Design and Development of task light simulator for Quality Lighting Factor and Simulation of LED tube-based Illumination system for Laboratory

P. R. Yawale[1*], P.S. Varade[2], V.G. Wagh[3], A.D. Shaligram[4]

[1]* Dept. of Electronic Science, B.G.College Sangvi, Pune -27, India,

[2]Dept. of Electronic Science, Modern College Shivajinagar Pune, 05, India

[3] V. N. Naik College, Nasik-05, India,

[4] Dept Pune University, Pune, 07 I. of Electronic Science Savitribai Phule India.

Email [1]yawalepravin@yahoo.co.in

Email [2] psvarade1@gmail.com

Email [3] vgwaghele@gmail.com

Email [4]adshaligram@gmail.com

Abstract

Daylight is only the natural light available surrounding us which is mostly useful in outdoor use. Artificial lighting is used to a greater extent in the world for a variety of indoor as well as outdoor applications. The fundamental requirement of light is to see the objects in a dark time. Nowadays powerful light sources are developed to fulfill the fundamental requirement and the quality illumination. Quality lighting provides uniform distribution in space, good color rendering, and adequate light. The requirement of every task is different and the quality of lighting depends on a number of factors, so there must be a database available that will provide recommended values for a given task. Though there are several simulation software available for analysis of illumination, they are able to provide only information of illumination pattern based on user inputs. There is a need fora user-friendly GUI (Graphical User Interface) which provides necessary parameter values for good lighting design and spectral power distribution of different LED (Light Emitting Diode) sources. The main aim of this work is to model and simulation of spectral characteristics of monochromatic and white LED. Develop a MATLAB-based GUI to select recommended values for different tasks according to Illuminating Engineering Society (IES) standards which helps lighting designers for selection of proper light sources. Uniform illumination is obtained and energy is saved by the integration of daylight with artificial light. A case study of LED tube-based glare-free illumination for the laboratory is also reported.

Keywords: *Visual comfort, discomfort glare, task lighting, LED, TLSIM, daylight.*

1. Introduction

Daylight is only the natural light available surrounding us which is mostly useful in outdoor use and its advantages of natural light are quietness, softness, calmness, and comfort. However, due to the availability of daylight for a limited time and at times limited luminance levels to perform a certain task, makes use of artificial lighting necessary. The use of electrical lighting is quite recent; it is widely spared after the development and use of

incandescent bulbs. Powerful light sources such as fluorescent tubes, high-intensity discharge lamps, CFL, and LED lamps were developed in recent years which lead to quality lighting. Lighting quality is more important than the appropriate quantity of light. Different parameters decide the quality of lighting, these include visual comfort, uniformity, glare, color rendering index, correlated color temperature, etc.[1] There are physical as well physiological parameters that may influence the quality of lighting. Lighting quality cannot be decided only on photometric measurement but also on physical, physiological, and health aspects. Parameters of different aspects are listed in the table1. For different task lighting, the recommendation gives a range of illuminance values. In addition to this, it is the important color of the light source which is described by color rendering index (CRI) and correlated color temperature (CCT). The Colour characteristics of light can be determined by spectral power distribution (SPD). Different spectral distribution of light hasa different effect on the human body, most electrical light sources are unable to produce spectral distribution to perform complete biological functions. [2]
Nonuniform illumination causes discomfort, complete uniform illuminance in space is undesirable. Uniformity is the ratio of the minimum illumination level to the average illumination level in space. As compare to conventional light sources, CFL and LED sources light can more concentrated on task area so that the uniformity in task plane is more and energy efficient lighting is possible. These are visual and photometric aspects reported. [3,4]

Table 1. Lighting Parameters

Aspect	**Lighting parameter**
Visual	Visual comfort, work performance, flicker, and visual acuity
Photometric	Illuminance level, efficacy, uniformity, color rendering index, horizontal illuminance, vertical illuminance, apex angle, luminance intensity, and correlated color temperature.
Physiological	Arousal, pleasantness, Aesthetic Judgment, acceptability and satisfaction, and mood effect.
Physical and health	The strain on eye, glare (Discomfort glare and disability glare) threshold increment, Circadian Rhythm.

Lighting can be designed for more acceptable, attractive, and appropriate functions. An unacceptable lighting environment affects the task performance hence productivity. The variation in luminance and color of light strengthens the attractiveness, emotions, and mood of the person in the task area. This will increase task performance and thus productivity. This is a physiological aspect. [5]

Most of the researchers now concentrated on the biological effects of light on humans. The biological effect is also called the non-visual effect of light i.e. physical and health aspects.

The health aspect is related to circadian rhythm, eye strain. Health effects due to lighting are not yet well known and research is needed to explore this aspect.[6]

i) The retailer does not care about the lighting quality, as it more emphasis on increasing business. There are different approaches to define the quality of lighting some of them are, Based on photometric indices calibrated to the subjective response.
ii) Effect of lighting conditions on task performance, health, and behavior.
iii) Ability to discriminate color, texture surface finishing without discomfort.
iv) On the basis of holistic design process depends on the designing pattern.
v) Lighting design that meets objectives and constraints set by the client. General objectives are uniform illumination, enhancement in task performance, good visual comfort, low energy consumption, and low operating cost. Common constraints are budget and time frame for design and installation.

Universally good quality lighting is based on photometric quantities. On basis of quality, lighting can be classified as bad quality lighting, indifferent quality lighting, and good quality lighting.[7] Discomfort lighting which does not allow us to see what we need to see easily is called bad quality lighting. Indifferent quality lighting does not create visual discomfort but it does not allow seeing what we want to see easily and quickly. Good quality lighting is the lighting that allows us to see quickly and easily without discomfort and enhances human performance. To eliminate bad quality lighting and bridge the gap between indifferent quality lighting and quality lighting development of lighting criteria is necessary. The Illuminating Engineering Society (IES) published the first code for lighting quality. Recommendations for the quality of lighting are updated with source technologies. Indoor lighting can be enhanced using the proper use of available daylight, the use of natural resources of light will saves electric energy.[8]

2. *DIALux*

There areseveral simulation software available and each software is specialized in different aspects of lighting quality. Tools prefer by designers are DIALux, Radiance, DAYSIM, Velux, 3DsMax,and AGi32.These tools simulate the selected luminary arrangement and give illumination results but to get the required illumination pattern number of simulation iterations required for different luminary arrangementswhich aretime-consuming process.These toolscan simulate daylight, reflectionsfrom surfaces, diffuse light, and so on.DIALux is most popular because it is also useful to design luminary, its energy evaluation is as per DIN V18599 and EN15899 standards and it is easy to use freeware. DIALux can be used to design exterior, interior, emergency lighting, and road lighting. DIALux also gives a visualization of illumination in a given area. For input room, workplace, or exterior scene can be created or we can import.DWG or .DXF file format to create the scene. Luminaries can be imported from a catalog or luminary.IES or EULUMDAT or LTLI files from luminary manufacturer can be included in the database. The output shows calculation results and visualization pictures. DIALux calculations are based on international standards such as

EN126, EN 1838, etc.[9] But for a given task how many luminaries are required, which is a suitable luminary, what are standard values of lighting quality parameters for the task are not reflected by DIALux. To design a luminary using LED spectral content must be known. At present all simulation software is unable to simulate the SPD of LED. Therefore there is a need for some tool that provides the recommended lighting parameter values for the specific task. This paper presents MATLAB-based software with GUI which helps a designer for getting recommended values of lighting parameters and the SPD of LED. Using standard values of lighting quality factors a case of the laboratory is studied and required luminaries are obtained. Uniform illumination is obtained with daylight integration and on average 15 % energy consumption is saved per working day.

1. TLSIM

Task light simulator (TLSIM) is a rider developed for getting proper input values for DIALux. TLSIM is MATLAB-based software that consists of three basic modules, SPD module, task lighting quality parameter module, and source module. Input parameters for DIALux like the number of sources, selection of source from the database, placement of sources, dimensions of the room, altitude and azimuth, reflection coefficient for the floor, ceiling, walls, the position of doors, and windows. The output from TLSIM modules are input parameters in DIALux as shown in fig.1

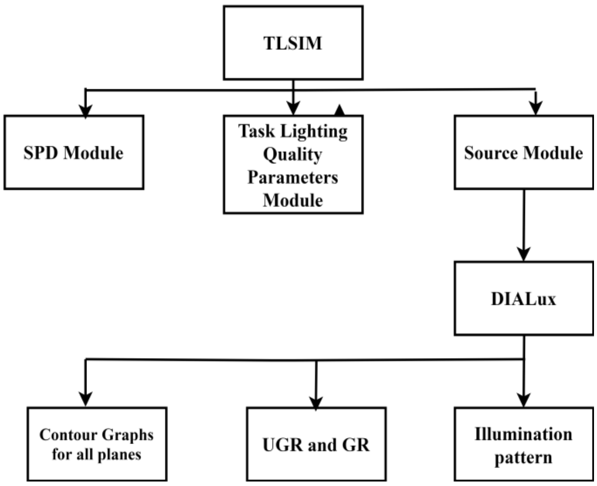


Fig.1. TLSIM modules output as Input given to DIALux

1.1 SPD module

Nowadays,LED sources are widely used for illumination applications. The spectral power emitted per unit wavelength by a LED is important to find its correlated color temperature. This module requires peak wavelength as input. Using a split Gaussian function spectral power distribution is modulated. Light power emitted per unit wavelength is called spectral power density (SPD). The spectral power distribution of LED is unique as compared to incandescent light which has an evenly distributed spectrum over a wide range of the visible spectrum. Most of the study shows that single LED SPD can be model using Gaussian function (eq.1). But using the Gaussian function,thewhite LED SPD cannot be model. White LED SPD is the combination of blue light from the LED chip and yellow light from the phosphor layer. SPD is an important criterion to determine optical parameters such as CCT, CRI, and lumen of the source. A Gaussian function is used to simulate the SPD but it not useful to simulate white LED SPD as it has two different peaks. Split Gaussian function (eq.2) is used to simulate SPD for white LED[10]

$$P(\lambda) = A * exp\left(-\frac{(\lambda-\lambda_c)^2}{\sigma^2}\right) \quad 1$$

$$P(\lambda)_w = \sum_{i=1}^{2} A_i * exp\left(-\frac{(\lambda-\lambda_i)^2}{{\sigma_i}^2}\right) \quad 2$$

$$\sigma = \frac{FWHM(\theta_{1/2})}{2.355} \quad 3$$

Where A_i is amplitude and λ_i is peak wavelength of i^{th} peak. σ_i is the width of the Gaussian function and it depends on full power spectral width.The gaussian term is obtained using equation 3. Flowchart for SPD module is as shown in fig. 2.

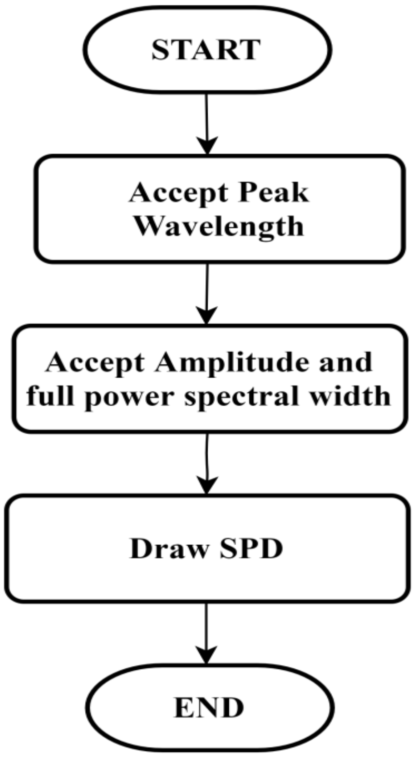
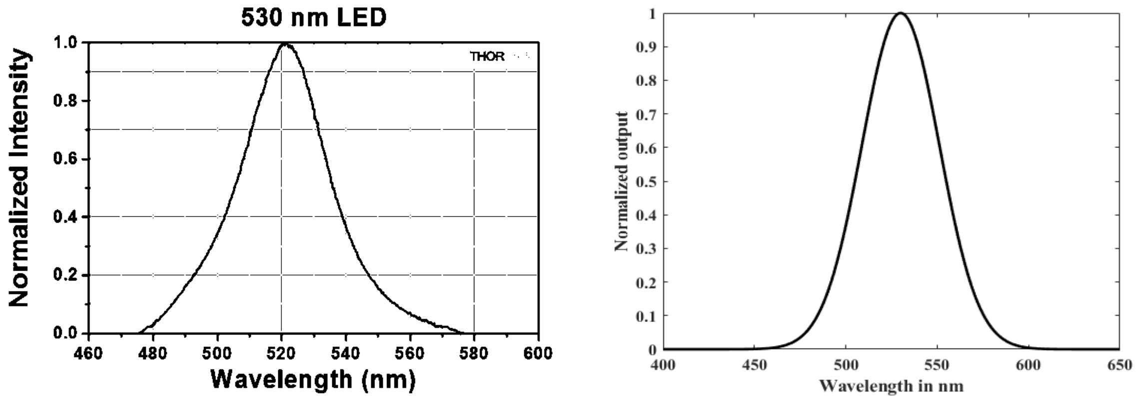
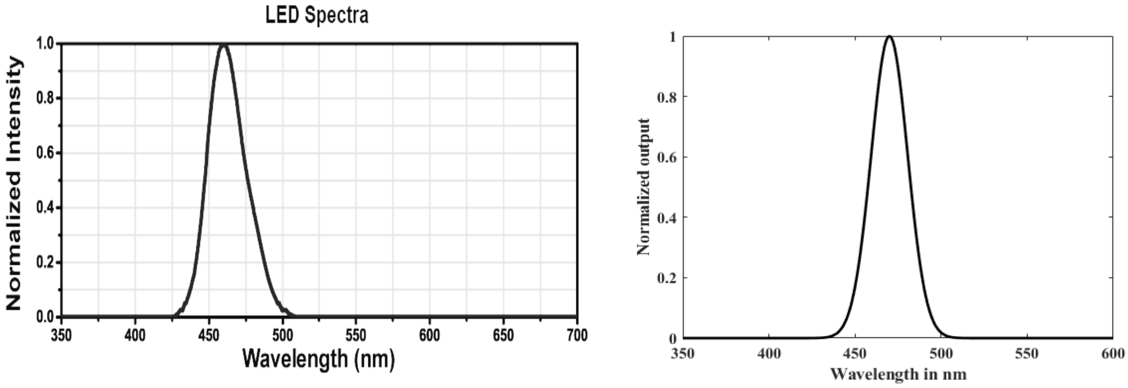


Fig.2. Flow chart of SPD module



(a) (b)

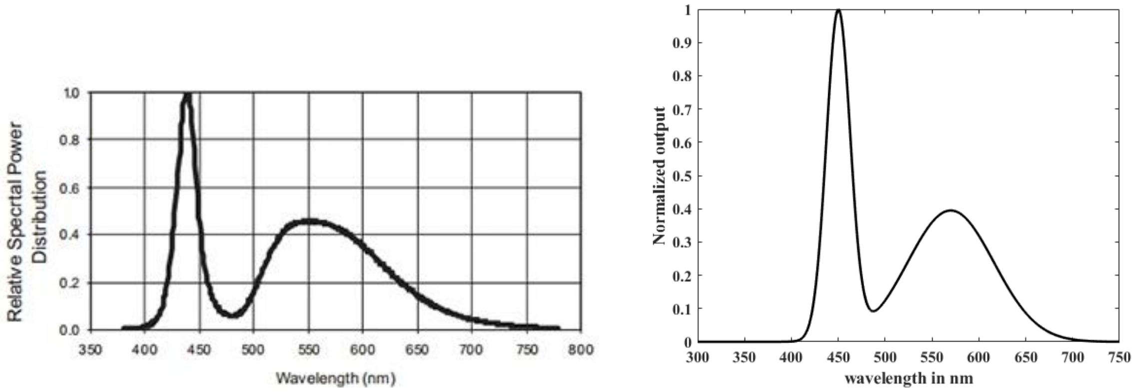
Fig.3. (a) Typical SPD of Green LED (b)simulation result



(a) (b)

Fig.4.a) Typical relative SPD of Blue LED b) Simulation result.

The simulation is carried out using MATLAB. The typical SPD for the green LED of peak wavelength 530 nm in fig 3 (a), andthe simulation result is shown in fig 3(b). Blue LED with a peak emission of 470 nm relative spectral power distribution and simulation result is in fig. 4.Fig. 5(b) shows cool white LED with blue of wavelength 450 nm and a yellow phosphor of 570 nm simulations SPD which matches with typical SPD of cool white LED as in fig. 5(b). SPD using stellar Net spectrophotometer obtained practically matches with simulation result of all LEDs.



(a) (b)

Fig5 a) Typical SPD of cool white LED b) Simulation Result

1.2 Task Lighting Quality Parameters Module

The graphical user interface is designed in MATLAB to select the recommended lighting parameter values for designing acceptable lighting. The database is generated in excel where the number of the task are identified and their recommended illumination level and different lighting parameter values are obtained from different standards IES, European standards, etc. The database contains a main class of lighting, subclass, illumination level, uniformity, CRI, and CCT. The number of the task are identified and their requirement for a quality lighting database is created. Lighting is initially classified into nine classes each class contains a number of subclasses. Once the user selects class and subclass recommended lighting parameters are displayed by the software. Total 35 different subclasses are identified their requirements suggested by IES standers are find out and these are included in the database. The flowchart or lighting quality parameter module is in fig 6. Output window reflectstask lighting quality parameter.

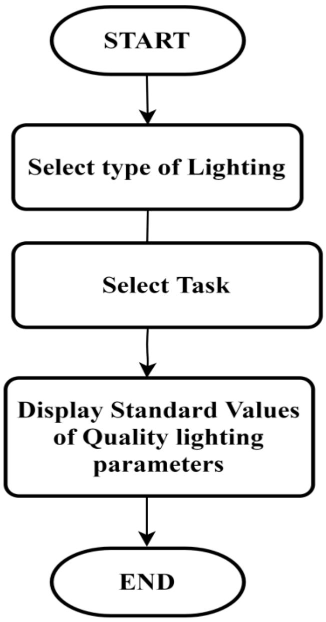


Fig.6.Flow chart of Task lighting quality parameters module

1.3 *Source Module*

This module is developed to calculate the number of luminaries required for the indoor lighting system. Dimensions of the room, work plane height and source distance from roof, and the illumination of luminary are required input parameters. This module returns the room index and the number of luminaires required. The number of luminaries required is calculated using the lumen method [11].The maintenance factor and utilization factor are selected as 0.9 and 0.9 respectively for the well-maintained room. The flow chart for the source module is in Fig.7. Include the IES file of a selected luminary in the DIALux database and simulate the workplace by inserting the number of luminaries obtained from TLSIM.

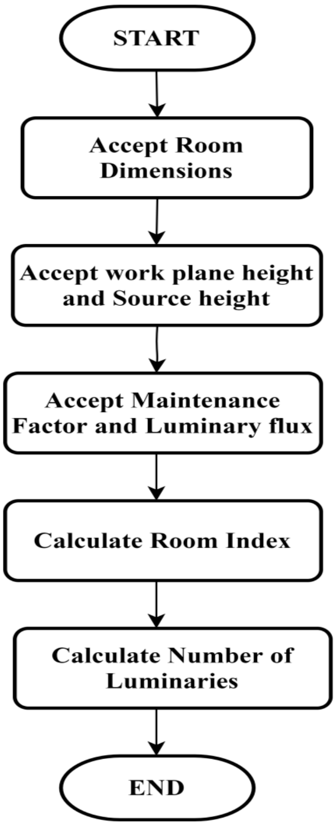


Fig.7.Flow chart of Indoor lighting source module

2. Case study of Laboratory lighting

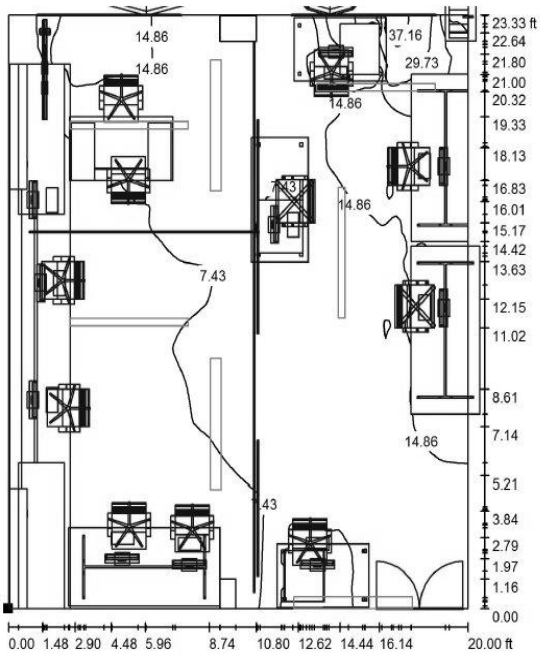
Well, design lighting systems provide glare-free, hard shadows-free, adequate, and uniform illumination over the task surface. The quality of light not only depends on fixture qualities and their orientation but also depends on illumination surface properties like reflection, absorption, and color. It also depends on the maintenance cycle of the space. To consider these effects in design two important factors are considered in the designing process.

Coefficient of Utilization or Utilization Factor is defined as the ratio of lumen received by the surface to the total lumen emitted by the source. It indicates the effect of interior surface properties on horizontal illuminance. Its typical value is 0.9, lighting manufacturers provide its value in the catalog under standard conditions.

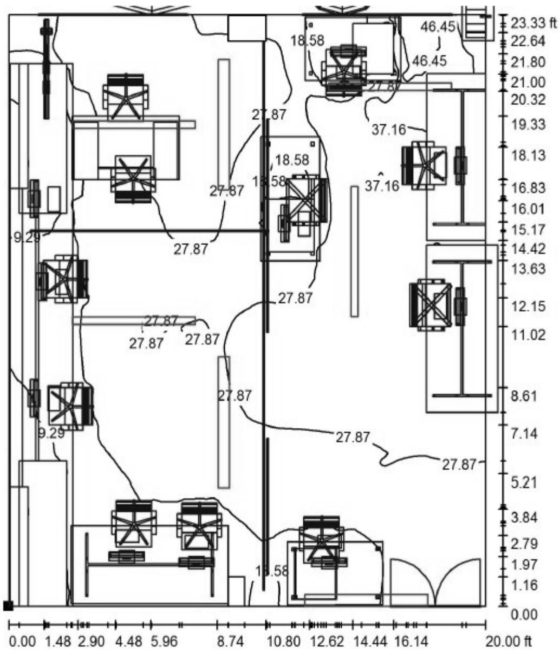
Maintenance Factor (MF) is the ratio of illuminance halfway through the cleaning cycle to the illuminance when the installation is clean. This factor gives a decrease in light output due to dust, lamp black, and dirt on the globe of source and reflectors. Its typical value lies from 0.8 to 0.9 depending upon the maintenance cycle.

Room Index: room index is the ratio that describes how the room heights compare to its length and width. Room index is useful to find utilization factor, typically its value ranges from 0.75 to 5. If E Illuminance is lux for the task, A is the area of task plane, F luminance flux from each lamp in the lumen, UF utilization factor, and MF maintenance factor.Thenthe number of luminaries required is obtained using the source module. The number of luminaries once find out then simulate selected luminaries with a different arrangement using suitable lighting software DIALux, Relux, etc.

Consider the case of a laboratory having a length of 23 ft (7.01 m) and width of 20 ft (6.1m) and height 10.75 ft (3.28 m) workplace height 2.493 ft (0.76 m) with floor reflectance of 0.52, ceiling reflectance 0.86, and wall reflectance 0.82. The laboratory utilization factor 0.9 and the maintenance factor 0.9 as regular maintenance and cleaning take place. There are 10 computers and provision for 11 occupants. The room index for luminaries fitted to the ceiling is determining and it is 1.3. GELIGHTING 93010942 NL LED MARINER T8 SINGLE 1500MM 865 27W tubes of luminous flux 3000 lumens, CRI 88, and CCT of 6500 K are used to illuminate the laboratory. The lumen efficiency of the source is 111 lumen per watt. It has no dimming control. Different orientations and positions of sources are simulated. Using daylight simulation andluminaire arrangement required illumination level is obtained.



(a)



(b)

Fig.8. a) Daylight simulation at 10 am b) Simulation withartificial lighting at 10 am

The number of luminaries required to get an illuminance of 500 lux in the workplace is9. Considering furniture and fittings area number of luminaries is calculated to obtain required illumination on the workplace are 7 only.

3. Result and Discussion

Daylight simulation in fig8 (a) for the clear day at 10 shows that light intensity with average illumination of 107.6 lux (10 fc) is not sufficient to perform the task. There is no glare at any point in the workplace. Artificial lighting is necessary to increase illuminance level, comfort, and pleasantness without an increase in glare. Fig.8 (b) shows illumination distribution with artificial lighting. A simulation result of seven LED tube arrangements isobtained usingDIALux 4.13. A total of 10 GR observer points and UGR points are considered for glare calculation. The uniform illumination obtained with average illumination of 269 lux (25 fc), maximum illumination level 559.52 lux (52 fc), and maximum UGR is 16 and GR is 18 both are less than tolerable values. For GR observer 8 and 10 glare rating is less than 10. Fig. 9shows UGR simulation result. GR and UGR values for different observers are indicated in table 2 andtable 3.

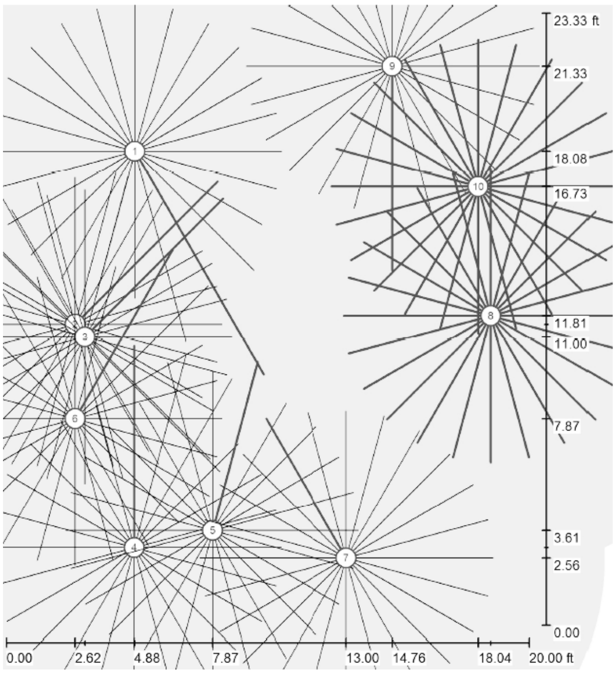


Fig.9.UGR simulation result

Table 2. GR values

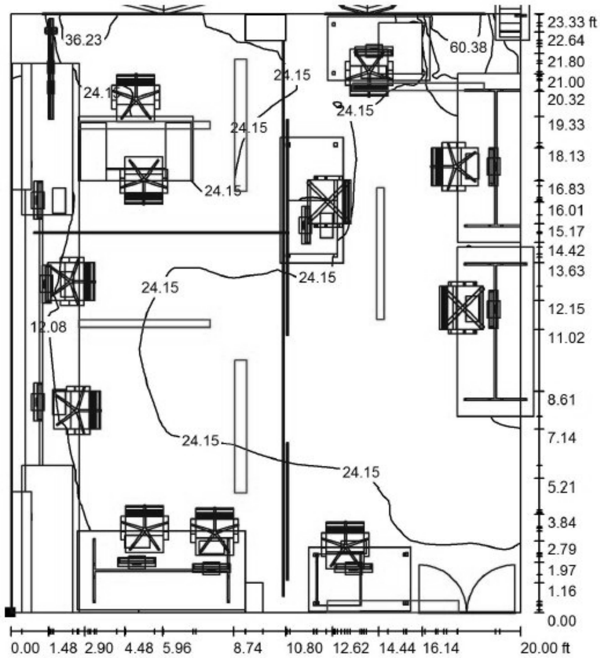
GR Observer Position in ft (x,y,z)	Glare Rating
(4.905,18.085, 4)	18
(2.625,11.483, 4)	14
(3,11,4)	13
(4.881,2.953,4)	14
(7.874,3.609,4)	12
(2.625,7.874,4)	13
(13,2.558, 4)	11
(18.528,11.811,4)	<10
(14.764,21.325,4)	14
(18.044,16.732,4)	<10

Table 3. UGR values

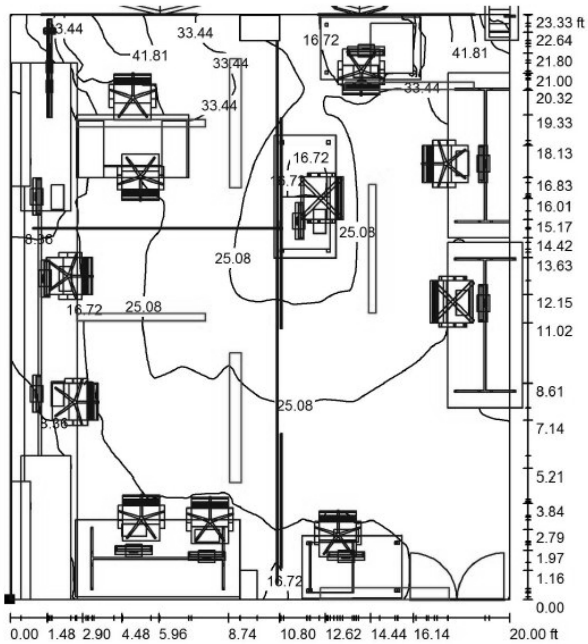
UGR calculation Position in ft (x,y,z)	UGR Value
(2.625, 16.076, 4)	16
(2.297, 20.997, 4)	15
(4.921, 2.953, 4)	12
(2.625,7.874,4)	16
(7.874,2.953,4)	12
(13.123,1.968,3.937)	-
(17.701, 11.869, 3.937)	-
(18.528, 17.388, 3.937)	-
(12.139, 16.076, 3.937)	<10
(14.059, 21.040, 3.937)	-

To save energy, maximum utilization of daylight is necessary. Dimming simulation experiments are carried out by considering the workplace in two zones. The door side zone has poor daylight so all four tubes are continuously on while dimming of the remaining three tubes simulated. Four different dimming levels are 80% ON, 50% ON, 20% ON, and 0% ON (100% off) at intervals of two hours from 10 am to 4 pm. The results are shown in Fig.10 a andb.The uniform distribution is obtained with average illumination of 258.24 lux (24 fc) at the different dimming levels. For the first two hours dimming level is 80 % which saves 16.2-

watt electric power. Next two hours 50 % dimming level is suitable which saves 41-watt electric power. Uniformity is always greater than 0.3 and workplace illuminance is greater than 400 lux as shown in fig. 11.



(a)



(b)

Fig.10.(a) Light distribution at 10 amwith three 80 % dimming (b) Light distributions at 12 pmwith three 50 % dimmingwith all seven tubes are on

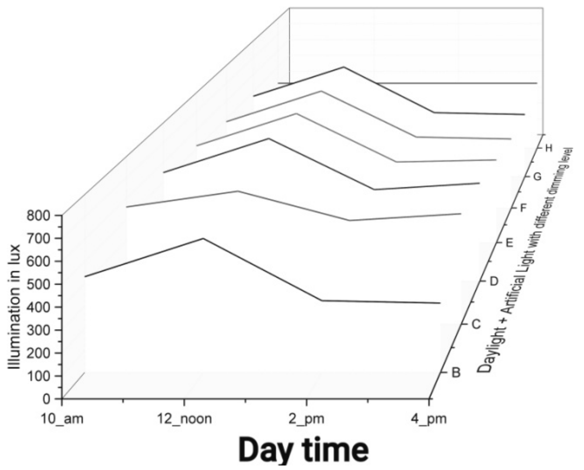


Fig.11. Illumination overwork plane.

There is a number of approaches to design lighting quality. Lighting quality depends on several parameters. These parameters are related to visual, photometric, physiological, and physical, and health aspects. To design quality lighting all aspects are to be considered. In the present paper we have identified different tasks and their requirements a database is created and it can be updated for the new task. A user when approaches the designer, a solution for good quality lighting is possible. Once the required number of luminaries is found out for a given task, the application can be simulated using suitable lighting software like DIALux. Using split Gaussian function we can obtain SPD of a single color as well as white cool and warm LED. Simulation results of SPD for different standard LEDs are obtained. Numbers of LED tube required for laboratory work are calculated. To save energy lab is divided into two zones actual workplace and region under furniture and fittings. Numbers of LED tube required for effective work plane are calculated. The recommended illumination level for laboratory work is 500 lux and our simulation results give 559.52 lux maximum intensity and 269 lux average intensity oflight in the laboratory.

The simulation result shows that sufficient illumination can be obtained using seven LED tubes. An increase in glare index in the work plane due to artificial lighting is tolerable. Using 80 % dimming for the first two laboratory hours and 50% dimming for the next two hours we get sufficient illumination at the workplace which saves 9% electric power 10 am to 12 pm time and 21.43 % power saving between 12 pm to 2 pm. The suggested configuration utilizes daylight more efficiently and saves electric power.

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Authors' information

P.R.Yawale (b. 1965) Completed B.Sc. and M.Sc. in Physics and M.Phil.and Ph.D. in Electronics from Savitribai Phule Pune University.Currently working as assistant professor at B.G. College Sangvi Pune. India
E-mail: *yawalepravin*@yahoo.co.in.

P.S. Varade(b.1974) Completed B.Sc, M.Sc. and Ph.D. in Electronics from Savitribai Phule Pune University.Currently working as associate professor Modern College Shivajinagar Pune. India
E-mail: psvarade1@gmail.com

V.G.Wagh(b. 1963) Completed graduation and post graduation from Pune University and Ph.D. from YCM University Nasik.Presently working as Associate Professor in Electronic Science at V.N.Naik College Nasik. India
E-mail: vgwaghele@gmail.com

A.D. Shaligram (b. 1960) Completed graduation, postgraduation and Ph.D. from Pune University. Currently working as professor in Electronic Science at Savitribai Phule Pune University,Pune. India
E-mail: adshaligram@gmail.com
