Program for Sustainable Designs of led lighting systems

Programa para Diseños Sustentable de sistemas de iluminación led

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Abstract

Computer Program made in MATLAB that allows sustainable designs of lighting systems with Led lamps for different user requirements. The program requires as data the dimensions, reflectance, cavities and the desired lighting level of the work area to be illuminated and the type of LED luminaire to be used. The calculations are carried out in a deterministic, precise and exact way, using the lumens method and the Official Mexican Standard for lighting designs. The program provides information such as the total number of luminaires to be used, the calculated lux level, the electrical power density, among others, as well as a graph that indicates an adequate design for the accommodation and distribution of the lamps in the work area to be illuminated. , complying with the Lighting Design Standards. The program correctly performs each of the calculations and at the end delivers the most suitable design for the accommodation of the lamps and their distances. Correct lighting means achieving an optimal balance between human needs, architectural considerations and energy efficiency.

Led lighting design, Computer program, Sustainability

Resumen

Programa Computacional realizado en MATLAB que permite diseños sustentables de sistemas de iluminación con lámparas Led para diferentes requerimientos de usuarios. El programa requiere como datos las dimensiones, reflectancias, cavidades y el nivel de iluminación deseado del área de trabajo a iluminar y el tipo de luminaria led a utilizar. Los cálculos se realizan de manera determinística, precisa y exacta, utilizando el método de los lúmenes y la Norma Oficial Mexicana para diseños de iluminación. El programa entrega información como el número total de luminarias a utilizar, el nivel de luxes calculado, la densidad de potencia eléctrica entre otras, así como un gráfico que indica un diseño adecuado para el acomodo y distribución de las lámparas del área de trabajo a iluminar, cumpliendo con las Normas de diseño de iluminación. El programa realiza de manera correcta cada uno de los cálculos y al final entrega el diseño más adecuado para el acomodo de las lámparas y sus distancias. Una correcta iluminación significa lograr un equilibrio óptimo entre las necesidades humanas, las consideraciones arquitectónicas y la eficiencia energética.

Diseño de iluminación Led, Programa computacional, Sustentabilidad

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Introduction

A computer programme with MATLAB that allows the sustainable design of lighting systems with LED lamps requires algorithms coded in the Live Script to perform the calculations and deliver as a result a precise, deterministic and accurate design in accordance with the lighting standards, method of lumens and user requirements.

The program is able to design various requirements of LED lighting systems with technical information and a graphical proposal of the distribution of LED luminaires respecting the requirements established in the Mexican lighting standards.

The lighting design is very important to maintain correct lighting in the area we wish to illuminate in order to avoid health risks and accidents,

Having a computer program will serve as a tool for engineers interested in making lighting design calculations with LED lamps in a sustainable, fast, precise and accurate way. This computer programme significantly reduces the time required to make the calculations to obtain a suitable design in accordance with standards.

The effects of good lighting are: a) it improves the mood and desirability of such spaces and can contribute greatly to a sense of well-being and improve the quality of life, b) it cares for visual health, c) it improves productivity and performance depends to a large extent on adequate lighting. d) Good lighting means achieving an optimal balance between human needs, architectural considerations and energy efficiency.

Poor lighting can cause eye fatigue, as eye muscles strain to focus and compensate for poor light.

Lighting design in most cases goes unnoticed and can have negative consequences.

Methodology

Phase 1.- General concepts that encompass an entire LED lighting design.

Nowadays, study, work, recreation centres and places where we live are environments in which people carry out their activities according to their needs and that a lighting designer must take into account. For example, in a lighting installation, the solutions taken are required to be part of a set that generates pleasant, ergonomically correct and energetically rational environments.

The main concepts to be taken into account when designing a lighting installation are the following:

- Required illuminance (lux).
- Uniformity of illuminance distribution.
- Limitation of glare.
- Limitation of luminance contrast.
- Effects of light colour.
- Consideration of natural light sources.
- Luminaire control and dimming system.
- Knowledge of lighting design standards such as the Mexican Official Standard NOM-025-STPS-2008.
- The activity to be developed.
- Types of LED luminaires on the market.
- The importance of the colour of the surroundings such as walls, floor, ceiling, etc.

Lumens. - are generated by the luminaires. A lumen (lm) is the unit of the International System of Measurement that measures the luminous flux emitted by a light emitting source.

Luminous flux. - It is a measure of the amount of light that comes out of a lamp. It gives us an idea of the amount of light emitted by a light source, e.g. a light bulb, in all directions in space. In contrast, if we think of a spotlight, it is easy to see that it only illuminates in one direction. See figure 1.

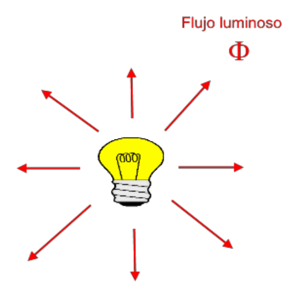

Figure 1 Representation of light sensation in different directions
Source: Compara LUX. Notes on lighting technology. Fundamental physical quantities

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Luminous flux is the power (W) emitted in the form of luminous radiation ϕ to which the human eye is sensitive. The ratio of watts to lumens is called the luminous equivalent of energy and is equivalent to:

1 watt-light at 555 nm = 683 lm.

Luminous intensity. - Luminous intensity is the luminous flux emitted per unit solid angle in a specific direction. Its symbol is I and its unit is the candela (cd). Knowing its value gives an idea of how light energy reaches each point in space.

$I=\phi/\Omega$
1 candela = 1 lumen / steradian
I = Luminous intensity (cd)
ϕ = Luminous flux in lumens (lm)
Ω = Solid angle differential element, in steradians (sr)

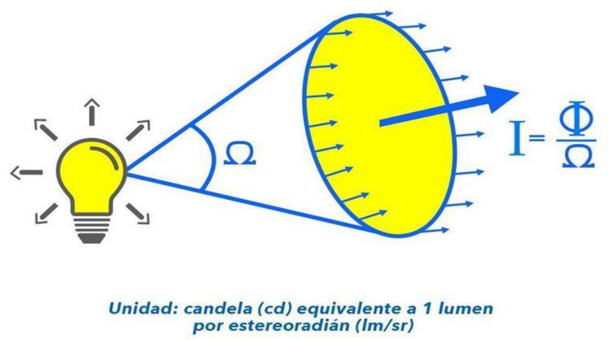

Figure 2 Representation of light sensation in one direction only
Source: Luminous intensity. Celasa

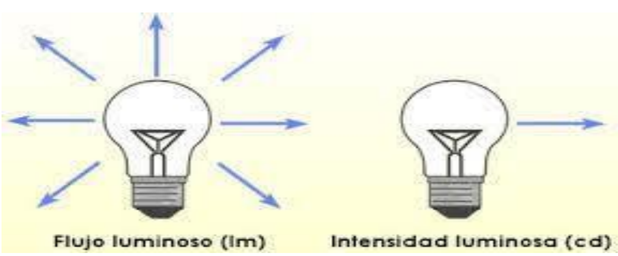

Figure 3 Comparison of luminous flux and luminous intensity
Source: Magnitudes and units of measurement. Celasa

Illuminance

If we shine a torch on objects at different distances. If we put our hand in front of the torch we can see that it is strongly illuminated by a small circle and if we illuminate a distant wall the circle is large and the light is weak. This simple experiment explains well the concept of illuminance.

Figure 4 Illuminance graphical description
Source: Magnitudes and units of measurement. Celasa

Illuminance is defined as the luminous flux received by a surface. Its symbol is E and its unit is lux (lx) which is one lm/m².

E = Illuminance (lx) = ϕ/S (surface)

The following table shows examples of different luminances.

Illuminance in lux (lux)	Type of lighting
5	Full moonlight
10	Small candle glow
60	Halogen beacon light
150	Commercial corridor light
500	Interior fluorescent light
1000	Sunset sun
2000	Sunrise sun
25000	Midday sun cloudy
50000 a 15000	Midday sun clear

Table 1 Different light sources
Source: Lighting systems. Miguel Ángel Asensio

Work area is the place in the workplace where a worker normally carries out his or her activities

Workplace is all places such as buildings, premises, facilities and areas, where production, marketing, transport and storage or service provision activities are carried out or where persons who are subject to an employment relationship work.

The lighting level is the amount of luminous flux per unit area measured on a work plane where activities are carried out, expressed in lux (SECRETARIA DEL TRABAJO Y PREVISION SOCIAL, 2008).

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Type of activity	Minimum required level in lux (lx)
Outdoor: distinguish traffic area, walking, surveillance, vehicle movement.	20
Indoors: distinguish transit area, walking, surveillance, vehicle movement.	50
Circulation areas and corridors; waiting rooms; rest rooms; store rooms; platforms; boiler rooms.	100
Simple visual requirement: visual inspection, parts counting, bench and machine work.	200
Reading rooms, kitchen, simple assembly, clerical works	300 a 500
Fine detail distinction: precision machining, assembly and inspection of delicate work, handling of precision instruments and equipment, handling of small parts	750
High degree of expertise in fine detail distinction	1000 a 2000
Operating rooms	5000 a 10000

Table 2 Examples of lighting levels
Source: NORMA Oficial Mexicana NOM-025-STPS-2008, Lighting conditions in workplaces

Luxmeter

It is a measuring instrument that allows a simple and quick measurement of the real and non-subjective luminance of an environment. The unit of measurement is lux (lx). It contains a photoelectric cell that captures the light and converts it into electrical impulses, which are interpreted and represented on a display or needle with the corresponding lux scale.

Figure 5 The luxmeter
Source: Creative Commons. Luxmeter

Lighting systems. - This is the set of luminaires in a work area or plane, distributed in such a way as to provide a specific level of lighting for the performance of activities.

Factors that influence correct lighting

Power of LED luminaires: They indicate the amount of electricity they need to operate in watts (w). The higher the light power, the higher the energy consumption.

Colour of the light: Depending on the temperature at which the bulb operates, it will emit light of a different colour, from warmer colours (2,000 - 3,000K), ideal for rest areas such as living rooms or bedrooms, and cooler colours (5,000 - 7,000K), more suitable for offices, kitchens and bathrooms. LEDs with intermediate values of white light can be found.

Luminous flux: This is the amount of light provided by the LED. It is expressed in lumens (lm) and the higher it is, the more light it provides. The most common is to indicate the luminous efficiency, that is to say, the lumens per unit of power: lm/W. To compare LEDs of different wattages, you only need to multiply the luminous efficiency of each LED by its wattage to find out which one provides the greatest luminous flux.

Useful life: This is the average duration of the LED in hours of operation.

Angle of aperture: Some bulbs, such as LEDs, give a focused light, with angles between 40º and 120º. The greater the angle, the lower the focus effect and the better the illumination of the room.

Importance of correct lighting

The positive effects of the right lighting on quality of life are vital: visual health, comfort, productivity and performance depend to a large extent on the right lighting.

Correct lighting means achieving an optimal balance between human needs, architectural considerations and energy efficiency.

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LED stands for LIGHT EMISSING DIODE and is an electronic device that emits light. It is an electronic device that emits light. The LED has a simple and solid structure, consisting of a small microchip embedded in a simple electrical circuit. It does not have a filament that produces heat unlike incandescent bulbs. It is ignited by electron movements in a semiconductor material.

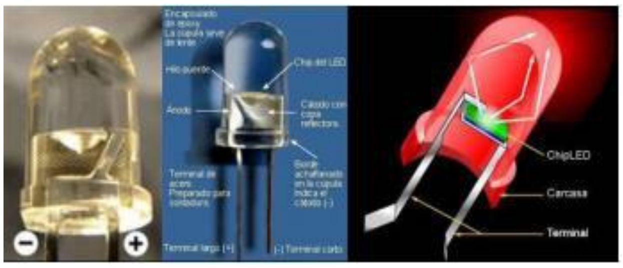

Figure 6 Basic elements of LEDs
Source: Ing. Jorge A. Caminos. Lighting and colour design criteria

Features and benefits of LEDs

The inherent features of LEDs define it to be the best alternative to conventional light sources and provide a wide range of use. Small size. The LED can be extremely small and provide a beam of light of high luminous performance.

Low power consumption

Generally designed to operate with low current and voltage consumption, this means that a basic LED needs no more than 0.1 W to operate.

Long life

Life of approximately 100,000 hours with operation at normal voltage, current and suitable environment.

High luminous efficacy and low heat emission They can convert almost all the energy used into light, so their performance translates into high luminous efficacy and low heat emission. Favouring sustainable lighting systems

Environmental protection

They are made of non-toxic materials unlike fluorescent lamps with the mercury they contain and the pollution hazard they pose. In addition, they can be recycled.

Unbreakable

The electroluminescent device is completely encased in an epoxy resin enclosure, this makes it more robust than the conventional filament lamp and fluorescent tube, inside the solid epoxy enclosure there are no moving parts, it is resistant to impact and vibration. All this makes them robust.

Reduced maintenance for cost savings

There is no need to replace the LED lamp frequently, thus reducing or eliminating costs. Many of the critical lighting applications such as emergency exits and security lighting require periodic maintenance to check for correct operation or replacement and LEDs save on this maintenance. For example in applications where replacement makes the job difficult. Radio antennas, ship lights, aircraft lights, bridges and tunnels where expensive lighting and maintenance is required due to their location. With LEDs, the frequency of maintenance can be reduced or even eliminated, thus saving money.

Greater energy savings due to their efficient use

White lamps deliver more than 20 lumens per fixture per watt, and can reach more than 50 lumens per watt. Faster payback on your investment due to energy savings. Other benefits include vivid colours and elimination of filters.

Design flexibility

They are small and because of this allow for different and varied lamp designs. Lighting can be distributed at many points over the surface to be illuminated instead of mounting a high-power lamp (optical reflector).

More vivid colours without the use of filters. - Multiple colours can be created without the use of filters, reds, greens, blues, etc. Usually in incandescent lamps, when a specific colour is desired, this filter is added to the white light of the lamp, allowing the desired colour to pass through. These filters block a considerable part of the unwanted light allowing only the desired wavelength to pass through.

Due to their high efficiency, luminosity and useful life, LED luminaires have advanced at an incredible speed in recent years and are used in practically all sectors such as hotels, restaurants, clubs, discotheques, wedding halls, architectural lighting, town halls, buildings, stadiums, airports, schools, hospitals, churches, bridges, cars, advertisements, televisions, etc.

Phase 2.- Methodology for the calculation of the lighting system design.

Calculation by the method of lumens

This method is used only for the calculation of indoor lighting and is based on the definition of lux, which is equal to one lumen per square metre. A correct lighting design through a design methodology is necessary. If it is desired to obtain the average value of the overall lighting in a room, the lumen method is recommended.

This method assumes that each room consists of three different zones or cavities. Each of these will be treated as a whole, as they have an effect on each of the other cavities to produce uniform illumination. This method calculates horizontal average illuminance levels across a space.

This system divides the room into three separate cavities, these are: 1. This is the area measured from the plane of the luminaire to the ceiling. For pendant luminaires there will be a ceiling cavity; for luminaires placed directly on the ceiling or recessed in the ceiling there will be no ceiling cavity. 2.- Room cavity. This is the space between the working plane where the task is to be performed and the bottom of the luminaire; the working plane is normally located above floor level. In some cases where the working plane is considered to be at floor level, the space from the luminaire to the floor is considered to be the room cavity. In lighting language the distance from the working plane to the bottom of the luminaire is called "luminaire mounting height". 3.- Floor cavity. It is considered from the floor to the top of the working plane, or the level where the specific task is performed. For office areas this distance is For workbenches in industry this distance is approximately 0.76 mt. For workbenches in industry this distance is approximately 0.92 mt. If the work or task is performed on the floor, there is no floor cavity.

Determine the characteristics of the problem

Basic theory considers in this method of lighting calculation that the light produced by a lamp or luminaire is reflected by all surfaces in the area. The multiple reflections of light from the luminaire and from the room surfaces act to produce the light in the working plane. Because of this it is very important to determine

Room length
Room width
Room height
Ceiling reflectance: 90% very bright, 80% bright and 70% medium-dark.
Wall reflectance: 70% very light, 50% light and 30% medium/dark.
Floor reflectance: 20% is a normal value that is always used.
The height of the ceiling cavity
The height of the working area from the floor

Determination of the required illumination level

It is important to consult the Mexican Official Standard NOM-025-STPS-2008, to determine the lux required according to the Lighting conditions in workplaces. These tables offer recommended values for the different work areas to be illuminated where visual tasks are to be carried out, which will allow for visual comfort. It is important to note that there are publications that recommend values different from those proposed by the Mexican Official Standard NOM-025-STPS-2008, Lighting conditions in workplaces, such as the standards of other countries.

Determining the type of lamp and its data

By means of catalogues, we must choose which of the lamps on the market meet our needs. Some of the factors that help to determine the luminaire to be used are:

Brand
Type of lamp
Number of lamps in each luminaire
The lumens emitted by each lamp
Consumption
Cost
Size
Weight
Aesthetic appearance

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Calculate room cavity ratios, ceiling and floor cavity ratios and effective ceiling reflectance
Room cavity ratio (RCL) in metres

RCL= 5-HL-(L+A)/(L-A) (1)

Where
RCL is the room cavity ratio
HS is the floor cavity
L is the length
A is the width

Ceiling Cavity Ratio (RCT) in metres

RCT= 5-HT-(L+A)/(L-A) (2)

Where
CPR is the roof cavity ratio
HS is the floor cavity
L is the length
A is the width

Floor cavity ratio (FCR) in metres
RCP= 5-HS-(L+A)/(L-A) (3)

Where
FCR is the floor cavity ratio
HS is the floor cavity
L is the length
A is the width

Room cavity (HL). It is the space between the working plane where the task will be performed and the bottom of the luminaire In lighting language the distance from the working plane to the bottom of the luminaire Floor cavity (HS). From the floor to the top of the working plane, or the level where the specific task is performed. For office areas this distance is approximately 0.76 mt. For industrial workbenches this distance should be considered to be approximately 0.92 mt. If the work or task is carried out on the floor, the following figure shows the cavities mentioned above.

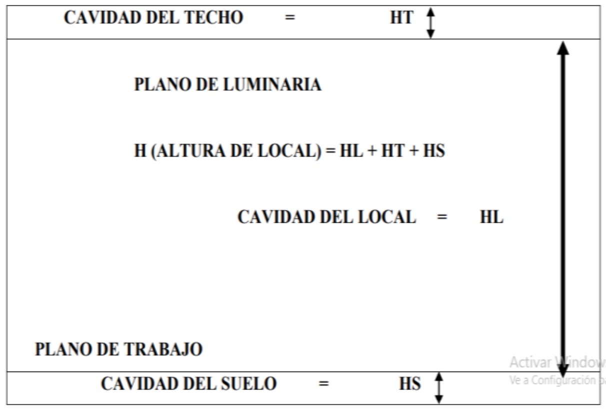

Figure 7 Cavity dimensions of a room
Source: Own Elaboration

To obtain the values of 80% or 90% Base Reflectance of floor, ceiling or wall, tables from lighting manuals such as the Westinghouse manual can be consulted (see figure below).

REF	RELACION DE CAVIDAD														
PARED	0.2	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	8.0	10.0
90	89	88	87	87	86	85	83	82	80	79	77	75	73	68	65
80	88	87	86	85	83	80	77	75	72	70	69	59	61	55	51
70	88	86	84	82	80	76	72	68	64	61	58	53	49	42	36
50	86	84	80	77	75	68	62	57	52	48	44	38	34	27	22
30	85	81	77	73	69	61	53	47	42	37	33	28	24	18	15
10	84	79	74	69	64	55	47	40	34	31	25	20	16	12	09
0	82	76	73	67	62	51	43	36	30	26	22	16	11	06	04

Figure 8 Wall cavity ratio data at 90%.
Source: Westinghouse Lighting Manual 1985

Determination of the coefficient of utilisation (CU)

The coefficient of utilisation is the factor of the lumens reaching the working plane and the total lumens generated by the luminaire. This factor takes into account the efficacy and distribution of the luminaire, its mounting height, the dimensions of the room and the reflectances of the walls, ceiling and floor.

Because of the multiple reflections that occur within a room, some of the light passes downwards through the imaginary working plane more than once, so that in some circumstances the utilisation factor may exceed unity.

The desired utilisation coefficient can then be determined for the room cavity ratio itself and the appropriate wall and ceiling cavity reflectances.

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For ceiling-mounted or recessed luminaires, the reflectance of the ceiling cavity is the same as that of the actual ceiling. For suspended luminaires, however, it is necessary to obtain the effective reflectance of the ceiling cavity.

In general, the higher and narrower the room, the higher the proportion of light absorbed by the walls and the lower the utilisation coefficient. This effect is accounted for by the room cavity ratio (RCL).

Consult the tables for calculation according to the type of luminaire being used.

Determination of the maintenance factor

From the first day the lighting is put into operation the illumination changes as the lamps age. In addition, accumulated dirt also affects the factors contributing to light loss. The net effect is almost always a decrease in the level of illumination. Two values of the maintenance factor are used: 0.8 if it is a clean place where the design will be made, 0.6 if it is a dirty place.

Calculation of the number of luminaires

The number of luminaires (lighting units) can be calculated as follows:

$$N = (E\text{-}Ar) / (\phi\text{-} I\text{-}CU\text{-} FM) \quad (4)$$

Where:

N = Number of luminaires or lighting units.
E = Required lighting level
Ar = Area
ϕ = Luminous flux
I = Number of lamps per luminaire
CU = Coefficient of Utilisation
FM = Total Loss Factor

Note: If the result exceeds the whole number, it is approximated to the next higher value to obtain the total number of luminaires to be installed.

Determination of luminaire placement

The placement of luminaires depends on the overall architecture, the dimensions of the building, the type of luminaire and the location of existing power sockets.

In order to achieve a uniform distribution of lighting over an area, it is recommended to respect the spacing no greater than the height of the working plane shown in figure 7 and which is a function of the mounting height (to the working plane), in most cases, it is necessary to place them closer together in order to obtain the required lighting levels,

The distance between luminaires must be calculated:

$$S=\sqrt{(Ar/N)} \quad (5)$$

Where:

S = Distance between luminaires depending on the room.
Ar = Area
N = Number of luminaires

Once the number of luminaires has been determined according to the actual plan, the light level is recalculated in the following ratio:

$$Ee = N\text{-}\phi\text{-} I\text{-}CU\text{-} FM/Ar \quad (6)$$

Where:

Ee = Resulting illuminance according to new specification.
N = Number of luminaires
ϕ = Luminous flux
I = Number of lamps per luminaire
CU = Coefficient of Utilisation
FM = Total Loss Factor
AR = Area

If we do not obtain the required lighting level and uniform distribution when calculating, we must further increase the number of luminaires.

The electrical power density of lighting should also be calculated, the (DPEA) should be consulted in accordance with the Mexican Official Standard NOM-007-ENER-2014 to verify compliance with this Standard. Energy efficiency for lighting systems in non-residential buildings The purpose of this Standard is to set the amount of power required to obtain the optimum lighting level.

The determination of the EPED of the lighting system of a new non-residential building, extension or modification of an existing one, of the types covered by this Mexican Official Standard, shall be calculated from the total connected lighting load and the total area to be illuminated according to the methodology indicated below.

The generic expression for the calculation of the Electrical Power Density for Lighting (EPDL) is

(DPEA) is:
DPEA=CTC/ATI (7)
Where
CTC = Total Connected Load for Lighting
ATI = Total Illuminated Area

Where the Density of Electrical Power for Lighting (DPEA) is expressed in W/m^2, the total connected load for lighting, which includes the total power of the lighting system, is expressed in watts and the total illuminated area is expressed in square metres.

Phase 3- Algorithms coded in Matlab Script for the calculation of lighting designs.

This program uses the calculation methodology of Phase 2 and obtains the values of all required tables through interpolation algorithms and intermediate value theorems using decision structures, repetition structures and graph functions.

This program then becomes a useful tool, because the user only enters minimum values for the lighting design and does not require any values that require the use of tables, because the designed algorithms execute the numerical method that provides the information required by the lumen method precisely and accurately. In addition, the program offers a menu of LED lamps that could be used by the user when designing the lighting system. This is really an advantage because sometimes looking up values in the table becomes a time-consuming and cumbersome job, e.g. interpolating intermediate values that the table does not take into account.

Below, lines of code from the script file are shown, as an example of how the program code was created. If you are interested in obtaining all the code, please contact the author of this article.

The following are sections of the code for the Lighting Design program

```
% Autor Ing. Jesús Fausto Cordova Manzo
clear all close all clc
disp ('CALCULO DE DISEÑO DE ILUMINACION');
disp ('INICIA CALCULO POR EL METODO DE LOS LUMENES');
lux = input('Ingrese el nivel de iluminación requerido en luxes: ');
HT = input('Digite la cavidad del techo en metros: ');
HS = input('Digite la cavidad del piso en metros: ');
H = input('Digite la altura del local en metros: ');
HL = H - (HT + HS);
fprintf ('%s%.2f\n' , 'La cavidad del local en metros es =    ',HL);
L = input('Digite el largo del área a iluminar en metros: ');
A = input('Digite el ancho del área a iluminar en metros: ');
AR = L*A;
fprintf ('%s%.2f\n' , 'La superficie a iluminar en metros cuadrados es = ',AR);
RTE = input ('Digite la reflectancia del techo: ');
RPA = input ('Digite la reflectancia de la pared: ');
RPI = input('Digite le reflectancia del piso: ');
RCL = (5*HL*(L+A))/(AR);
fprintf ('%s%.2f\n' , 'La relación de cavidad del local RCL =  ',RCL);
RCT = (5*HT*(L+A)/AR);
fprintf ('%s%.2f\n' , 'La relación de cavidad del techo RCT =  ',RCT);
 RCS = (5*HS*(L+A)/AR);
fprintf ('%s%.2f\n' , 'La relación de cavidad del suelo RCS = ',RCS);
if RCT < 0.2
disp ('No es necesario realizar el cálculo de la reflectancia efectiva del techo');
else if RCT >= 0.2
if RTE == 90
if RCT >= 0.2 & RCT <= 0.4 & RPA == 90
y0 = 89;
y1 = 88;
x0 = 0.2;
x1 = 0.4;
elseif (RCT > 0.4 & RCT <= 0.6 & RPA == 90)
y0 = 88;
y1 = 87;
x0 = 0.4;
x1 = 0.6;
```

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```
elseif (RCT > 0.6 & RCT <= 0.8 & RPA
== 90)
y0 = 87;
y1 = 87;
x0 = 0.6;
x1 = 0.8;
elseif (RCT > 0.8 & RCT <= 1.0 & RPA
== 90)
y0 = 87;
y1 = 86;
x0 = 0.8;
x1 = 1.0;

% Salto 1 de sección del Código
if RCT >= 0.2 & RCT <= 0.4 & RPA == 80
y0 = 88;
y1 = 87; x0 = 0.2; x1 = 0.4;
elseif (RCT > 0.4 & RCT <= 0.6 & RPA
== 80)
y0 = 87; y1 = 86; x0 = 0.4; x1 = 0.6;
elseif (RCT > 0.6 & RCT <= 0.8 & RPA
== 80)
y0 = 86;
y1 = 85;
x0 = 0.6;
x1 = 0.8;
elseif (RCT > 0.8 & RCT <= 1.0 & RPA
== 80)
y0 = 85;
y1 = 83;
x0 = 0.8;
x1 = 1.0;
elseif (RCT > 1.0 & RCT <= 1.5 & RPA
== 80)
y0 = 83;
y1 = 80;
x0 = 1.0;
x1 = 1.5;
elseif (RCT > 1.5 & RCT <= 2.0 & RPA
== 80)
y0 = 80;
y1 = 77;
x0 = 1.5;
x1 = 2.0;
% Salto 2 de sección del Código
y0 = 77;
y1 = 75;
x0 = 2.0;
x1 = 2.5;
elseif (RCT > 8.0 & RCT <= 10.0 & RPA
== 90)
elseif (RCT > 3.0 & RCT <= 3.5 & RPA
== 70)
y0 = 64;
y1 = 61;
x0 = 3.0;
x1 = 3.5;
elseif (RCT > 3.5 & RCT <= 4.0 & RPA
      == 70)
y0 = 61;
y1 = 58;
x0 = 3.5;
x1 = 4.0;
elseif (RCT > 4.0 & RCT <= 5.0 & RPA
== 70)
% Salto 3 de sección del Código se
muestran la parte
end
end
end
% Inicia Código de parte intermedia
del programa
CURCT = y0+(y1-y0)*((RCT-x0)/(x1-x0));
fprintf ('%s%.2f\n' , 'La reflectancia
efectiva del techo es = ',CURCT);
disp ('Para calcular el coeficiente de
utilización hay que buscar en la tabla
que proporciona el fabricante');
disp ('¿El valor de RCL es un valor
entero o hay que interpolar?');
CALCU = input ('Digite 1 si es un
valor entero o 2 si hay que
interpolar: ');
if CALCU == 1
 disp('Digitara este valor más
adelante');
elseif CALCU == 2
v1 = input('Digite el primer valor:
');
v2 = input('Digite el segundo valor:
');
v3 = input('Digite el tercer valor:
');
v4 = input('Digite el cuarto valor:
');
end
Cu = (v1+v2+v3+v4)/4;
CU2 = fprintf ('%s%.2f\n' , 'El
coeficiente de utilización es = ',Cu);
disp ('Para determinar el factor de
mantenimiento dependerá si el lugar es
limpio o sucio');
disp('0.8 si es un lugar limpio o 0.6
si es un lugar sucio'); FM =
input('Digite el factor de
mantenimiento: ');
phi = input('Digite el flujo luminoso:
');
I = input('Digite el número de
lámparas por luminaria: ');
CU = input('Digite el coeficiente de
utilización: ');
NNN = (lux*AR)/(I*phi*CU*FM);
fprintf ('%s%.2f\n' , 'El número de
luminarias es =  ',NNN);
NN = fix (NNN);
N = NN + 1;
fprintf ('%s%.2f\n' , 'El número de
luminarias redondeando es =  ',N)
S = sqrt(AR/N);
fprintf ('%s%.2f\n' , 'La distancia
entre luminarias en metros es = ',S);
Ee = (N*phi*I*CU*FM)/AR;
fprintf ('%s%.2f\n' , 'El nivel de
iluminación en luxes es = ',Ee);
NNLL = L/S;
NNLA = A/S;
fprintf ('%s%.2f\n' , 'El número de
luminarias a lo largo es = ',NNLL);
fprintf ('%s%.2f\n' , 'El número de
luminarias a lo ancho es = ',NNLA);
disp('El sistema se distribuye por
columnas y filas');
disp('incrementa la columna al
inmediato superior y la fila baja a su
inmediato inferior');
NLL = fix (NNLL);
NLA = fix (NNLA);
```

```
NLL1 = NLL + 1;
fprintf ('%s%.2f\n' , 'El número de columnas es = ',NLL1);
fprintf ('%s%.2f\n' , 'El número de filas es = ',NLA); TL = NLL1*NLA;
fprintf ('%s%.2f\n' , 'El número total de luminarias es = ',TL); NL = TL;
NEe = (NL*phi*I*CU*FM)/AR;
fprintf ('%s%.2f\n' , 'El nuevo nivel de luxes es = ',NEe);
if NEe >= lux
disp('Optimo');
elseif NEe < lux
disp('No optimo, aumente la fila en uno a su inmediato superior y disminuya la columna a su inmediato inferior');
col = input('Columna: ');
fil = input('Fila: ');
nl = col*fil;
NEe = (nl*phi*I*CU*FM)/AR;
fprintf ('%s%.2f\n' , 'El nuevo nivel de luxes es = ',NEe);
end
CTC = input('Digite la carga total conectada para el alumbrado en watts: ');
DPEA = (CTC*NL)/AR;
fprintf ('%s%.2f\n' , 'La densidad de potencia eléctrica en watts-metro cuadrado es = ',DPEA);
PaLaFi = A/NLA;
fprintf('%s%.2f\n' , 'La distancia en metros lampara-lampara a lo ancho es = ',PaLaFi);
PALAFI = PaLaFi*(NLA-1);
pAlAfI = ((A-PALAFI)/2);
fprintf('%s%.2f\n' , 'La distancia en metros pared-lampara a lo ancho es = ',pAlAfI);
PaLaCo = L/NLL1;
fprintf('%s%.2f\n' , 'La distancia en metros lampara-lampara a lo largo es = ',PaLaCo);
PALACO = PaLaCo*(NLL1-1);
pAlAcO = ((L-PALACO)/2);
fprintf('%s%.2f\n' , 'La distancia en metros pared-lampara a lo largo es = ',pAlAcO);
C = input('Numero de columnas: ');
F = input('Numero de filas: ');
if F == 1
% Diseño del grafico de distribución de las luminarias
x = linspace(0,C+2,C+2);
y= (0);
y1= (1);
y2= (2);
plot(x,y,'',x,y1,'*',x,y2,'');
% salto hasta líneas finales del programa
if F == 14
x = linspace (0,C+2,C+2);
y = (0); y1 = (1); y2= (2); y3 = (3);
y4 = (4); y5 = (5); y6 = (6); y7 = (7); y8 = (8); y9 = (9);
y10 = (10); y11 = (11); y12 = (12);
y13 = (13); y14 = (14); y15 = (15);
plot(x,y,'',x,y1,'*',x,y2,'*',x,y3,'*',x,y4,'*',x,y5,'*',x,y6,'*',x,y7,'*',x,y
8,'*',x,y9,'*',x,y10,'*',x,y11,'*',x,y
12,'*',x,y13,'*',x,y14,'*',x,y15,'');
title (' DISTRIBUCION DE LAS LUMINARIAS ','color','b');
xlabel (' C O L U M N A S ','color','b');
ylabel (' F I L A S ','color','b');
%grid on
end
```

Results

Evaluation of the programme

The programme is evaluated with the design of the lighting system for the multi-purpose classroom of the Engineering Faculty of the Universidad Veracruzana Coatzacoalcos. It is required to determine the lighting design and the number of luminaires needed for the multi-purpose room and to comply with the minimum lighting level required, using LED lamps, with the following dimensions: Length: 18 metres Width: 9 metres Height: 4 metres

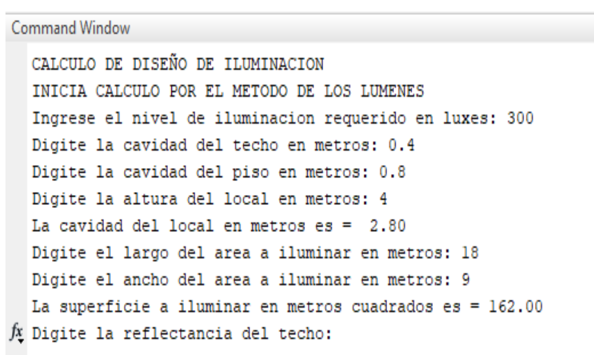
Ceiling Reflectance: 80% Wall Reflectance: 50% Floor Reflectance: 20% Ceiling Cavity: 0.4 metres Floor Cavity: 0.8 metres

1°. Determine the lighting level for the multi-purpose room. According to the standard the required illumination level is 300 lux. The execution of the programme is shown below

2°. Determine the luminaire to be used.

Slim T8/T12 tubular LED luminaire
2 lamps per luminaire
7200 lumens per luminaire
72w

3°. Calculation of cavity ratios and effective reflectances.


```
Command Window
CALCULO DE DISEÑO DE ILUMINACION
INICIA CALCULO POR EL METODO DE LOS LUMENES
Ingrese el nivel de iluminacion requerido en luxes: 300
Digite la cavidad del techo en metros: 0.4
Digite la cavidad del piso en metros: 0.8
Digite la altura del local en metros: 4
La cavidad del local en metros es = 2.80
Digite el largo del area a iluminar en metros: 18
Digite el ancho del area a iluminar en metros: 9
La superficie a iluminar en metros cuadrados es = 162.00
fx Digite la reflectancia del techo:
```

```
Command Window
Digite el ancho del area a iluminar en metros: 9
La superficie a iluminar en metros cuadrados es = 162.00
Digite la reflectancia del techo: 80
Digite la reflectancia de la pared: 50
Digite le reflectancia del piso: 20
La relacion de cavidad del local RCL =  2.33
La relacion de cavidad del techo RCT =  0.33
La relacion de cavidad del suelo RCS =  0.67
La reflectancia efectiva del techo es =  75.00
```

4°. Utilisation rate

```
Command Window
La reflectancia efectiva del techo es =  75.00
Para calcular el coeficiente de utilizacion hay que buscar e
¿El valor de RCL es un valor entero o hay que interpolar?
Digite 1 si es un valor entero o 2 si hay que interpolar: 2
Digite el primer valor: 0.57
Digite el segundo valor: 0.51
Digite el tercer valor: 0.54
Digite el cuarto valor: 0.48
El coeficiente de utilizacion es = 0.53
```

5° Maintenance Factor

```
¿El valor de RCL es un valor entero o hay que interpolar?
Digite 1 si es un valor entero o 2 si hay que interpolar: 2
Digite el primer valor: 0.57
Digite el segundo valor: 0.51
Digite el tercer valor: 0.54
Digite el cuarto valor: 0.48
El coeficiente de utilizacion es = 0.53
Para determinar el factor de mantenimiento dependera si el
0.8 si es un lugar limpio o 0.6 si es un lugar sucio
Digite el factor de mantenimiento: 0.8
```

6°. Calculation of the number of luminaires

```
Command Window
Digite el flujo luminoso: 7200
Digite el numero de lamparas por luminaria: 2
Digite el coeficiente de utlizacion: 0.53
El numero de luminarias es =  7.96
El numero de luminarias redondeando es =  8.00
La distancia entre luminarias en metros es = 4.50
El nivel de iluminacion en luxes es = 301.51
El numero de luminarias a lo largo es = 4.00
El numero de luminarias a lo ancho es = 2.00
El sistema se distribuye por columnas y filas
incrementa la columna al inmediato superior y la fila
```

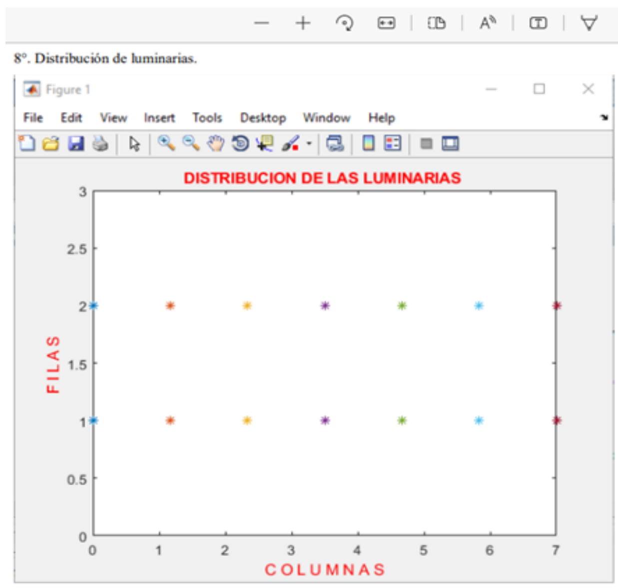
```
Command Window
La distancia entre luminarias en metros es = 4.50
El nivel de iluminacion en luxes es = 301.51
El numero de luminarias a lo largo es = 4.00
El numero de luminarias a lo ancho es = 2.00
El sistema se distribuye por columnas y filas
incrementa la columna al inmediato superior y la fila
El numero de columnas es = 5.00
El numero de filas es = 2.00
El numero total de luminarias es = 10.00
El nuevo nivel de luxes es = 376.89
Optimo
```

7°. Electrical Power Density.

```
Command Window
El numero de columnas es = 5.00
El numero de filas es = 2.00
El numero total de luminarias es = 10.00
El nuevo nivel de luxes es = 376.89
Optimo
Digite la carga total conectada para el alumbrado en watts: 76
La densidad de potencia electrica en watts-metro cuadrado es = 4.69
```

8°. Distribution of luminaires

The programme generates the following graph



Results displayed in Matlab Command Windows>>

```
>>
El número total de luminarias es = 10.00
El nuevo nivel de luxes es = 376.89
Optimo
La carga total conectada para el alumbrado en watts: 76
La densidad de potencia eléctrica en watts-metro cuadrado es =0.69
La distancia en metros lampara-lampara a lo ancho es =0.50
La distancia en metros pared-lampara a lo ancho es= 2.25
La distancia en metros lampara-lampara a lo largo es = 3.60
La distancia en metros pared-lampara a lo largo es = 1.80
Numero de columnas: 5
Numero de filas: 2
>>
```

Conclusions

The MATLAB computer program allows sustainable designs of lighting systems with LED lamps for different user requirements. The calculations are carried out in a deterministic, precise and exact way, using the method of lumens and respecting the Mexican Official Norm for lighting designs. The programme provides information such as the total number of luminaires to be used, the calculated lux level, the electrical power density, among others, as well as a graphic that indicates a suitable design for the arrangement and distribution of the lamps in the work area to be illuminated.

The programme achieves in a sustainable way a correct lighting that is reflected in an optimal balance between visual health, comfort and energy efficiency.

The programme works correctly and eliminates the use of tables for effective ceiling reflectance, and also eliminates the time consuming manual calculations. A numerical method was designed that calculates the values of the tables in the program and delivers the result quickly.

Finally, the program correctly performs each of the calculations and at the end delivers the most suitable design for the arrangement of the lamps and their distances. The program is linear and can be visually improved with the GUIs.

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