lighting technologies worldwide, in the document "Analysis of energy saving in industrial LED lighting: A case study" (Ana Serrano-Tierz, 2015), metal halide luminaires are replaced by LED luminaires, achieving energy savings close to 50%, in the same document, it is expected that by 2020 75% of the lighting will be based on LED technology, in accordance with the decision adopted by the European Parliament on June 17, 2010.

DEVELOPMENT

Considering the provisions of the Mexican Official Standard NOM-025-STPS-2008, Lighting conditions in workplaces (SECRETARIA DEL TRABAJO Y PREVISION SOCIAL, 2008), the lighting level survey is developed with the following steps:

Determination of the Plant Lighting Level

Characteristics of the Production Plant

The necessary characteristics of the production plant under study are identified in Table 1 as well as the distribution of its areas Figure 1.

Calculation of the Room Constant-k

Calculation of Luminaire Heights

Luminaire height (h)

$$h = \frac{2}{3}(H - h') \tag{1}$$

Table 1. Characterization of the production plant under study.

Characteristics	Description
Height of the room (H)	3.6 m
Height of the working plane (h')	0.8 m
Length (x)	36.4 m
Width (y)	29.6 m
Wall color	Medium gray
Ceiling color	Old white
Activities performed in the work area	Garment manufacturing
Internal work areas (Figure 1)	(1) buttonholes and buttons, (2) embroidery, (3) preventive quality, (4) production

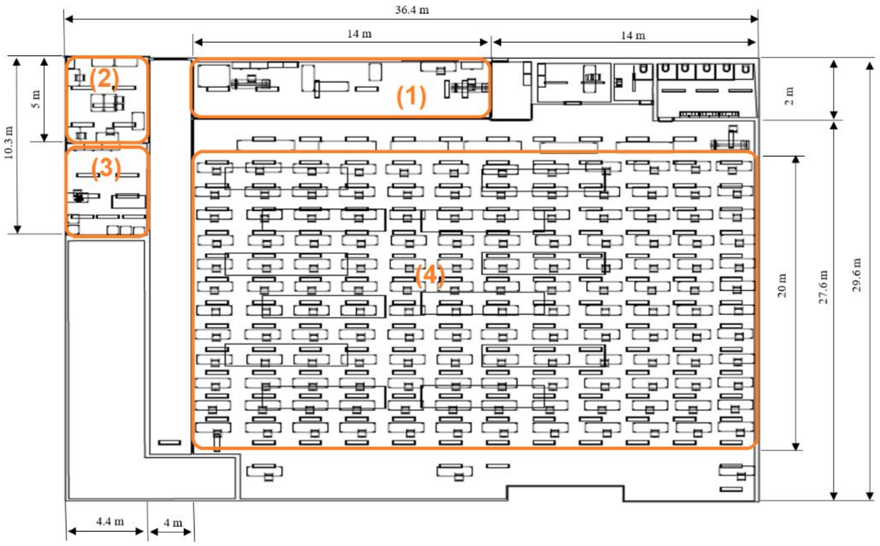

Figure 1: Distribution of internal work areas under analysis.

Where:
h' = working plane height
H = room height

Calculation of the Room Constant (K)

Room constant K

$$K = \frac{\text{A x B}}{h\ (A + B)} \quad (2)$$

Where:
A = length of the work area
B = width of the working area
h = height of luminaires

Table 2. Characterization of the lighting system.

Features	Description
Type of lighting	Natural (skylights), artificial (during the day), and localized (located in machines).
Number of luminaires	and localized (located in machines)
Type of lamp	191 luminaires located in the manufacturing area (each luminaire has 2 lamps)
Power of each lamp	(each luminaire has 2 lamps)
Lamp dimensions	Fluorescent
Luminous flux	59W
Number of lamps	(1200 × 26) mm
Life time	1 870 lm

Table 3. Correlation of the area index and the number of measurement areas.

Area index	Minimum number of zones to be evaluated
IC < 1	4
1 ≤ IC < 2	9
2 ≤ IC < 3	16
3 ≤ IC	25

Identification of the Number of Measurements to Be Taken in the Productive Areas

For this determination and in accordance with the proposed use standard, the following procedure is defined.

Main Characteristics of the Area Lighting System Under Study, Which is Summarized in Table 2

Location of Measurement Points: Based on the characteristics of the 4 defined areas, the IC area index must be identified to identify the number of measurement zones, considering the equation:

Area index IC

$$IC = \frac{(x)(y)}{h\,(x+y)} \tag{3}$$

Where:

IC = area index

x,y = dimensions of the area (length and width), in meters

h = Height of illumination with respect to the working plane, in meters

Considering the resulting CI value, the minimum number of zones to be evaluated is identified in Table 3.

As an example for the area of buttons and eyelets, considering that the CI is 1.1 and the minimum number of zones to be evaluated is 9, the area can be divided as shown in Figure 2.

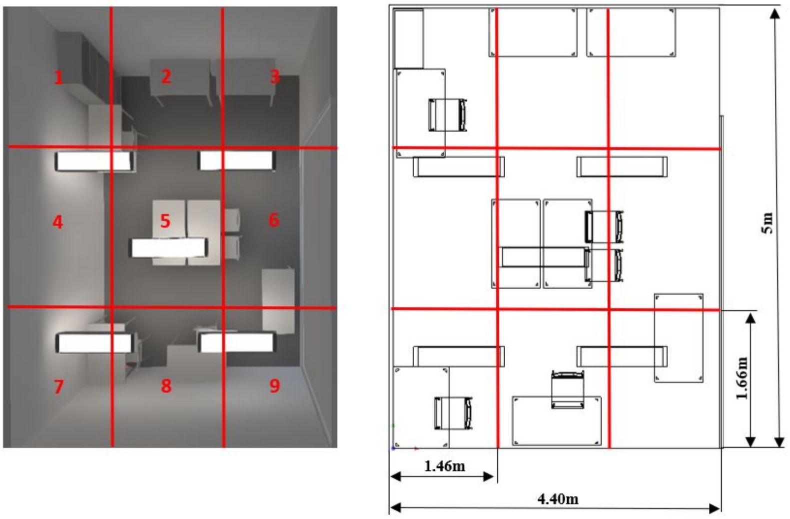

Figure 2: Light measurement points in the study area.

Table 4. Example, forecast in the area of Buttonholes and Buttons.

AREA	DATE	TIME	TYPE OF ILLUMINATION
Buttonholes and Buttons	Tuesday	08h00-10h00	Artificial y natural
	Wednesday	10h00-12h00	Artificial y natural
	Thursday	12h00-14h00	Artificial y natural

Table 5. Example of average illumination measurement.

Recording of illumination measurements (lux)			
Sampling points	Days of measurement		
	Tuesday	Wednesday	Thursday
1	246	237	210
2	202	181	165
3	140	180	125
4	134	125	120
5	168	140	150
6	370	290	250
7	184	180	168
8	210	200	205
9	260	253	249
Average	212.6	198.4	182.4
	Overall average	**197.8**	

Measurement of Illumination Levels

Based on what is proposed by the standard, the chronogram for taking illumination measurements is developed and an example in the buttonhole and button area is shown in Table 4.

Table 5 shows the values resulting from this measurement.

Table 6. Summary of lighting levels of the production facility.

Section	Length x Width (m)	Luminaire height (m)	Area index	Minimum number of areas to be evaluated	Average illuminance (lux)	Number of luminaires	Number of lamps	Number of workers
Buttonholes and buttons	5.0 × 4.4	2.12	1.10	9	197.8	5	10	1
Printing and embroidery	5.3 × 4.4	2.12	1.26	9	411.5	7	14	2
Preventive quality	14 × 2	2.12	0.92	4	618.7	6	12	2
Production	28 × 20	2.12	6.14	25	442.2	173	346	97

Table 7. Percentage of compliance with the illumination level of the plant under study.

Working section	Current average illumination level (lux)	Minimum recommended levels (UNE, Asociación Española de Normalización, 2022) (lux)	Percentage of compliance
Buttonholes and buttons	197.8	750	**26.37 %**
Printing and embroidery	411.5	750	**54.87 %**
Preventive quality	618.7	1000	**61.87 %**
Production	442.2	750	**58.96 %**

Table 6 shows the results of the lighting identification procedure of the production plant areas.

Comparison of Lighting Levels of the Plant With Values Proposed in the UNE-EN 12464-1:2022 Standard (UNE, 2022)

Table 7 presents the level of compliance of the illumination of the studied area with the appropriate values.

Identification of Conditions Affecting Personnel Working in Low-Light Environments

In the document "Health Effects of Changes in Artificial Lighting Conditions on Workers: A Systematic Review" (Avendaño Toloza, 2018), the following is identified.

An illumination level at 150 lux, below the required standards, 84.6% of the subjects analyzed show some visual symptom, 65% defective vision, 85% near vision, 11% astigmatism, color 15% and 45% heterophony.

With the data presented and compared to the initial illumination levels, it is affirmed that more than 80% of the people exposed to this level will present visual symptoms.

IMPROVEMENT PROPOSAL APPLYING LIGHTING TECHNIQUES AND THE USE OF SPECIALIZED SOFT-WARE

Design of the Simulation of the Proposal

Calculations are made to determine the parameters involved in this system, such as: utilization coefficient, reflection coefficient, maintenance

Table 8. Effective reflectances for certain colors and textures (% values).

Tone	Color		Surfaces		Construction finishes	
Very clear	New white	88	Maple	43	Light-colored	18
	Old white	76	Walnut	16	quarry	27
	Cream	76	Mahogany	12	Cement	40
	blue	81	Pine	48	Concrete	45
	Cream	65	Light wood	30-50	White marble	25
	Blue	76	Dark wood	10-25	Vegetation	07
	Honey	83			Clean asphalt	17
	Grey	72			Rock paving	13
	Green blue				stone	30-50
					Gravel	15-25
					Light brick	
					Dark brick	
Clear	Cream	79				
	Blue	55				
	Honey	70	METAL FINISHES			
	Gray	73				
Medium	Blue green	54	Polarized white	80		
	Yellow	65	Polished aluminum	75		
	Honey	63	Matt aluminum	75		
	Gray	61	Clear aluminum	63		
Dark	Blue	08				
	Yellow	50				
	Brown	10				
	Gray	25				
	Green	07				
	Black	03				

Source: Cálculo del Número de Luminarias para un Espacio Arquitectónico por el Método de Lúmenes (Coordinación de Universidad Abierta, Innovación Educativa y Educación a Distancia de la UNAM, 2021).

co-efficiency, total luminous flux, number of luminaires, luminaire placement height and luminaire placement; finally, with the help of DAILUX evo 8.2 software, the design and simulation of the proposed new lighting system is carried out.

Luminaire Height Calculation

The initial values are maintained as there is no change of locality, using equation (1).

Calculation of Room Constant-k

The initial values are maintained in the absence of a change of location, using equation (2).

Determination of Reflection Values

Starting from the wall and ceiling colors and with the help of Table 8, the effective reflectance measured in percent can be determined.

Table 9. Utilization coefficient considering reflectances and room index.

K	p Ceiling	0.80		0.50		0.20	
	P Wall	0.80	0.40	0.80	0.40	0.80	0.40
	1	0.94	0.85	0.52	0.65	0.42	0.39
	2	0.91	0.87	0.65	0.75	0.53	0.38
	3	0.89	0.71	0.50	0.62	0.42	0.37
	4	0.81	0.72	0.53	0.60	0.41	0.25

Source: Cálculo del Número de Luminarias para un Espacio Arquitectónico por el Método de Lúmenes (Coordinación de Universidad Abierta, Innovación Educativa y Educación a Distancia de la UNAM, 2021).

Table 10. Maintenance factor values (Fm) by CIE.

Frequency of cleaning (years)	1				2			
Ambient conditions	**P**	**C**	**N**	**D**	**P**	**C**	**N**	**D**
Luminaires open	0.96	0.93	0.89	0.83	0.93	0.89	0.84	0.78
Reflector top open	0.96	0.90	0.86	0.83	0.89	0.84	0.80	0.75
Reflector top closed	0.94	0.89	0.81	0.72	0.88	0.80	0.69	0.59
Reflectors closed	0.71	0.94	0.88	0.82	0.77	0.89	0.83	0.77
Dust-proof luminaires	0.98	0.94	0.90	0.86	0.95	0.91	0.86	0.81
Luminaires with indirect emission	0.91	0.86	0.81	0.74	0.86	0.77	0.66	0.57

On the ceiling
We choose a gray color, the closest possible in this case is:
Medium gray = 61 = 0.50
On walls
It is determined with a wall color, white:
Old white = 76 = 0.80

Determination of the Utilization Coefficient Value

After having calculated the reflection values and the calculation of the room constant (K), the utilization coefficient is found in Table 9.

$$Cu = 0.52$$

Determination of the Maintenance Factor fm

It will be done through Table 10 presented by the International Science Council (ISC) (Saavedra et al., 2016), in which it is sufficient to specify the frequency with which maintenance will be performed on the lighting installations, the type of lamp and finally the environmental conditions to which the system is subjected.

$$Fm = 0.89$$

Where:
P = Pure or very clean;

C = Clean;
N = Normal;
D = Dirty

Calculation of the Total Required Luminous Flux

$$\Phi t = \frac{E_m \times S}{Cu \times Fm} \qquad (4)$$

Em = Average illumination level (Standard 12 464.1) (lux)
Φt = Luminous flux that determines room or zone needs (lum)
S = Surface to be illuminated (m^2)

The luminous flux is related to utilization coefficients (Cu) and the maintenance factor (Fm), which are defined below:

Cu = It represents the ratio between the luminous flux received by a body and the flux emitted by the light source.

Fm = That which indicates the degree of conservation of a luminaire.

$$\Phi t = \frac{1000 \times 14 \times 2}{0.52 \times 0.89}$$

$$\Phi t = 60\,501.29 \text{ } lumens$$

Calculation of the Number of Luminaires

The following formula will be used to calculate the number of luminaires:

$$Nl = \frac{\Phi t}{n \times \Phi l} \qquad (5)$$

Donde:
NL = number of luminaires;
Φt = total luminous flux required in the zone or room;
Φl = luminous flux of a luminaire;
n = number of lamps in the luminaire;

$$Nl = \frac{60\,501.29}{2 \times 1250}$$

$$Nl = 24 \text{ } luminaires$$

Displacement of Luminaires

Once the number of luminaires required has been calculated, they are distributed on the work plan to achieve uniformity through the following formulas:

Number of rows across the width of the room

$$N_{rows\ width} = \sqrt{\frac{Nl \times a}{b}} \qquad (6)$$

$$N_{rows\ width} = 1.85$$

$$\therefore N_{rows\ width} = 3$$

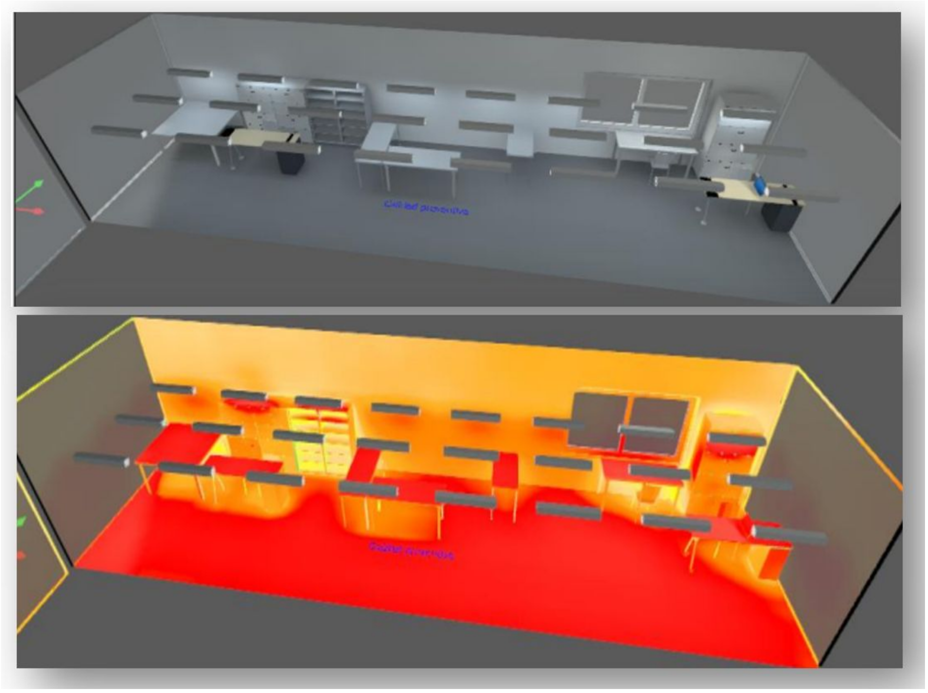

Figure 3: Simulation of the working environment.

Number of rows along the premises

$$N_{\text{rows long}} = N_{\text{width}} \frac{b}{a}$$

$$\mathbf{N}_{\text{rows long}} = \mathbf{12.95}$$

$$\therefore \mathbf{N}_{\text{rows long}} = \mathbf{8}$$

With the data obtained, the simulation of the work area is developed Figure 3, in the DIALux evo 8.2 program, observes the luminous flux that will generate the proposal that includes LED lamps and the distribution at 0.80 meters from the ground as work plane.

Estimation of Lighting Levels

At the end of the simulation process of the optimal lighting level, Table 11 shows the adequate lighting levels in each of the studied areas in compliance with the European standard on indoor lighting (UNE, 2022).

Increased Well-Being of the Collaborators

The proposal will satisfy the lighting requirements for the development of work activities, comparatively with the study "Health effects of changes in artificial lighting conditions in workers" (Avendaño Toloza, 2018), it is expected to improve at least 6 of 15 eye fatigue ratings, i.e. the benefits would be increased by 40%, to all employees of the plant, resulting in an increase in labor welfare.

Calculation of productivity increase. Analogous to what is presented in the document "Process Optimization of Advertising Articles Using an Integrated

Table 11. Comparative summary of illumination levels before and after the proposal.

Section	Initial illumination (lux)	Initial luminaires	Luminaires required (DIAL Gmbh, 2021)	Required illumination (UNE, 2022)	Proposed illumination (DIAL Gmbh, 2021) (lux)
Buttonholes and buttons	197.8	5	9	750	915
Printing and embroidery	411.5	7	9	750	790
Preventive quality	618.7	6	24	1000	1058
Production	442.2	173	151	750	856

Strategy of Production and Environmental Care" (Espejo-Viñán, 2021), the increase in productivity is estimated as follows

$$\textit{Increased productivity} = \left(\frac{\textit{Final Productivity}}{\textit{Initial Productivity}}\right) - 1 \quad (8)$$

$$IP = \left(\frac{\frac{\textit{Finished product}}{\textit{Proposed electrical energy consumption}}}{\frac{\textit{Finished product}}{\textit{Initial electrical energy consumption}}}\right) - 1 \quad (9)$$

$$IP = \frac{\textit{Initial electrical energy consumption}}{\textit{Proposed electrical energy consumption}} = \frac{703.17}{125.23}$$
$$= 5.615 - 1 = 462\% \quad (10)$$

The proposal foresees an increase in productivity, related to electricity consumption in the order of 462% and a corresponding reduction in environmental pollution due to a reduction in energy use, which in the study period is mainly supplied by hydroelectric energy.

CONCLUSION AND FUTURE WORK

This research proposes a clear and simple methodology of the application of international norms of illumination compared to its standards, and with the help of the method of lumens and the simulation software DIALux, it is possible to show that it could be passed from an average non-compliance by low illumination of 50% to 0%. 52% to 0%, which affects more than 80% of the people in their labor welfare, related to the visual part, hoping to reduce this affectation by at least 40%, and finally there will be an increase in productivity related to electrical energy of 462%, by optimizing resources by replacing fluorescent lamps by a better distribution with LED luminaires with lower energy consumption.

In the future, lighting and energy expenditure controls should be incorporated after the implementation of the proposal, with the purpose of increasing the monitoring of the visual affections of the employees, as well as the reduction of the energy used in the plant in favor of greater increases in productivity and labor welfare of the collaborators.

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