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MATHEMATICAL MODELING OF COLOR INFLUENCE IN DIALUX SOFTWARE IN INTERIOR LIGHTING BUILDING

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ABSTRACT

The energy consumed by the lighting of the buildings represents a not negligible part of the total energy. LED lighting has significantly reduced this part with advantages over the reduction of greenhouse gas emissions. Much more related to the standard related to lighting, many studies using optimization algorithms have reduced the amount of lux emitted by lamps to stay close to normative values. In this article, we propose a mathematical model for estimating the coefficient of influence of colors on the lighting level of buildings. The model shows that the value of the level of lighting is strongly influenced when using primary colors and that this influence decreases for the other colors (secondary, tertiary, etc.). The interest of such a model lies in the possibility for the user to have an idea of the change in the level of illumination of a room when it changes color. Furthermore, the need for energy savings can be predicted without the need for prior simulation on software such as DIALux to know the values of the lighting levels to be reached. This saves computing time.

Keywords: Lighting, Mathematical Model, DIALux, Colors, Energy Savings.

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1. INTRODUCTION

The world's energy needs are constantly increasing. Statistics give a consumption of about 40% for the building alone [1,2] with about 20 to 45% for lighting [3]. If nothing is done, this growth will increase and create a big gap between energy supply and demand. To prevent this risk, many countries around the world have undertaken a number of reforms setting consumption limits for buildings. The future goal is to achieve energy-producing buildings.

In order to achieve these objectives, several studies have been carried out with expectations of results by 2050. Some have been interested in optimizing the type of construction, showing the energy savings related to the type of glazing [4,5], the shape of the building [6-9], its geographical position [10], the type of building material [11], etc. Others have worked on the type of equipment by addressing consumer pockets such as cooling [12], ventilation [13-15], heating [12, 16, 17], lighting [18-21], and many others.

For the reduction of lighting consumption, several researchers have done remarkable work. In [22,23], a simple analysis method is used to evaluate the potential energy savings associated with electrical lighting when it is combined with daylight use. A fuzzy controller was developed in [24] to maintain the lighting illuminance level suitable for robotic manipulation in specific environments. The same approach was developed in [25], using a fuzzy controller to save lighting energy based on user displacements. In [26], the authors have implemented neural networks model to find an optimal position of some luminaires. In [27], lighting control has been modeled as a linear programming problem to accomplish energy efficiency and satisfy occupants' lighting preferences. In [28], a feed-forward neural network model was proposed to describe the relationship between the dimming level of LED luminaires and the illumination on a table without using simulation software. The actuation command to the luminaires was generated by a feed forward neural network control strategy. Some researchers in [29], use simulation software to carry out the lighting configuration in the test room to establish the relationship between lights and table illuminance. However, to the best of our knowledge, no work in the literature design a mathematical model of color impact factor in an interior building using DIALux software with energy savings objective.

In this article, we propose a mathematical model for estimating the coefficient of influence of colors on the lighting level of buildings. The article is organized as follows: in section 2, the color characterization is presented, followed by a mathematical formulation problem for the case of office lighting. To close this part, an estimation procedure of color factor is given. The validation of the mathematical model is shown and discussed in section 3 when in section 4 the conclusions of this research are presented.

2. METHODOLOGY

2.1. Color specificity

Color is the visual perception of the appearance of a surface or light, based, without being rigorously linked to it, on the spectral distribution of light, which stimulates specialized nerve cells located on the retina called cones. In physics, colour is associated specifically with electromagnetic radiation of a certain range of wavelengths visible to the human eye.

An electromagnetic wave can be defined by its wavelength. It is a quantity that is expressed in units of length, and it can vary from one-millionth of a meter to one kilometer.

Among the electro-magnetic waves that we cannot see are X-rays, ultra-violet rays (responsible for our tanning), infra-red rays (which we cannot see, but which we can feel in the form of heat), or radio waves.

Our eyes are only sensitive to radiation with a wavelength roughly between 0.38 and 0.74 millionths of a meter (380 to 740 nanometers, noted "nm"). Depending on the value of the latter, we perceive radiation as the light of a certain color. Table 1 gives an approximate correspondence between colors, wavelengths, and frequency (in TeraHertz, noted "THz").

Table 1: Approximate correspondence between colors, wavelengths, and frequency

Colors	Wavelength (nm)	Frequency (THz)
Red	625 to 740	480 to 405
Orange	590 to 625	510 to 480
Yellow	565 to 590	530 to 510
Green	520 to 565	580 to 530
Blue	446 to 520	690 to 580
Purple	380 to 446	790 to 690

For example, if you look at a lamp that emits light with a wavelength of 400 nm, you will see it purple. If it emits a shorter wavelength, you will not see anything: it is below what you can perceive (in this case, ultraviolet).

Colors are mainly defined by 3 characteristics: the hue is the frequency that produces that color, the value represents the light amplitude that defines this color, and Saturation represents the purity of the color. **Most of the colors obtained are the result of mixing several primary colors, which can not be obtained by mixing other colors.**

In the traditional color wheel (see Figure 1a), which is used for painting, the primary colors are red, yellow, and blue. These colors were chosen apparently because of their vivid distinctness [30]. From the primary colors, secondary colors are obtained through the following combinations: red and yellow produces orange, then blue and yellow produces green while, mixing red and blue produces purple, as presented by the color wheel (see Figure 1b).

a b

Figure 1: (a)The color wheel containing primary, secondary and tertiary colors. (b)The primary and secondary colors.

2.2. Mathematical formulation in interior lighting

The illuminance and the uniformity of lighting represent the two means characteristic in interior lighting. All these characteristics are normalized (EN 12464) [31]. The final issue of modelization is to minimize energy consumption. This optimisation is obtained by reducing the power consumption of the different luminaires in an interior building. It is known in physics theory that, the illuminance at a specific point of the work plane level (E_i), can be represented as a linear combinaton of the contribution of each luminaire on that measurement point (ω_{ij}) and the corresponding dimming level of that luminaire (d_j) [27, 32, 33, 34].

$$E_i = \sum_{j=1}^{N} d_j \, \omega_{ij} \quad (1)$$

where N is the number of luminaire and i depend on the number of measurements point M

When introducing the specific factor β_k due to color effect in different parts of a piece [35], it is possible to build the mean illuminance as follows:

$$E_m = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} d_j \beta_k \omega'_{ij}}{M} \quad (2)$$

where ω'_{ij} is the value of measure illumination with a neutral color.

The ration of E_{min} (minimum value of illumination) and E_m defined the uniformity g_0.

2.3. Estimation procedure of color factor

2.3.1 Office simulation

The modeling procedure is carried out first of all on a 5 x 4.5 x 2.8 m desk. The LED luminaire DN450B 1xDLM2000/840 of constructor PHILIPS are chosen because of their low energy consumption (25W, 2000lm). The color of the piece is modified to appreciate the variation of illuminance. Primary colors (red, blue and yellow) and secondary colors (green, orange, purple) are chosen for different experimentation while the initial color is white for all part of the room office. Table 2 shows the Hue Saturation Brightness (HSB) values used for differents colors. The other color is not chosen because of their dependant on a primary color and secondary color. Figure 2 shows the implantation principle.

Table 2: Colors value in HSB system

Colors	**Red**	**Blue**	**Yellow**	**Green**	**Purple**	**Orange**	**White**
Hue	0	160	40	80	180	20	160
Saturation	240	240	240	240	240	240	0
Brightness	120	120	120	120	120	120	240

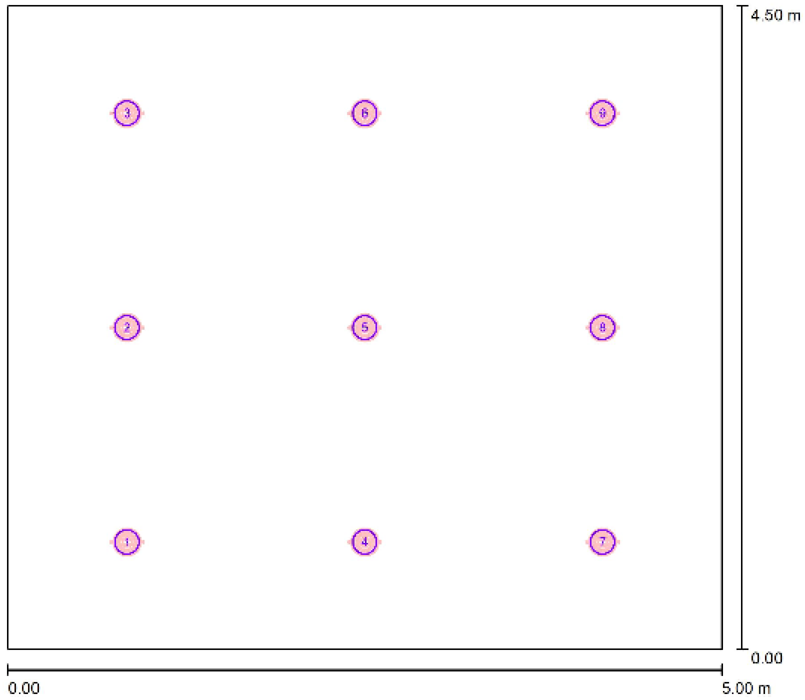
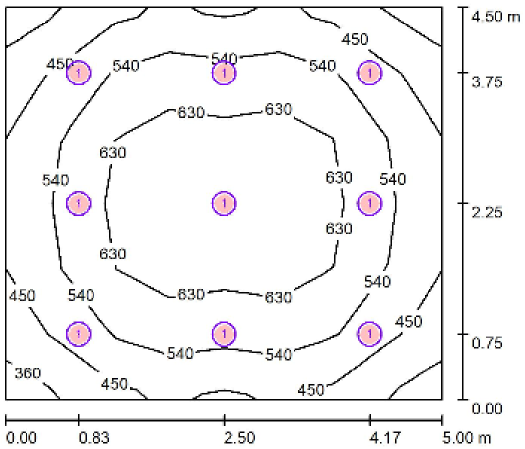


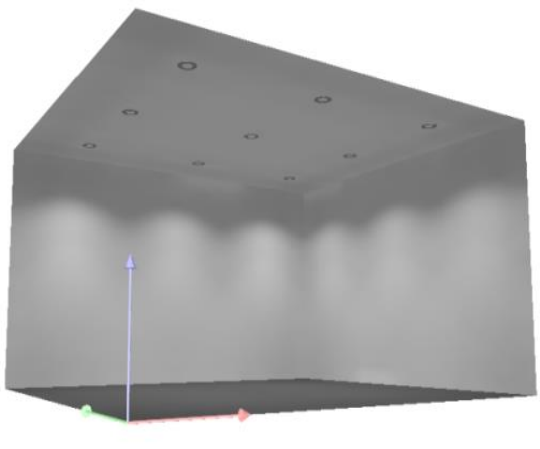
Figure 2: Visual form of the office and arrangement of the luminaires insides the room

DIALUX is used for simulation and the illumination and uniformity are fixed by the norm 12464 [31]. In this case, the minimum values are E_m= 500lx and g_0= 0.6. The light loss factor is chosen 0.8 and the height of the working plane around 0.800 m. The surface reflectance values of ceiling, wall and floor are 70%, 50% and 20% respectively, according to the Illuminating Engineering Society (IES) [36, 37] recommendations.

Figure 3a shows the illumination isoline for a neutral color and Figure 3b the 3D view.



(a)



(b)

Figure 3: (a) Illumination isoline for white color (b) 3D view for white color

To extend the test data, the room in figure 2 is used for the experiment by changing its dimensions (or the number or type of luminaire) to have several different simulation cases. The primary colors (red, blue and yellow) and the secondary colors (orange, purple and green) are chosen for different experiments with either white or black as the initial color chosen.

The other colors are not chosen because of their dependence on the primary and secondary colors. The simulation is conducted on DIALux and yields the results reported in Table 3. The ratio between the illuminance obtained with a neutral color and that obtained with the primary and secondary colors for the test cases is evaluated in Table 4.

Table 3: Simulation results for primary and secondary colors

Colors	E_m					
	Test 1	***Test 2***	***Test 3***	***Test 4***	***Test 5***	***Test 6***
Red	818	682	463	732	780	824
Blue	595	501	336	532	566	599
Green	605	512	345	540	578	608
Orange	620	526	355	554	595	624
Yellow	573	484	324	511	546	575
Purple	610	514	345	545	581	614
White	562	475	317	501	534	564

Table 4: Ratio of illuminance levels for primary and secondary colors

Color	ω/ω'					
	Test 1	***Test 2***	***Test 3***	***Test 4***	***Test 5***	***Test 6***
Red	1.456	1.436	1.460	1.461	1.461	1.458
Blue	1.059	1.055	1.059	1.062	1.060	1.060
Green	1.077	1.078	1.088	1.078	1.082	1.076
Orange	1.103	1.107	1.119	1.106	1.114	1.104
Yellow	1.020	1.019	1.022	1.020	1.023	1.018
Purple	1.085	1.082	1.088	1.088	1.088	1.088
White	1	1	1	1	1	1

2.3.2. Approximation approach of color factor

To obtain our mathematical model, the procedure consists of first collecting the necessary data on the sample parts. Then, the illumination level of the corresponding part is measured with a neutral color as the initial color. This color is then modified (using primary and secondary colors) to obtain the other lighting levels. The mathematical model is obtained after estimation of the parameter β by relating the illumination level with the neutral color to those obtained with the other colors. Finally, through an analysis of other illuminance measurement cases, the results obtained are consolidated and a conclusion can be drawn. This procedure is summarised by the flow chart in Figure 4.

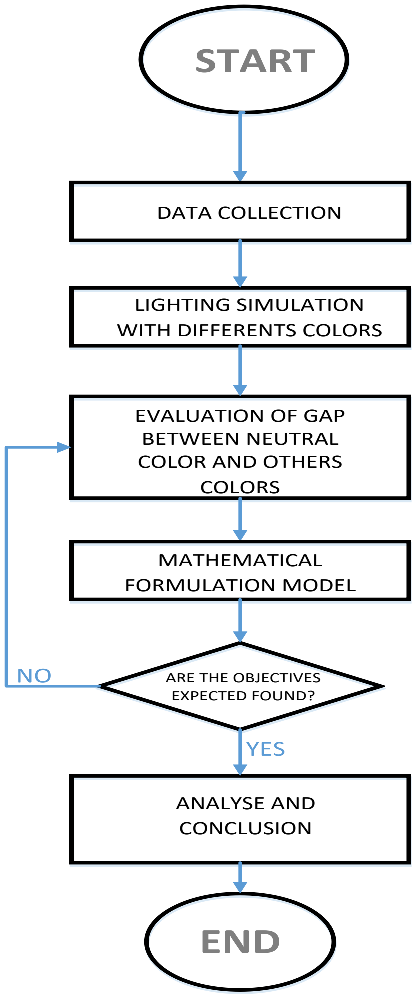


Figure 4: Flowchart For the Simulation Environment Architecture.

3. RESULTS AND DISCUSSIONS

The procedure of modeling leads us to choose a sample part (Figure 2), simulate it on DIALux with a neutral color first (Figure 3), then the other colors (primary and secondary). The results of the simulation are given in table 3.

Starting from Table 3, we want to evaluate the relationship existing between the different illuminance values according to the chosen color. We have seen that the ratio ω/ω' was almost the same for the different case studies (see Table 4). We can then approximate the value of this parameter as presented in Table 5.

Table 5: Color parameter approximation $\boldsymbol{\beta}$

Color	Color parameter ($\boldsymbol{\beta}$)	ω/ω'
Neutral	β_0	1
Red	β_{re}	1.455
Blue	β_{bl}	1.059
Green	β_{ge}	1.080
Orange	β_{or}	1.109
Yellow	β_{ye}	1.020
Purple	β_{pu}	1.087

Taking the above into account, we can write, using Polynomial Approximation, the approximate equation for the evaluation of the color factor in the following form:

$$\boldsymbol{\beta_k = 1 + \xi . \beta_0} \quad (3)$$

where β_k is the color parameter for the other colors (index k) apart from neutral colors

β_0 is the color parameter for neutral colors

ξ is a parameter that depends on the color type and ranges from 0 to 0.5.

The accuracy of this relationship can be verified by performing further tests where the illuminance values obtained from simulation are compared with those obtained from the Equation (3) (see Table 6). Figure 5 shows the evolution of the illuminance values calculated from the mathematical model and by simulation on DIALux. It can be seen that these curves overlap, thus showing the reliability of the mathematical relationship. The rate of change is less than one percent. It is, therefore, possible, thanks to this relationship, to estimate the level of illumination of a room when the basic color is changed (neutral or other colors) and the initial illumination is known. This allows the user to have an idea of the possible energy savings by using certain colors. It is shown that [38], with the red color, the greatest energy savings are obtained. It is the color with the highest energy saving factor ξ. It should also be noted that color variation has a positive impact on uniformity, as uniformity is improved each time the color is changed from color with a low factor ξ to color with a higher factor ξ. The range of variation of the color factor (from 1 to 1.5) shows that energy savings of up to 50% can be achieved. This percentage increases when the dimming level of the luminaire (d_j) is lowered using the optimization technique such as neural networks or genetic algorithms [32,35].

Table 6: Mean illuminance values obtained by calculation and simulation

Color	Em (with Math Model)	Em (with simulation)	Gap (%)
Red	693	687	0.87
Blue	504	504	0
Green	514	512	0.39
Orange	528	524	0.76
Yellow	486	485	0.21
Purple	517	516	0.19
White	476	476	0

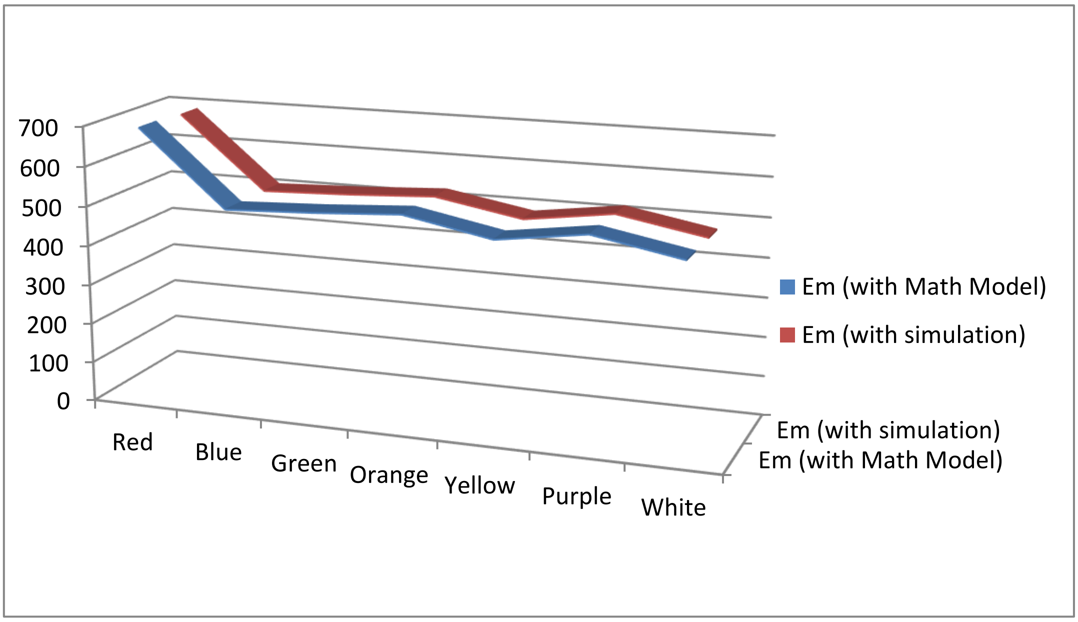


Figure 5: Graph variation of mean illumination according to the chosen color

4. CONCLUSION

Starting from the problem of reducing the consumption of lighting in buildings, this article highlights the mathematical model of color influence in DIALux software in interior building. The article proposes a mathematical model for estimating the parameter of influence of colors on the illumination level of buildings. It starts from the classification of colors into primary and secondary colors to highlight some colors relevant for experimentation. The various simulations/tests carried out make it possible to arrive at a linear equation for calculating the parameter β_k. The reliability of this mathematical model is then shown in further tests by comparing the illuminance levels obtained by calculation and simulation. Finally, the interest of this model is explained with the need to control the energy savings to be made in buildings because of the current global requirements for optimizing energy consumption in the building sector.

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