Light & Engineering
Vol. 28, No. 1, pp. 70–78, 2020
https://doi.org/10.33383/2018-052
Svetotekhnika #3, 2019, pp. 64–71

AN EMPIRICAL VALIDATION OF ESTIMATION MODEL (OPTIMLUM) FOR ENERGY EFFICIENT LUMINAIRE LAYOUT DESIGN IN OFFICES

İlknur Erlalelitepe Uygun, Tuğçe Kazanasmaz and Serdar Kale

Izmir Institute of Technology, Turkey
Emails: tugcekazanasmaz@iyte.edu.tr; ilknurerla@gmail.com; serdarkale@iyte.edu.tr

ABSTRACT

This study performed with the purpose of constructing and validating a model named OptimLUM (Optimizing Luminaire Layouts) to estimate the most accurate location, number and type of artificial light sources according to average illuminance and maximum uniformity in an office. OptimLUM is appling through Excel Spreadsheet to develop the model and uses Evolver, which is basing on genetic algorithm to implement optimization routine. To validate the reliability of the proposed model, luminaire layout scenairos generated for two types of luminaires after taking illuminance measurements in an actual office. OptimLUM illuminance values were comparing statistically with measurement and DIALux results to test the applicability of the model. The model performance is highly accurate in determining luminaire positions: coefficient of determination R^2 and coefficient of variation CV were equal to (86–99)% and to (0.04–0.12) respectively, and for all scenarios. Its outputs are closer to the actual measurements when compared with DIALux outputs.

Keywords: luminaire layout, optimization, offices, artificial lighting

1. INTRODUCTION

Lighting design of a workspace is a complicated task that includes multiple criteria based on many physical and psychological aspects [1]. Occupants need to work in comfortable and healthy environments but also in energy efficient buildings. A significant amount of office buildings' energy consumption is due to artificial lighting [2]. The planning of artificial lighting systems involves in office buildings, like any other buildings, consideration of the metrics of lighting quality and quantity [3]. These metrics are illuminance, uniformity and the location of luminaires. Lighting designers select and decide on the types of lamps and luminaires according to these metrics and as result of mathematical simulations of lighting installations. Softwares, such as DIALux, Relux, Radiance, use engineering computational tools and architectural rendering together. These softwares are good assisting tools for lighting designers, presenting luminaire layout alternatives due to grid layouts [1,4]. However, they are not result in the most accurate or optimum position of luminaires irregardless of array layout arrangement and without the intervention of the user. Potential solutions/designers' assumptions for better performance cannot be confirmed or rejected through effective search mechanism. In this sense, it is necessary to propose optimal and alternative solutions by maximizing comfort conditions and minimizing energy consumption by practical optimization techniques, such as genetic algorithm, heuristics and meta-heuristics etc…

There are some researches about deciding luminaire positions. Mourshed et al. proffer a novel method named Phi-array to fit visualization and decide luminaire position. Authors used the simulation program Radiance to get illuminance performed with a frame, which includes illuminances of reference points. Similar grid frame was appling for lighting source locations estimation. The both illuminance on the horizontal and vertical surfaces are analyzing by simulation program. These, three dimensional, data are evaluating by Genetic Algorithm for optimization process [3]. Researchers continue developing and using different methods while they also validate them to show their reliability. F. Cassol et al. presented a new methodology to find luminaire location by getting satisfying illuminance and lowest power consumption. The generalized extremal optimization (GEO) algorithm is used to solve the problem and this type of solution technique supply a set of luminaire layout solutions [5]. Another study designed a fuzzy logic controller according to daylight, users' movement and lighting comfort. A lighting system was set up in an office and the controller is experimentally tested by getting illuminance measurements [6]. De Rosa et al. prose a new code about prediction of daylight illuminance on the inside surfaces. The code name is INLUX was validated by comparing its calculated illuminance with illuminance measurements inside a scale model 1:5 [7].

There are many ways to validate new proposals about lighting studies. With reference to these studies, the main objective of this study is to evaluate the prediction accuracy of interior illuminances carried out by OptimLUM through comparison of the simulation results with measured data. Thus, the performance of optimization model OptimLUM was empirically testing by getting measurements in a test case and by the DIALux models to explore its applicability and validity. The validation process involves the formulation of a linear regression line developed in scatter diagrams to compare the measurements and proposed model illuminances for different luminaire layouts and observe the strength of their relationship. Coefficient of determination (R^2), root mean square error (*RMSE*), normalized root mean square error (*NRMSE*) and coefficient of variation (*CV*) were also calculated.

2. APPLICATION OF PROPOSED MODEL OPTIMLUM

This section presents process of setting an optimization model through calculating the uniformity and illuminance to conclude the best possible layout design. User's data generation about selected room and luminaire type and the calculation method to acquire the optimum solution are explaining.

2.1. Construction of User's Data Set

Lighting design can be simplified by determination of the correct luminaire positions to avoid unbalanced illuminance distribution while selecting the accurate light source for the volume to be illuminated [8]. User needs to contribute some basic information about luminaire type, office dimensions and surfaces to Excel Spreadsheet. Model was developing through Excel. Information about office consists of room dimensions (height, width and length) and surface reflectances (wall, ceiling and floor). A luminaire database for offices was generating for OptimLUM users to select luminaire type effortlessly. This database includes luminous flux and photometric data of luminaires from various manufacturers. Photometric data not only provides luminous intensity of luminaires that varies according to vertical (Gamma, γ) and horizontal (C) angles but also makes it possible to calculate illuminance.

2.2. Calculation Process

The basic metric for visual comfort is illuminance. Calculation of illuminance can be possible through a certain number of mathematical processes related to the behavior of light to get adequate illuminated spaces. These mathematical calculations guide designers to decide lighting sources' layout. Point method is one of them based on illuminance at any point on observed surface [9]. Uniformity is another metric that helps to understand differentiation of illuminance values in the whole space. To make the OptimLUM run flexible at different room dimensions and with different luminaires, calculation formulas were encoding in Visual Basics (VBA). The first step was to generate grids on the working plane and ceiling to determine calculation points and luminaire location points. Their coordinates on x, y and z plane were generated through calculating the arithmetic mean of the room length and width. Calculation points and luminaire location points placed at least of 0.46 m away from the surface of the walls. The grid size of calculation points was set to be (400×600) mm. Furniture not taken into acoount in calculations. Since mostly, their layout can be flexible. Workplane illuminance has the significance in uniformity and average illuminance calculations. Therefore, the model is an abstraction of the empty office geometry. Suspended ceilings generally used in offices and their size mostly (600x600) mm. Because of these reasons, the grid size of luminaire location points was (600x600) mm, and, according to architectural qualities of the space, recessed mounted modular luminaires were selecting. Such non-aligned grids were using to get the contribution of various distribution angles of the luminaires, and that resulted in dissimilar illuminances. Based on these grids, γ and C angles between calculation points and location points of light source were calculating as outputs at this step. C angle is the resulting angle between light source and calculation point on horizontal plane, Fig. 1.

The model provides us flexibility to change the grid size and its distance to the wall so there is a possibility to include different dimensions of luminaires i.e. linear type. The orientation of luminaires to specify their position is defining by C and γ angles.

Two components have impact on illuminance considering point method. These are direct and indirect component of horizontal illuminance. Direct component is the effect of luminous intensity from light source on a point. Direct component calculating according to given formula (1) is using:

$$E_h = \frac{\left(\frac{\Phi}{1000}\right) \cdot I_{rel} \cdot \cos^3 \alpha}{h^2}, \tag{1}$$

where Φ is total luminous flux of lumuminaire, I_{rel} is the reduced luminous intensity on the point according to C-γ angles (cd/klm), h is the vertical distance between the lamp and the point, and α is the angle between these [10]. Total direct illuminance would be calculating by repeating this formula (1) for all concided points of space.

To calculate indirect component (E_{ind}) from the operation of the light occurring by reflection from surfaces formula (2) is using:

$$E_{ind} = \frac{\varnothing}{\sum F_n} \cdot \frac{\rho_{avg}}{1-\rho_{avg}}, \tag{2}$$

where $\rho_{avg} = \frac{\sum \rho_n F_n}{\sum F_n}$, Ø is the luminous flux leaving the luminaires, $\sum F_n$ is the total area of the room surfaces, ρ_n is the reflectance of each surface and ρ_{avg} is the average reflectance of all room surfaces (2).

Uniformity is significant to understand differentiation of illuminances on all surfaces. Because different lighting design alternatives proposed may cause some bright or darks regions in the horizontal plane due to the overlap or gap of the luminous intensity distribution curve. Non-uniform light distribution could cause glare when one region in the interior space is brighter than the general brightness [9]. Generally, it is defining as ratio of the minimum to the average illuminance. Yet, this ratio is an overall measure to give an idea about illuminance balance. To test illuminance fluctuations in detail, mean relative deviation (*MRD*) (3) is using to calculate relative deviation of illuminance at each point from the average illuminance of the whole space, as cited in literature [10].

$$MRD = \frac{\sum_{i=1}^{N} \left| E_i - E_m \right|}{NE}. \tag{3}$$

3. OPTIMIZATION APPROACH

Optimization is a progress to find most appropriate solution for a problem having many conceivable solutions. EVOLVER6 (ADD-INS for Excel) was used as optimizer which is for non-linear optimization problems and the EXCEL spreadsheet application [13]. EVOLVER uses genetic algoritm (GA) which is an optimization method based on Darwinian principles of natural selection and OptQuest Engine, which includes metaheuristic, mathematical optimization, and neural network components to get best solutions to decision and planning problems of all types.

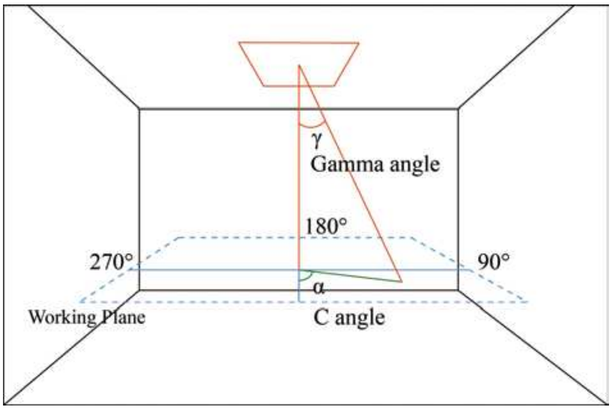


Fig. 1. Gamma(γ) and C angles between calculation points and location points of light source

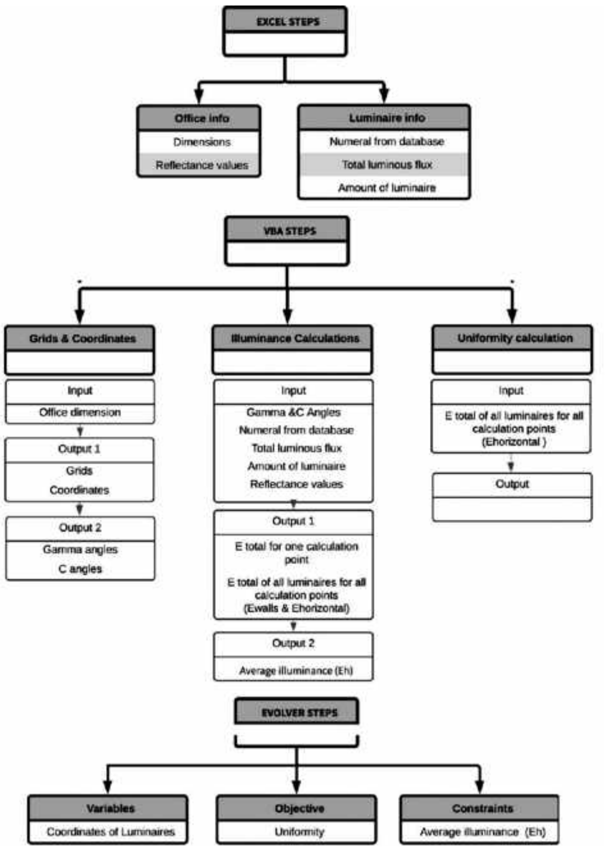


Fig. 2. Flow chart of calculation progress

The optimization model includes many decision variables based on the objective function, and constraints. So, all possible luminaire location points, illuminance at each calculation point, average illuminance and uniformity (*MRD*) were calculated and were used as the main input data in the optimization model. Here, the primary objective of the research is to get illuminance uniformity (4) closer to zero on the working plane (0.8m) that means minimum deviation between illuminance levels at each calculation point [12]. There are two hard constraints, which are recommended illuminance between (300–500) lx [14], (5, 6). E_{avg} is the average illuminance of working place. E_i is the illuminance level at one calculation point, and E_m is the mean of illuminance at all these points.

Variables are to find location of luminaires:

$(x_1,\ \ y_1,\ \ z_1),(x_2,\ \ y_2,\ \ z_2),(x_n,\ \ y_n,\ \ z_n)\ldots\ldots$

Minimize uniformity: $MRD = \dfrac{\sum_{i=1}^{N}\left|E_i - E_m\right|}{NE}$

is subject to: $300 \le E_{avg} \le 500$ (4), [12].

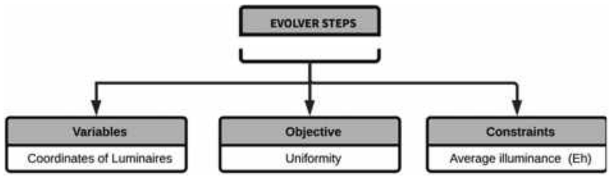


Fig. 3. Flow chart of optimization progress

4. EMPRICAL VALIDATION OF OPTIMLUM

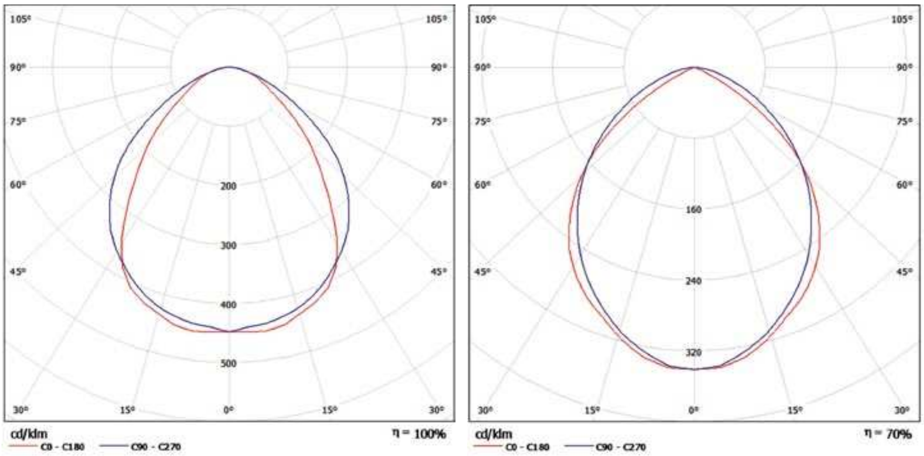
To test the accuracy of the model outputs an office illuminance selected as a case study. An actual office room located at İzmir Institute of Technology, (5.33×3.32×2.9) m in size was testing to check the proposed optimization model. Luminance meter was used for reflectance coefficients measurements, which were calculated for walls, floor and ceiling in accordance with formula (5), [15].

$$\rho_s = \rho_{white}\frac{L_{surface}}{L_{white}}, \qquad (5)$$

where ρ_s is the reflectance value of surface, ρ_{white} is the reflectance value of white surface, $L_{surface}$ is the luminance of measured surface, and L_{white} is the luminance of white surface. According to these measurements, ρ_{wall} was calculated as 0.37, $\rho_{ceiling}$ as 0.27 and ρ_{floor} as 0.60.

Two different luminare types were selecting for the test case: LED and FL. Luminous flux of luminaire with LED is 3700 lm while the one with FL is 3780 lm. OptimLUM ran two times with two luminaires, defining luminaire location grids and calculation grids initially. The first grid consists of 40 discrete points to estimate location of light source; while there were 60 calculation points at which illuminance was calculated based on luminare data sheets (Fig. 4) one by one in each iteration.

Each light source location is designating with a number starting from the first upper left grid –1 and ending at the last lower right grid – 40. Employing these two grids, objective function and constraints together, OptimLUM generated in sum 22359 possible installation scenarios for LED luminaires. The 2359 were the best trials among 19626 valid trials. It is also produced 22483 total trials for FL luminaires. The number of best trials was 9691 among 11507 valid trials. The computational times for calculating the optimal solutions were 809 s and 814 s respectively. OptQuest engine was the optimization engine to get solutions of both luminaire types.



CoreLine/ Surface-mounted/ LED
SM120V LED37S/840 PSU W60L60

Centura/ Surface-mounted/ Fluorescent
TCS160 4xTL-D18W HF C3

Fig. 4. Data sheets of selected LED and Fluorescent luminaires

Model estimated two optimum layout scenarios using three LED and fluorescent separately, presenting the minimum deviation in uniformity and satisfying the required average illuminance (Fig. 5).

4.1. Validation of Calculation Process

4.1.1. Layout scenarios for measurements and simulations (DIALux)

Besides layouts obtained from OptimLUM, two alternative ones offered to validate illuminance calculation of OptimLUM and optimized estimation of OptimLUM comparing illuminance and uniformity results (Fig. 6). In Alternative I, three luminaires were located linearly and had symmetrical distance from walls. Alternative II includes three luminaires placed arbitrarily in triangle layout (Fig. 6). One set of these three layouts analyzed including LEDs, while another set involved Fl luminaires.

In addition to these triple layouts above, to find the contribution of each luminaire to each measurement point, new layouts including single and double luminaires were determined for validation of the illuminance calculation process of OptimLUM. During the measurement step, illuminance values of single and double configurations of luminaires measured on workplane (0.8 m height) by switching on while the other luminaires are switching off in the actual test case. After this process, the 36 configurations were simulating in DIALux, additionally illuminance values calculated by OptimLUM (Table1). Calculation grid coordinates defined by OptimLUM used as illuminance measurement points in test case and as calculation points for simulation.

4.1.2. Statistical evaluation of measurements, simulation and OptimLUM calculation

Illuminance measurements and DIALux simulations aimed to test the illuminance calculation method of optimization model and to validate layout estimation of OptimLUM performance by com-

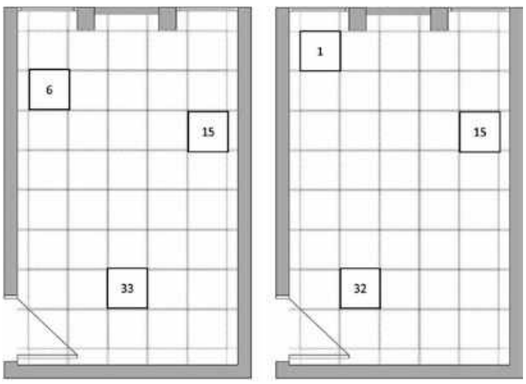


Fig. 5. OptimLUM estimations for luminaires with LED (left) and fluorescent (right)

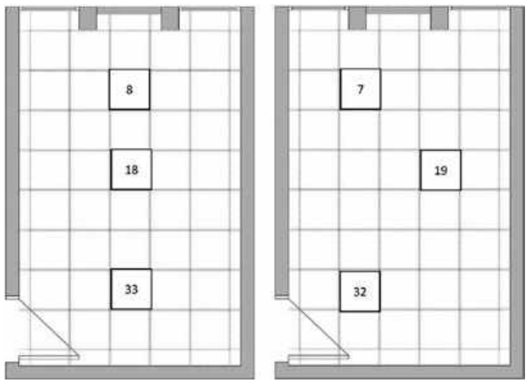


Fig. 6. Alternative luminaire layouts- Alternative I for LED and fluorescent (left) and Alternative II for LED and fluorescent (right)

Table 1. Number of Scenarios

		OptimLUM	Alternative I	Alternative II
LED luminaires	single	3	2	2
	double	3	3	2
	triple	1	1	1
Fl luminaires	single	2	2	2
	double	3	3	3
	triple	1	1	1

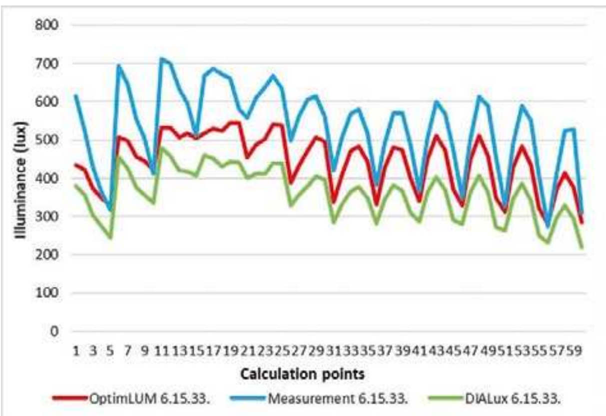
paring illuminance and uniformity. Illuminance distributions of all scenarios were comparing by line charts. It observed that OptimLUM outputs are closer to the actual measurements when compared with DIALux outputs. When we compare OptimLUM layout and Alternative I findings for LED in Fig. 7 regarding minimum, maximum, average values and standart deviations, OptimLUM outputs were very slightly higher than DIALux outputs while both of them remained lower than the measurement values. A few deviations between fluctuation lines of OptimLUM, DIALux and measurement values in OptimLUM layout observed when we compared it with Alternative I layout in Fig. 7.

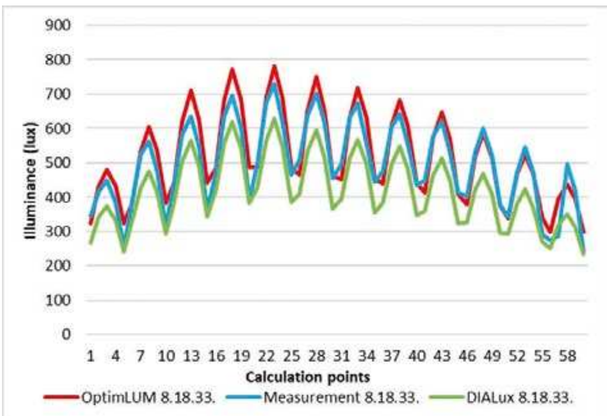
Therefore, calculated by OptimLUM illuminance values fits very well with the measurement values regarding the overall results for luminaires with fluorescent lamps.

Scatter diagrams were using to validate the OptimLUM model by comparing OptimLUM values and illuminance measurements. Excel calculated the coefficient of determination (R^2) and the linear regression equation. The model performance is highly accurate in calculating illuminance values with R^2 in range (86–99)% (Figs. 8,9 and 10). The highest coefficient of determination, which is 99 %, is observed in single luminaire configuration calculated by OptimLUM (Fig. 8) Root mean square error (*RMSE*) which is an indicator to show differences between outputs is calculated by given formula (6).

$$RMSE = \sqrt{\frac{\sum_{t=1}^{N}\left(o_{1,t} - m_{1,t}\right)^2}{N}}, \tag{6}$$

where o is the illuminance output of OptimLUM, and m is the measured illuminance for all calcula-

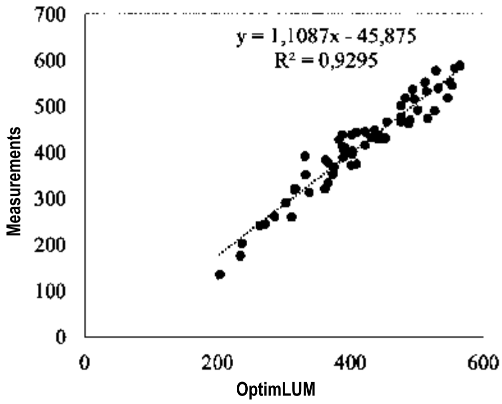


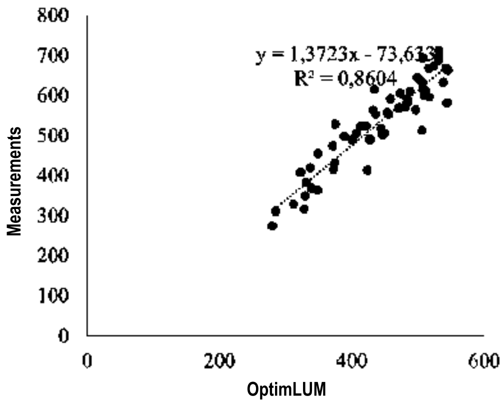


LED MODEL (6.15.33)	Min	Max	Avg	SD
OptimLUM	279.92	545.22	441.72	73.17
Measurements	273.90	713.00	532.55	108.25
DIALux	220.00	480.00	360.63	64.47

LED ALTERNATIVE I (8.18.33)	Min	Max	Avg	SD
OptimLUM	297.67	780.40	518.10	128.26
Measurements	241.40	730.00	495.63	120.87
DIALux	234.00	628.00	418.27	101.28

Fig. 7. Distributions of illuminance values in OptimLUM layout (left) and Alternative I layout (right) for Luminaire with LED

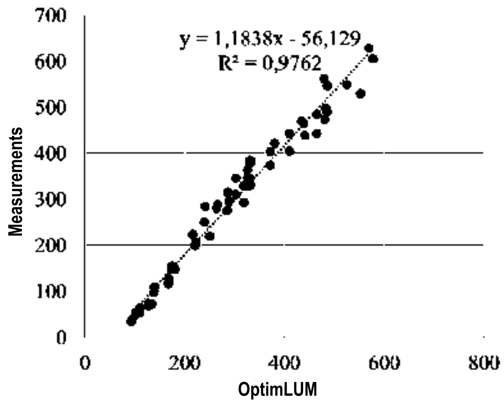


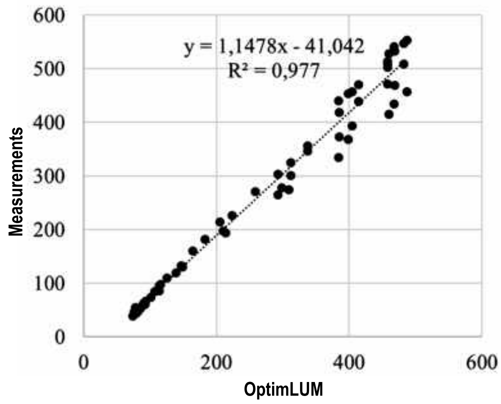


FLUORESCENT ALTERNATIVE II (7.19.32.)	
RMSE	25.95
NRMSE	0.08
CV	0.07

LED MODEL (6.15.33.)	
RMSE	102.90
NRMSE	0.04
CV	0.04

Fig. 8. Statistical analysis in Alternative II layout of Fluorescent and OptimLUM layout of LED





FLUORESCENT ALTERNATIVE I (8.18.)	
RMSE	35.70
NRMSE	0.07
CV	0.12

LED MODEL (6.15.)	
RMSE	34.54
NRMSE	0.08
CV	0.06

Fig. 9. Statistical analysis of double luminaires configuration in Alternative I layout of Fluorescent and OptimLUM layout of LED

tion points, N is the number of calculation points. These error values change between 17.88 lx and 102.90 lx in general. *RMSE* in range ± (17.88–18.40) lx is the least errors similarly obtained from single luminaire configuration by OpitLUM. Although model outputs fit the measurements with the highest R^2, the single LED configuration performs better with the minimum error rate. Normalized root mean square error (*NRMSE*) is another statistical error indicator to evaluate outputs reliability calculated by Eq. (7).

$$NRMSE = \frac{\sqrt{\frac{\sum_{t=1}^{N}\left(o_{1,t} - m_{1,t}\right)^2}{N}}}{o_{max} - o_{min}}, \tag{7}$$

where o_{max} is the maximum illuminance output of OptimLUM and o_{min} is the minimum illuminance output of OptimLUM. Similar and lower NRMSE values (0.04–0.08) for all configurations indicate the consistency of the OptimLUM (Fig. 6,7 and 8).

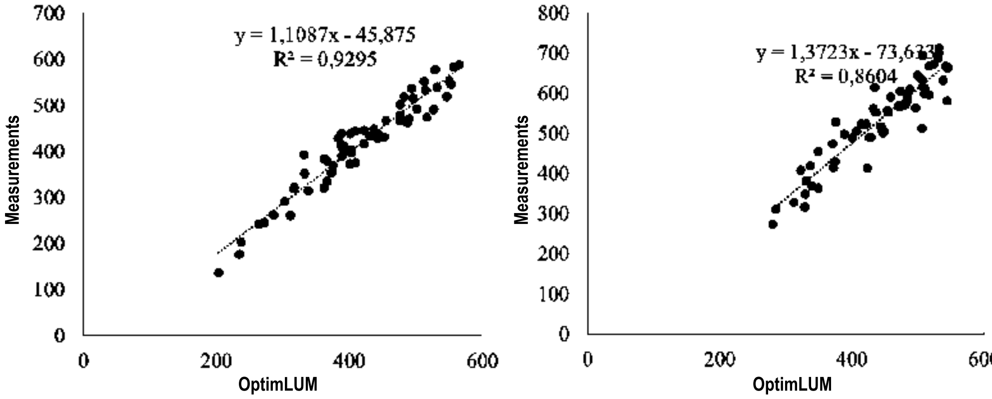
The *CV* (coefficient of variation of root mean square error) is one of statistical indices for determination of the optimization model similarity calculated by given formula (8).

$$CV = \frac{RMSE}{\bar{m}} * 100, \tag{8}$$

where $\bar{m}$ is the sample mean of illuminance measurements. As the *CV* is closer to 0 %, OptimLUM illuminance values are closer to illuminance measurements. *CV* for all scenarios between (4–12)% show the reliability of the model (Figs.6,7 and 8).

Table 2. The E_{avg} and Two Uniformity Results of OptimLUM Estimation layout, Alternative I and II for Luminaires with LED and Fluorescent Lamps

		OptimLUM	Alternative I	Alternative II
LED	E_{avg}	441.72 lx	518.09 lx	491.21 lx
	U (MRD)	0.13	0.21	0.17
	$U\ (E_{min}/E_{avg})$	0.63	0.57	0.45
Fluorescent	E_{avg}	327.83 lx	407.24 lx	387.89 lx
	U (MRD)	0.13	0.21	0.17
	$U\ (E_{min}/E_{avg})$	0.52	0.58	0.49



LED MODEL (6.)	
RMSE	18.40
NRMSE	0.05
CV	0.08

LED ALTERNATIVE I (8.)	
RMSE, лк	17.88
NRMSE	0.05
CV, %	0.08

Fig. 10. Statistical analysis of single luminaires configuration in Alternative I layout and OptimLUM layout of LED

4.2. Validation of Optimization Process

Model aimed to optimize the uniform illumination with an average illuminance based on standards [14]. Comparison between alternative layouts and OptimLUM proposed layout shows that the evolved one by OptimLUM achieved an average illuminance closer to the standards (300–500) lx, while Alternative I for luminaire with LED did not. In addition, regarding uniformity, OptimLUM layout provided better uniformity with 0.13 of MRD for both types of luminaires (Table 2). Since this shows us the minimum deviation, which is close to zero. Additionally, *U=(Emin/Eavg)* is calculated as 0.63 which is the highest among others and closest to the reference uniformity value of 0.8 [14].

5. CONCLUSION

This work presents the development and the validation processes of a new optimization model named OptimLUM to find the optimum position for luminaires providing energy efficient layout and visual comfort requirements. Energy efficient is basing on using the minimum number of luminaires in the best possible layout design, unlike lighting design solutions of DIALux reticulate and symmetrical layouts. This proposed tool is a new alternative approach of applying an optimization model in architectural lighting research. We expect to have a less time consuming, effective and dynamic model for early design phase.

In an actual test case, this new proposed tool was studing by illuminance measurements and simulations. Two different types of luminaires (LED and fluorescent) used for case study. Apart from OptimLUM layout results for two luminaires, two alternative layouts including single and double luminaire configurations were determined. Based on illuminance distributions for all scenarios, OptimLUM outputs are closer to the actual measurements when compared with DIALux outputs. Model outputs present a high accuracy with the illuminance measurements. Considering the validity of the OptimLUM outputs, it can be using by the architect or lighting designer to determine the correct position of the luminaire to avoid unbalanced illuminance distribution while selecting the accurate light source.

REFERENCES

1. Shikder, S. H., Mourshed, M. M., Price, A. D. F., "Luminaire position optimisation using radiance based simulation: a test case of a senior living room," in Proceedings of the International Conference on Computing in Civil and Building Engineering, 2010.

2. Erkin, E. and Onaygil, S. An approach for calculating lighting energy saving potentials in the office buildings on the basis of LENI data // Light & Engineering, 2014. V22, No3, pp. 37–46.

3. Mourshed, M., Shikder, S., Price, A. D.F. Phi-array: A novel method for fitness visualization and decision making in evolutionary design optimization// Advanced Engineering Informatics, 2011.V25, pp. 676–687.

4. Zheltov, V.S., Budak, V.P. Mathematical simulation of lighting installations using a computer, Light & Engineering, 2017. V.25, No.2, pp. 113–120.

5. Cassol, F., Schneider, P. S., França, F. H. R., Silva Neto, A.J. Multi-objective optimization as a new approach to illumination design of interior spaces// Building and Environment, 2011. V46, n# 2, pp. 331–338.

6. Liu, J., Zhang, W., Chu, X., Liu, Y. Fuzzy logic controller for energy savings in a smart LED lighting system considering lighting comfort and daylight// Energy and Buildings, 2016. V127, pp. 95–104.

7. De Rosa, A., Ferraro, V., Igawa, N., Kaliakatsos, D., Marinelli, V., INLUX: A calculation code for daylight illuminance predictions inside buildings and its experimental validation// Building and Environment, 2009. V44, #8, pp. 1769–1775.

8. Rocha, H., Peretta, I. S., Lima, G. F. M., Marques, L. G., Yamanaka, K., Exterior lighting computer-automated design based on multi-criteria parallel evolutionary algorithm: Optimized designs for illumination quality and energy efficiency// Expert Systems with Applications, 2016. V45, pp. 208–222.

9. IESNA (Illuminating Engineering Society of North America IESNA), Lighting handbook reference & application, 2000.

10. Congradac, V., Milosavljevic, B., Velickovic, J., Prebiracevic, B. Control of the lighting system using a genetic algorithm. Thermal Science, 2012. V16, pp. 237–250.

11. CIBSE (Chartered Institution of Building Services Engineers), Code for lightıng, Oxford, Butterworth-Heinemann, 2002.

12. Ferentinos, K. P., Albright, L.D. Optimal design of plant lighting system by genetic algorithms // Engineering Applications of Artificial Intelligence, 2005. V18, #4, pp. 473–484.

13. Palisade Corporation, Evolver. 2013.

14. CIBSE (Chartered Institution of Building Services Engineers), Office Lighting Guide LG7, Society of Light and Lighting, London, 2005.

15. Fontoynont M., Berrutto V. Daylighting performance of buildings: monitoring procedure// Right Light, 1997. V2, # 4, pp. 119–127.

İlknur Erlalelitepe Uygun is Ph.D. student in Department of Architecture at Izmir Institute of Technology. She got her Master's degree from same department in 2012. She is a research assistant in the Department of Architecture in İzmir Institute of Technology, Turkey since 2009. Her research topics are energy performance, architectural lighting and optimization

Tuğçe Kazanasmaz, Prof. Dr., held a Doctor of Philosophy in Building Science from Middle East Technical University (METU). She has 18 years academic experience in architectural lighting, building physics and energy efficient design. At present, she is a Professor in the Department of Architecture in İzmir Institute of Technology, Turkey

Serdar Kale, Prof. Dr., got his Master's degree in Construction Project Management from Heriot-Watt University, Edinburgh, UK, 1994. He held a Doctor of Philosophy in Civil Engineering from Illinois Institute of Technology, Chicago, USA. His research topics are construction management, technology and innovation management, and performance evaluation. At present, he is a Professor in the Department of Architecture in İzmir Institute of Technology, Turkey