REVISTA CÁTEDRA

Aprendizaje significativo de la luminancia por el método punto por punto

Significant learning of luminance by the point-by-point method

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Resumen

Este artículo describe el proceso experimental realizado en la obtención de la luminancia de dos tipos de focos, el de incandescencia y el fluorescente en un mismo ambiente físico. Para realizar el mencionado estudio se eligió el método punto a punto, el cual permite conocer la luminancia en puntos concretos de una superficie bajo una fuente de luz que se ubica a una determinada altura. Además, se trata de conocer el grado de confort visual del sentido de la vista en un lugar de iluminación uniforme. Los resultados obtenidos permiten realizar diversas comparaciones en el uso de una determinada lámpara, tomando en cuenta la que más beneficios presenta en función de ofrecer un nivel de luminancia y un confort visual apropiado, un ahorro económico y de fácil obtención y reemplazo.

La experiencia en el aprendizaje de Luz e Iluminación en busca de un aprendizaje significativo evoca conocimientos previos tales como: flujo, intensidad, ángulo sólido y luminancia con el objetivo de entender el fenómeno, presentar una nueva información y hacer un f*eedback* en busca de una nueva información que acreciente su pensamiento en la vida cotidiana. Con los resultados obtenidos en la presente investigación se desea contribuya al mantenimiento de las luminarias de las aulas de la Carrera de Pedagogía de las Ciencias Experimentales Matemática y Física de la Universidad Central del Ecuador, las mismas que tienen características físicas similares al lugar en el cual se realizó la experiencia.

Palabras clave

Ángulo sólido, aprendizaje significativo, flujo, iluminación, luminancia, luz, medición.

Abstract

This article describes the experimental process performed in obtaining the luminance of two types of light bulbs, the incandescent and the fluorescent, in the same physical environment. To perform the mentioned study, the point-to-point method is chosen, which allows knowing the luminance at specific points of a surface under a light source located at a certain height; in addition, it is about knowing the degree of visual comfort of the sense of sight in a place of uniform illumination. The results obtained allow comparisons to be made in the use of a specific lamp, taking into account the one that presents the most benefits based on offering a level of luminance and appropriate visual comfort, economic savings and easy obtaining and replacement.

The experience analyzed allowed the application of the basic principles of light and lighting, subjects studied in the classroom, achieving a significant learning about: flow, intensity, solid angle and luminance, without neglecting the search for a pleasant atmosphere of a room through the qualitative and quantitative analysis of the phenomenon. In addition, it is expected that the results obtained in this research serve as a reference to initiate an improvement plan that contributes to the maintenance of the luminaries of the classrooms of the Pedagogy career of the Mathematical and Physical Experimental Sciences of the Central University of Ecuador, which have similar physical characteristics to the place where the research was carried out.

Keywords

Solid angle, meaningful learning, flow, lighting, luminance, light, measurement.

1. Introduction

The role of the education according to the Organic Law of Higher Education (LOES) (Art 13. Literal b) is to "promote the creation, development, transmission and dissemination of science, technology, technology and culture" (p. 11). This role inspired this article whose main objective is to foster an experimental study to compare the luminance between lamps of different species, located in the same physical environment. In addition, it aims to observe the development and obtain a meaningful learning of the principles of light and illuminance with its different themes.

It considers the comparison between the luminance results of a lamp of incandescent light and another of phosphorescent light, a situation that will allow an appropriate decision to be made in the selection of lamps for a daily use, especially in classrooms in which the learning process takes place. In this regard, Ausubel (1963) states that:

> Significant learning occurs when the contents are non-arbitrary and substantially related (not by-heart) to what the student already knows. Substantial and non-arbitrary relationships are understood as ideas related to some specifically relevant existing aspect of the student's cognitive structure, such as an image, an already significant symbol, a concept, or a proposition (p. 18).

To achieve meaningful learning, active methodologies such as experimentation should be used, resulting in students applying the knowledge to the achievement of a new one. Similarly, Ausubel (1976) and Moreira (1997) explain:

> Meaningful learning is the process by which new knowledge or information relates to the cognitive structure from which it is learned in a non-arbitrary and substantive or non-literal way. This interaction with the cognitive structure does not occur by considering it as a whole, but with relevant aspects present in it, which are called anchoring ideas (p. 2).

Anchoring ideas adapted to the study of artificial lighting in classrooms are a challenge to know whether the physical space in which classes are developed is pleasant and comfortable to the human eye, since performing all activities require stable lighting; this raises the good use of existing artificial lighting. Observational and luminance measurement of a LED or incandescent and fluorescent bulb helps to understand and obtain meaningful learning.

According to Borja Reyes (2017) "Good lighting is adaptable to the place to be illuminated creating a welcoming environment with stable visual comfort" (p. 64). The permanence of humans in a room depends a lot on the lighting of the spaces that are intended for leisure, rest or work. The light visible to the human eye is a small region of the electromagnetic spectrum between 380 nm and 780 nm wavelength, from ultraviolet to infrared, respectively. Studying the nature of white light shows that the set of wavelengths of the visible spectrum when traversing a crystalline prism propagates a range of colors ranging from infrared to ultraviolet, verifying that the wavelength in the infrared is higher than the ultraviolet.

A pleasant environment produces comfort to the sense of sight, in the visible spectrum it is known that the yellow-green light of wavelength 555 nm is the ideal light but accompanied by adequate lighting any activity can be developed with success. For example, churches, theaters, parks, streets, hospitals, classrooms, museums, among others.

The illumination of perpendicular surfaces requires certain levels of luminous flux, being more intense the illumination at the central point. If analyzing a point away from the central position the illumination decreases, being strictly related to the luminous intensity and height, since the Illumination is directly proportional to the luminous intensity and inversely proportional to the height squared.

2. Materials and methods

The research method used corresponds to quantitative work, verifying the capacity of two bulbs for domestic use in order to achieve significant learning of luminance by the "point-by-point" method. For this purpose, experimentation has been used in the laboratory of the Physics Unit of the Central University of Ecuador. In addition, bibliographic information has been collected from Physics texts, simulators and technological resources from the Web. All the resources mentioned have been identified sequentially in order to make a qualitative and quantitative description experience of the application of light and lighting through a complete experimental descriptive study of luminous phenomena in the study of the wave movement.

3. Related concepts

3.1 Rays of light and shadow

The first properties of light studied in the Wave Movement is the rectilinear propagation of light and shadows that are understood through the visual sense that places distances, directions and forms. For example, the solar clock entering the university theater of the Central University of Ecuador produces the formation of a sharp shadow of an iron pointer that takes advantage of sunlight to measure time.

Considering Huygens principle, each point on a moving wave front can be considered as a source of secondary waves. The wave front at any moment is the covering of these waves. Thus, according to Young (2009) light emitted in all directions through the point source of light can be represented by a series of spherical wave fronts that move away from the source at the speed of light" (p. 1144).

For these purposes, a point source of light is one whose dimensions are small compared to the distances studied. Notice that spherical wave fronts become virtually flat wave sources in any specific direction at distances far from the source. An imaginary straight line drawn perpendicular to the wave fronts in the direction of the moving wave fronts is called lightning. Of course, there are an infinite number of rays that start from the point source.

3.2 Light

According to León (2002) "Light is a manifestation of energy in the form of electromagnetic radiation capable of affecting the visual organ, is called radiation to the transmission of energy through space" (p. 3), that is, light is light is it consists of energized particles called photons, whose energy and frequency determines wavelength and color.

Light is defined as electromagnetic radiation that has isotropic behavior in all directions without the need for a means of propagation. The speed of light propagation is set to a value of 299 792 458 m/s, although it usually approximates 3×10^8 m/s. The speed of light is in perfect harmony at frequency and wavelength, with the units being the frequency Hertz (Hz) and wavelength in nanometers (nm). Visible light is able to stimulate the human eye through a luminous spectrum, ranging from ultraviolet to infrared with values between 380 to 780 nm, respectively.

3.3 Luminous flux

According to Domínguez -Martínez (2008) luminous flux "is the luminous radiation capacity valued by the human eye" (p. 30). The luminous flux analyzed as the total radiant power emitted by a light source is capable of affecting the sense of sight. Light sources emit electromagnetic energy distributed over multiple wavelengths. The electrical energy supplied to a lamp emits radiation. This radiant energy emitted by the lamp per unit of time is called radiant power or radiant flow. Only a small portion of this radiant power is found in the visible region: the region is between 380 and 780 nm and is called luminous flux. The sense of sight depends only on visible or luminous radiated energy per unit of time.

The human eye is not equally sensitive to all colors. In other words, equal radiant powers of different wavelengths do not produce the same brilliance. A 40W green light lamp looks brighter than a 40W blue light lamp. Figure 1 indicates the eye's response to various wavelengths. The sensitivity curve is bell-shaped centered approximately in the middle region of the visible spectrum. Under normal conditions, the eye is more sensitive to the green-yellow light wavelength of 555 nm. Sensitivity drops rapidly for longer and shorter wavelengths.

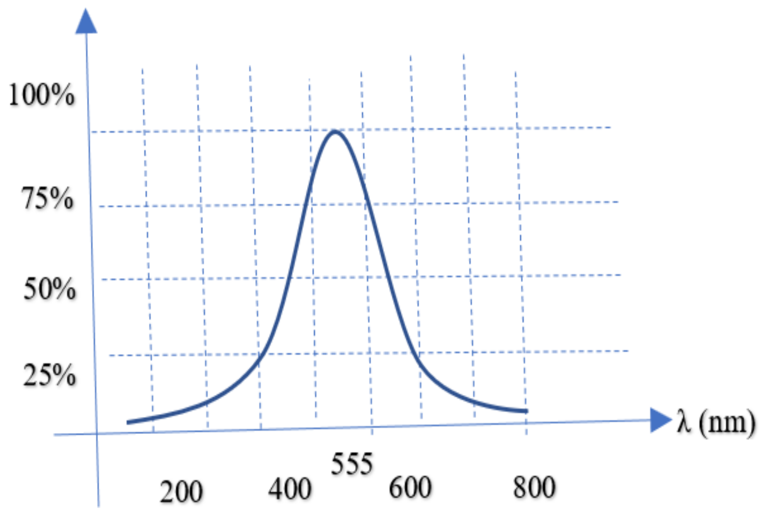

Figure 1. Sensitivity of light to the human eye

Luminous flux is the amount of energy in luminous form emitted by a source. Its unit is the lumen (Lm).

The concept of a solid angle must first be developed to refer to a lumen in terms of the pattern font. A solid angle in stereoradians (sr) is defined in the same way that a flat angle is defined in radians.

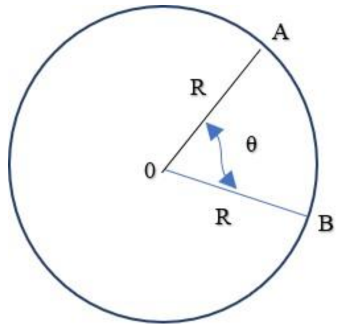

Figure 2. The radian

According to Figure 2, when the arc length AB is equal to the radius R a radian is obtained. The same occurs with the solid angle. This can be thought of as the opening at the end of a cone subtended by an area segment over the spherical surface.

A stereoradians (sr) is the solid angle subtended in the center of a sphere by an area on its surface that is equal to the square of its R radius. In general, the solid angle in steroradians is given by:

$$\Omega = \frac{A}{R^2}\ [sr]$$

Equation 1

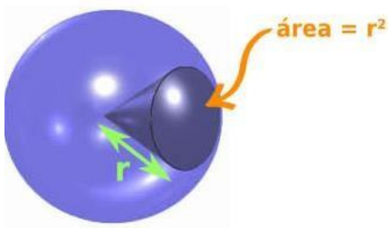

Figure 3. Stereoradians. Adapted from (Disfruta de las matemáticas, 2011)

As well as in the flat angle θ for obtaining the radian, the following consideration is made for obtaining the solid angle of a sphere:

$$\Omega = \frac{4\pi R^2}{R^2}$$

Equation 2

It is considered that: $\Omega = 4\pi$ sr, which is independent of the radius, when defining a lumen from the point of view of power it states that "a lumen (Lm) is the visible luminous flux or radiant power emitted from an aperture of 1/60 section of cm^2 from a light-emitting source, spatially forming a solid angle of 1 sr" (Tippens, 2007, p. 652).

A fluorescent lamp can emit about 4 000 Lm while the light entering through the window can range from 2 000 to 20 000 Lm. This magnitude is typical of each bulb and is a data provided by manufacturers. The light emission of the high solids at high temperatures establishes a standard source at the solidification temperature of the platinum of approximately 1773 °C. In everyday life incandescent lamps are used, which have been calibrated by comparison with the established pattern to understand the phenomenon.

The definition of the luminous flux unit states that "a lumen is equivalent to 1/680 W of 555 nm wavelength of green-yellow light" (Tippens, 2007, p. 652).

5.1 3.4 Luminous intensity

"Is the luminous flux per unit of solid angle in a particular direction. Its symbol is I and the unit in the international system is the candela (Cd)" ((INSHT) & Alvarez Bayonne [2015], 6). The luminous intensity (I) of a light source is the luminous flux (F) emitted per unit of solid angle (Ω) is:

$$I = \frac{F}{\Omega}$$

Equation 3

The essential magnitude of the luminous intensity of the International System (SI) is the candela "cd".

$$1\ [cd] = \frac{1\ [lm]}{1\ [sr]}$$

Equation 4

Because of the latter, the luminous flux is:

$$\mathrm{F} = \mathrm{I} \cdot \Omega$$

Equation 5

and the total flow of an isotropic source is:

$$\mathrm{F} = \mathrm{I} \cdot 4\pi$$

Equation 6

3.5 Lighting or luminance

Lighting or luminance ($\vec{E}$) of a surface (A) is defined as the luminous flux (F) per unit area:

$$\vec{E} = \frac{\vec{E})}{\mathrm{A}}$$

Equation 7

Replacing the luminous flux and solid angle in the previous expression:

$$\vec{E} = \frac{I \cdot \Omega}{A}$$

$$\vec{E} = \frac{I \cdot \frac{A}{R^2}}{A}$$

$$\vec{E} = \frac{I}{R^2}$$

Equation 8

The lighting unit E in its units is the Lux.

$$1\ [lux] = \frac{1\ [cd]}{1\ [m^2]}$$

Equation 9

"Luminance" The inverse law of the square states that the lighting level is proportional to the luminous intensity and inversely proportional to the square of the distance. This occurs in a certain direction in which it emits a light source (Álvarez, 2015, p. 12). When interpreting this definition, it is inferred that the light-emitting source produces illumination that decreases as it departs, but the luminous intensity (I) remains constant. For example, if we have a luminous intensity of 36 cd for surfaces located 1, 2 and 3 meters away, the lighting would be 36 Lux, 9 Lux and 4 Lux, respectively. This is because the illumination is inversely squared from the distance to the surfaces on which the light affects.

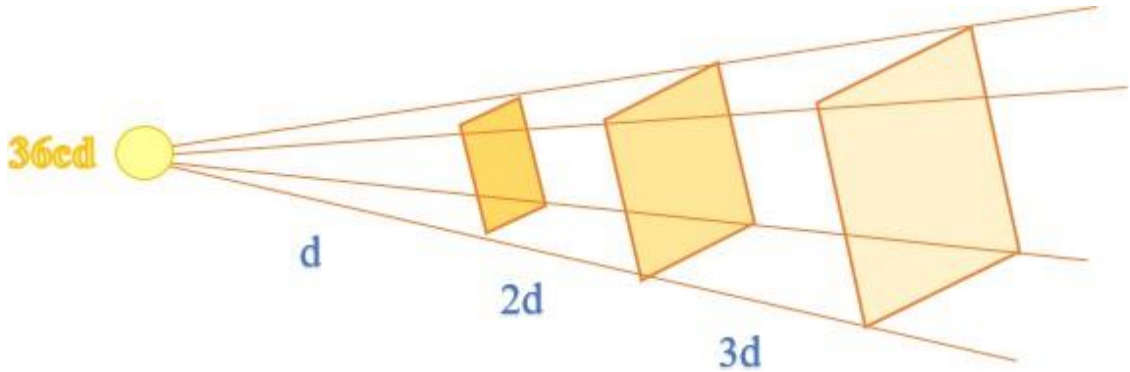

Figure 4. Surface location

The lighting of a surface as it moves away from its incidence area decreases considerably. The point-by-point method determines the lighting or luminance from the normal line to the surface by varying the spacing angles.

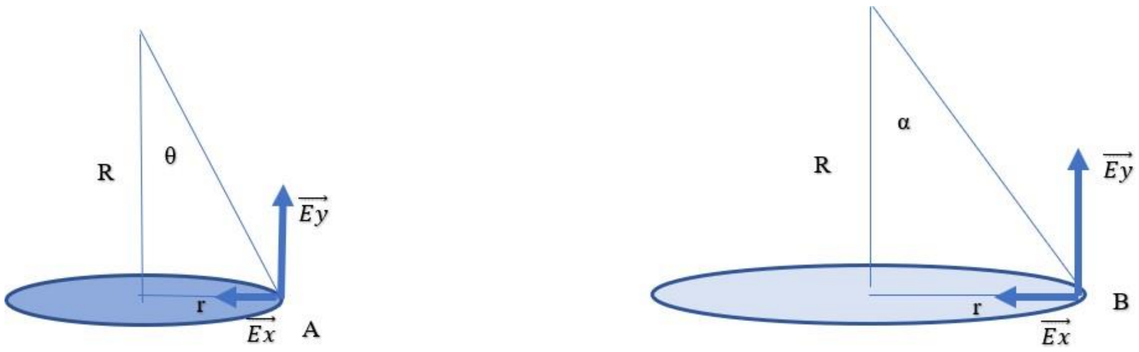

Figure 5. Luminosity of surfaces at different points

Being $\vec{Ex}$ and $\vec{Ey}$ the horizontal and vertical components, respectively, at a point A and B. The angle relative to the normal to the surface varies as it moves away at positions A and B, respectively, then it is met that: $\theta > \alpha$.

4. Point-by-point method

To achieve a cognitive change in the study of luminance, the point-by-point method is used to analyze a point anywhere in the light incidence area. For it, an evocation of what is known and is not known is made about the favorable and unfavorable characteristics of two different bulbs. For the learning obtained to be long-term, it is based on experimentation at the Physics Center of the Central University of Ecuador. Previous knowledge of the subject was used in addition to the data for the understanding of lighting produced by a light bulb. First, the height of the ceiling at which the light is suspended approximately at 3 m, then the observation of a 100 W incandescent bulb (watts) and a fluorescent bulb of 40 W (watts) were considered, being the intensity 130 cd and 200 cd, respectively.

The educational centers have specific lighting requirements, among other things because of the type of activities carried out. Poor lighting of teaching center's facilities, especially classrooms and spaces for classes, learning and study, can lead to visual fatigue, eye damage and could even cause an increase in the rate of school failure because of low student performance

Lightning Table by lux in a teaching center

Area	Luminance
Laboratory	250 to 1000 lux
General Lightning in the classrooms	350 to 1000 lux
Boards	300 to 700 lux
Conference romos	200 and 1000 lux
Library	300 and 750 lux

Cuadro 1. Niveles recomendados de iluminación por zonas. Adaptado de (Helios Strategia Ecuador)

Because of the latter it is inferred that the optimal would be approximately 400 Lux.

4.1 First step

When the angle of the luminous ray with the vertical is not known, then it is calculated as follows:

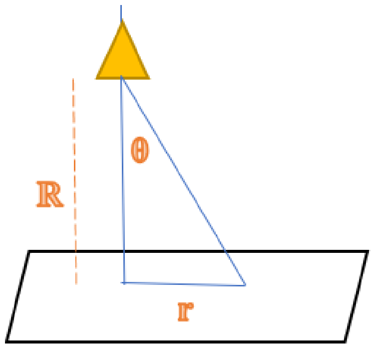

Figure 6. Angle relative to vertical

$$\tan \theta = \frac{r}{R}$$

Equation 10

4.2 Second step

This step determines the I (luminous flux intensity according to the direction of the point to the source). To do this, both the type of lamp and the type of lighting must be chosen. Once this data is available, the photometric curve or light distribution curve is consulted with the lighting manufacturer. Generally, this information can be consulted in any online catalogue of manufacturers of technical luminaires.

Type of lamp	Power	Light intensity	Graph identification
Incadescent lamp	100 W	130 cd	
Fluorescent lamp	40 W	200 cd	

Table 2. Lighting. Comparative table. Adapted from (Tables and Comparisons, s.f.)

A lighting containing a 100 W lamp is chosen, its luminous efficiency is 58 lm/W with a luminous intensity of 130 cd. A 40 W fluorescent bulb and a luminous intensity of 200 cd are also chosen; therefore, the two compact lamps that in total provide a luminous flux for the two bulbs.

$$F = 100\ \text{W x}\ \frac{58\ \text{lm}}{\text{W}} = 5800\ \text{lm}$$

Equation 11

$$F = 40\ W\ x\ \frac{58\ lm}{W} = 2320\ lm$$

Equation 12

The latter shows that the luminous flux is higher in the incandescent light. It should be noted that the luminous intensity is set by means of a standard unit, as mentioned in the luminous pattern produced by the platinum metal at 1 773 °C. Based on this data, it is verified that the manufacturers of electric bulbs indicate the luminous intensity in "cd". In the case of dispensing with this data, it is proceeded to check whether the manufacturer indicates the luminous flux in lumen "lm" and the solid angle has to be set in "sr" steroradian.

4.3 Third step

The point-by-point method measures an angle to the normal surface and calculates horizontal and vertical illumination with the following expressions:

$$Ex = \frac{I \cos^3 \emptyset}{R^2}\ [Lux]\ ; \qquad Ey = \frac{I \cos^2 \emptyset\ sen\ \emptyset}{R^2}\ [Lux]$$

Equation 13

But the resulting at point A point B is the result of the components $\vec{Ex}$ and $\vec{Ey}$ and it is obtained by applying the Pythagorean theorem:

$$E = \sqrt{Ex^2 + Ey^2}$$

Equation 14

4.4 Fourth step (results obtained)

The equations were applied prior to the experience of measuring the illuminance of an incandescent bulb and fluorescent bulb. The measurement of a 100-watt incandescent lamp is 130 cd and of the fluorescent 40 watts is 200 cd. The student states that in a classroom the ceiling is 3 m, his intention is to know the luminosity on a surface, therefore, the student sets the following measurement parameters at different separation angles from the normal line to the surface:

INCADESCENT LIGHT 130 cd

Θ (degrees)	Ex (Lux)	Ey (Lux)	E total (Lux)
0º	14.40	0	14.4
30º	9.38	5.41	10.82
45º	5.10	5.10	7.21
60º	1.80	3.12	3.60
75º	0.25	0.93	0.96
90º	0	0	0

FLUORESCENT LIGHT 200 cd

Θ (degress)	Ex (Lux)	Ey (Lux)	E total (Lux)

0º	22.22	0	22.22
30º	14.43	8.33	16.66
45º	7.85	7.85	
60º	2.77	4.81	5.55
75º	0.38	1.43	2.18
90º	0	0	0

Table 3. Data calculation

The "Isolux" diagram indicates the light incidence on a surface from the luminosity of the center towards the outside of the circle that illuminates the lamp:

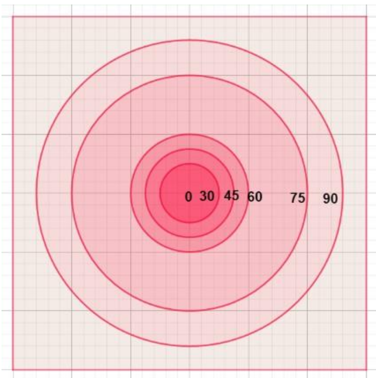

Figure 7. Isolux diagram of surface illumination

5. Conclusions

Applying the point-by-point method can be established the data that allows to assert that the maximum illumination (luminance) is obtained when a light source affects perpendicular to a surface; in the same way, when separated from the vertical it loses intensity. Luminous Flux is lower in the fluorescent bulb, while in the incandescent bulb is higher, unlike the luminance that is higher for the fluorescent bulb. This indicates that the luminous flux is inversely proportional to the comparative luminance of the two bulbs.

The fluorescent bulb produces more luminance at the points studied; therefore, it is much more efficient in addition to being much more cheap because of its low consumption of approximately 1/6 of the consumption in watts of the incandescent bulb. Calculations may vary by different factors, as there are places where the height of the room that was taken as a sample in certain parts is approximately 2.94 m and others of 2.98 m, but for calculation terms the measure indicated by the helpers established by Physics Center at Central University of Ecuador.

En el punto de ángulo 0° respecto a la vertical se produce la mayor iluminación horizontal de 14.4 Lux a 3 metros de altura, mientras que la bombilla fluorescente a la misma altura de tres metros y 0º presenta una **luminancia** de 22,22 Lux. Por lo que la eficiencia en luminancia en los dos casos estudiados en el laboratorio se debe colocar al menos 18 bombillas fluorescentes o 28 bombillas incandescentes.:

At the angle point 0° with respect to the vertical, the largest horizontal illumination of 14.4 Lux is produced at 3 meters high, while the fluorescent bulb at the same height of three meters and 0° has a luminance of 22.22 Lux. Therefore, the luminance efficiency in the two cases studied in the laboratory should be placed at least 18 fluorescent bulbs or 28 incandescent bulbs:

18 fluorescent bulbs x 22.22 Lux = 399.96 Lux.

28 incandescent bulbs x 14.44 Lux = 403.2 Lux

This demonstrates the greater efficiency of fluorescent bulbs, as they guarantee savings of electricity consumption, higher luminous intensity and the use of 10 bulbs less. In addition, the manufacturer guarantees longer number of duration, so it is highly recommended.

Fluorescent bulbs are white light or warm light, and the human eye is more sensitive to 555 nm of yellow light. This indicates that it is more advisable to use warm light bulbs, but it will depend on the person who performs the activities in that study area.

When applying the point-by-point method, it is concluded that its use is limited to knowing the illuminance at specific points based on previous studies performed in class and by experience in the handling of home bulbs. After being an active subject in experimentation and measurement, it acquires new information observing that a surface is made up of thousands of points so the responses are varied to different locations, even more if different types of bulbs are used. Significant learning in the study of light and enlightenment occurs when theory is closely linked to practice, obtaining new information and the ability to evoke knowledge and achieve successive feedback.

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