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A comparison of the calculations and measurements for a lighting design of the same room

***Abstract**. This work presents a comparative analysis of the results of the lighting parameters (average illuminance and uniformity in the task area) obtained as a result of a computer simulation carried out using DIALux 4.13, and the lighting measurements made using a professional illuminance meter in real circumstances, for the same simple office room. Issues such as the assumption of the proper reflectance values of the main areas, the discretization of photometric .ies file and the influence of the room furnishings on the simulation and measurement results were carefully analyzed. This research allows us to emphasize that the accuracy of the representation of reality by means of a computer simulation of a lighting design using DIALux 4.13 is high, and largely depends on the knowledge, reliability and experience of the lighting designer.*

Streszczenie.** W tej pracy wykonano analizę porównawczą wyników parametrów świetlnych (średniego natężenia oświetlenia i równomierność oświetlenia w polu zadania), uzyskanych w wyniku symulacji przeprowadzonej w programie DIALux 4.13 oraz pomiarów oświetlenia wykonanych za pomocą luksomierza w rzeczywistości, dla tego samego prostego pomieszczenia biurowego. Analizie poddano również kwestie przyjęcia odpowiednich wartości współczynników odbicia głównych powierzchni, próbkowanie pliku fotometrycznego, jak również wpływ wyposażenia pomieszczenia na uzyskane wyniki. Przeprowadzone badania pozwoliły podkreślić, że dokładność odwzorowania rzeczywistości poprzez komputerową symulację oświetlenia w programie DIALux 4.13 jest wysoka i dużym stopniu zależy od wiedzy, rzetelności i doświadczenia osoby projektującej oświetlenie. **(Porównanie obliczeń i pomiarów dla projektu oświetlenia tego samego pomieszczenia)

Keywords: lighting technology, lighting simulations, verification measurements, average horizontal illuminance, uniformity
Słowa kluczowe: technika świetlna, symulacja oświetlenia, pomiary weryfikacyjne, średnie poziome natężenie oświetlenia, równomierność

Introduction

Computer-aided lighting calculations are currently very popular. This is due to the fact that they greatly simplify and speed up the process of lighting design. In addition, a great deal of software is widely available on the internet and in some cases is completely free [1]. Many engineers and even scientists use this free software, which allows the results of the calculation of different photometric parameters for a modelled lighting scene to be obtained, as well as a visualization of the lighting design to be created, which has become a widely-used method nowadays [2-4]. In this case, many calculation assumptions are used, which do not always properly approximate to the reality of a given situation. Such software for lighting design should meet the requirements set out in the report of the International Lighting Commission (CIE), which guarantees the correctness of the performed calculations and the compliance of the simulation with reality [5,6]. This report presents several tests for software validation and (as the research shows), DIALux software is defined as giving, in most cases, reliable results for the calculation of particular lighting quantities [7,8]. However, it would also be worth checking how this software handles those cases occurring in standard design reality.

The lighting design process begins with an analysis of the geometry of the given space intended for lighting and the adoption of the lighting requirements and design assumptions used [9,10]. In the case of interior lighting, the basic standard in Poland is PN-EN 12464-1 [11]. Next, modelling is performed using a computer program, based on data provided by the customer or on one's own geometrical measurements, and a lighting simulation is performed. As a result, the values of the individual lighting environment parameters are obtained and, if they comply with the lighting requirements adopted, the design process ends with the preparation of the appropriate technical documentation, containing data on the types of lighting equipment used and its arrangement.

The design process presented above is very simplified and does not contain all the elements that a professional lighting designer should also pay attention to, which are, amongst other things, the influence of the room geometry and the luminous intensity distribution (LID) of a luminaire on the results of the calculations / measurements, as well as its energy efficiency and user preferences, etc. [12,13]. These issues are very complex and will not be described or analyzed in this work. The presentation of the design process in such a simplistic way was intended to show that, as a result of the design process, certain values of particular lighting parameters are obtained. Some of them, such as the average horizontal illuminance or uniformity, can be verified in reality after the design has been carried out, by means of appropriate measurements, which, in fact, is recommended by lighting standards [11]. During such verification measurements, it may appear that the reality differs significantly from the results of the computer simulation of the lighting design. This work examines the impact of particular factors on the mapping of reality, and then determines the accuracy of simulations relative to reality, based on tests performed in a simple office room [14]. These analyses, as well as their conclusion, may be useful for people who are just starting studies in lighting technology, or whose work involves the design of lighting or lighting design, but so far, have never had the opportunity to carry out verification measurements on their designs.

Room characteristics

The room being used as the basis for the analysis performed has dimensions as shown in Figure 1. It is an office room, with a height of 3.5 m. The luminaires are installed directly on the ceiling of the room and provide direct lighting. Therefore, in accordance with the requirements of EN12464-1, the following lighting requirements were adopted relating to the level of average horizontal illuminance – min. 500lx, uniformity – min. 0.60, UGR –max. 19 and CRI – min. 80. In this experiment, it was decided to focus on analyzing the results of average horizontal illuminance and uniformity. Glare issues are qualified as difficult to measure [15], and are not discussed. However, calculations using DIALux 4.13 show that, in all cases, the UGR parameter is less than 19, which is in accordance with the normative recommendations for this type of room. In addition, the normative requirement relating to the issue of color rendering was also met. The luminaires used were linear fluorescent lamps, which had a colour-rendering index of min. 80 [16].

Lighting equipment and measurement instrumentation

Four direct, raster luminaires, with 18W linear fluorescent lamps, were used in the room. New lamps were installed in each luminaire, which were subjected to operating for 100 hours before the performance of laboratory and illuminance measurements [17,18]. Based on laboratory measurements, it was determined that the total luminous flux of the light sources in each luminaire was 5325 lm, and its light output ration (LOR) was 67%. The luminous intensity distribution (LID) was classified as axially symmetrical to the luminaire and was measured by using a classical goniophotometer method [19]. Measurements were made for sampling on C planes using a 15° step (7 planes), while for gamma angles a 2.5° step was used. The appearance of the lighting fixture used in the room and its lightness curve for planes C0 and C90, obtained on the basis of these measurements, are shown in fig. 4.

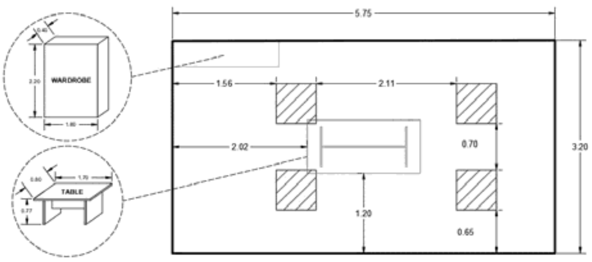

Fig. 1. The main dimensions of the room analyzed and the arrangement of luminaires and furniture

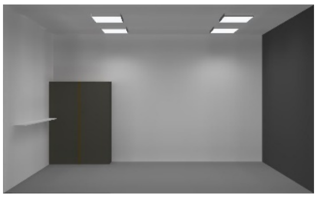

Fig. 2. Visualization of lighting design in the room analyzed (empty)

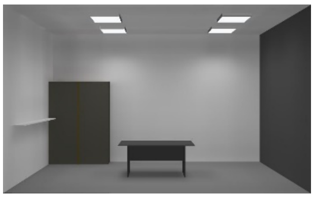

Fig. 3. Visualization of lighting design in the room analyzed (with a table)

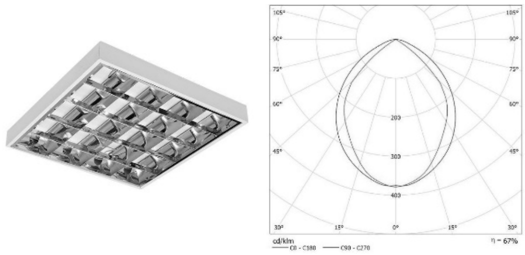

Fig. 4. Appearance of the luminaire used and its luminous intensity curve obtained from the laboratory measurements

An LMT Pocket Lux 2 illuminance meter (class B) was used to measure the horizontal illuminance of the interior [21]. Measurements were made on a working plane, placed at a height of h = 0.8m. The reflectance values of the main surfaces were determined using the assumption that they are characterized by diffusion reflection, which means that there is a relationship between illuminance and luminance, according to the relationship: L=ρE/π [20]. Measurements of illuminance and luminance were made at several of the same points, and then the average values of reflection coefficients of the main surfaces were determined. To perform luminance measurements, a Konica-Minolta LS-100 luminance meter [22] was used, as well as the LMT illuminance meter mentioned before. As a result of these measurements, it was determined that the reflectance values of the main surfaces of the room were as follows: ceiling and walls - 0.83, floor - 0.28, wood from which the table and wardrobes were made (one wall of the room consisted of a wardrobe) - 0.15.

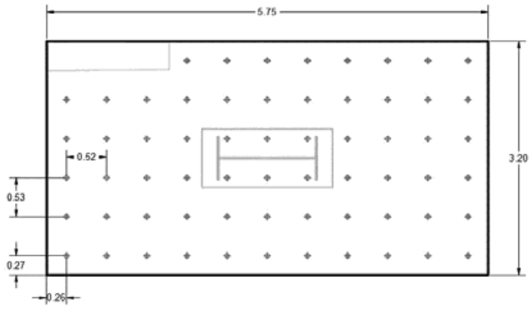

Fig. 5. Arrangement of points of the illuminance grid in the room analyzed

Table 1. Sets of reflectance values used for the analysis

Set	Ceiling	Floor	Walls	Furniture
A (assumption)	0.70	0.50	0.20	0.30
B (assumption)	0.50	0.30	0.20	0.30
C (measured)	0.83	0.83	0.28	0.15

Assumptions for simulations and measurements

Based on the formula specified in the EN-12464-1 standard, it was determined that the mesh of the measuring and computing grid would be 0.5m [11]. Therefore, measurements and calculations were made for a 6 x 11 points grid (fig. 5).

Calculations and measurements were made at a height of 0.8 m and for three different sets of reflectance values of the main surfaces (Table 1) and using two different tools available in DIALux 4.13 - the calculation surface and the calculation grid. Two cases were analyzed: an empty room, and a room with a table in the middle of the room (fig. 2 and 3). In addition, simulation calculations were made for various samplings of the LID described in the .ies photometric file, for the following cases:

- two planes C, sampling at gamma angles of 10°
- two planes C, sampling at gamma angles of 2,5°
- seven planes C, sampling at gamma angles of 10°
- seven planes C, sampling at gamma angles of 2,5°

In order to obtain the results for the initial time moment of the lighting system, the maintenance factor was assumed to be: MF = 1.0. The average value of horizontal illuminance was determined according to the formula (1), while the uniformity was determined according to the formula (2).

(1) $$E_{avg} = \frac{\sum_{i=1}^{n} E_i}{n} [lx]$$

(2) $$U_0 = \frac{E_{\min}}{E_{avg}} [lx]$$

where: E_{avg} – average horizontal illuminance[lx]; E_i– value of horizontal illuminance for the i-th point of the calculation or measurement grid [lx]; E_{min}– minimum value of horizontal illuminance[lx]; U_0– uniformity [-]

In order to analyze the results of the measurements, a formula was used which made it possible to compare the computer simulation results to those results obtained by measurement. Formulas (3) and (4) determine the relative errors of average horizontal illuminance and uniformity of illumination. It is worth noting that the absolute value of these errors was not specified. According to this operation, negative values indicate that the result obtained as a result of the lighting simulation is smaller than the value obtained by measurement.

(1) $$\delta_E = \frac{E_m - E_s}{E_m} \cdot 100\%$$

(2) $$\delta_{U0} = \frac{U_{0m} - U_{0s}}{U_{0m}} \cdot 100\%$$

where: δ_E – relative error of illuminance [%]; E_m – average horizontal illuminance based on measurements[lx]; E_s – average horizontal illuminance based on simulations [lx]; δ_{U0} – relative error of uniformity [%]; U_{0m} – uniformity based on measurements [–]; U_{0s} – uniformity based on simulations.

Results and discussion

Table 2 presents the results of the calculations of the average horizontal illuminance level and uniformity obtained on the basis of measurements taken in a real room, using an illuminance meter. Consequently, it is worth noting that the results of the measurements in the room meet the requirements of the interior lighting standard for the average level of horizontal illuminance on the task, (being 607 lx > 500 lx), but do not meet the requirements relating to uniformity (0.56 < 0.60). This can only be stated for the time being, because a maintenance system was not adopted in the calculations, which would be crucial for the further analysis of the results. However, it can additionally be stated that, with the use of appropriate maintenance activities (e.g. periodic replacement of light sources) the lighting system of this room would function properly.

Table 2. Results of measurements of average horizontal illuminance and uniformity

Variant	*h [m]*	*E_m [lx]*	*U_{0s} [-]*
Empty room	0.80	607	0.56
Room with a table		593	0.56

Table 3 presents the values of average horizontal illuminance and uniformity obtained as a result of the computer simulation. It should be noted that the values of illuminance and uniformity obtained differed slightly, depending on the calculation tool used from the DIALux 4.13 program. Lower values were usually obtained for the calculation grid, which may affect the positive verification of the implemented design. Unfortunately, it is difficult to find out what these differences arose from. The computational algorithms of the program are unknown, but lighting designers should be aware of the potential differences when using these different tools. The highest results were obtained for a set of reflectance values of the main surfaces, adopted on the basis of measurements (C). This is understandable because set (C) contains the highest reflectance values for the reflectance of the ceiling and walls. It also causes much more luminous flux from the luminaires to reach the task area, which results in higher values for the uniformity of lighting. In this case, when using the surface calculation tool, it appears that the normative requirements related to the uniformity of lighting are met. Therefore, the adoption of reflectance values for a given room, which are measured and not assumed (as in the case of typical values for sets A and B), positively affects the accuracy of mapping reality using simulation software. It is also worth paying attention to the issue of sampling of the LID described by the photometric file of the luminaires used. Although the differences are small (in the order of a few lux), it is necessary to formulate calculations only for well- and densely-photometered luminaires. Otherwise, the simulation errors could be much larger, which could negatively affect the verification of the lighting design performed using such measurements.

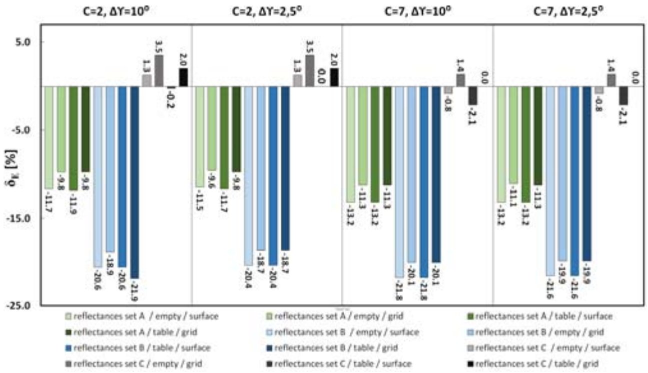

Fig. 6. Relative differences between the illuminance values obtained as a result of measurements and those values generated using Dialux 4.13

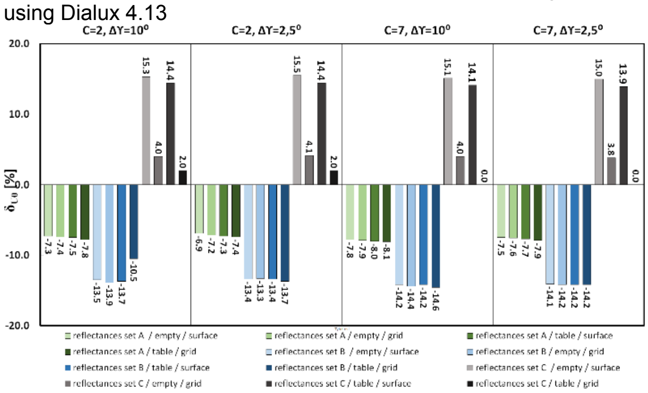

Fig. 7. Relative differences between the uniformity values obtained as a result of measurements and those values generated using Dialux 4.13

Table 3. Results of computer calculations of average horizontal illuminance and uniformity

h [m]	Reflectances	Variant	Tool	Sampling of the photometric file (.ies)							
				C=2 / ΔY=10°		C=2 / ΔY=2.5°		C=7 / ΔY=10°		C=7 / ΔY=2.5°	
				E_s [lx]	U_{0s}[-]	E_s [lx]	U_{0s}[-]	E_s [lx]	U_{0s}[-]	E_s [lx]	U_{0s}[-]
0,8	(A) 70/50/20/30	Empty	Surface	536	0.52	537	0.52	527	0.52	527	0.52
			Grid	535	0.51	536	0.52	526	0.51	527	0.51
		Table	Surface	535	0.52	536	0.52	527	0.53	527	0.52
			Grid	535	0.51	535	0.51	526	0.51	526	0.51
	(B) 50/30/20/30	Empty	Surface	482	0.49	483	0.49	475	0.48	476	0.48
			Grid	481	0.48	482	0.48	474	0.48	475	0.48
		Table	Surface	482	0.49	483	0.49	475	0.48	476	0.48
			Grid	463	0.50	482	0.48	474	0.47	475	0.48
	(C) 83/83/28/15	Empty	Surface	615	0.65	615	0.65	602	0.65	602	0.65
			Grid	614	0.58	614	0.58	601	0.58	601	0.58
		Table	Surface	606	0.64	607	0.64	594	0.64	594	0.64
			Grid	605	0.58	605	0.58	593	0.58	593	0.57

The presence of a table in the room actually reduces the level of lighting, which can be seen both from the results of measurements (table 2) and those of lighting simulations (table 3). However, contrary to expectations, these results are relatively similar - differences being at the level of individual lux at average horizontal illuminance, and hundredths of lux in the case of uniformity. This is probably due to the relatively small dimensions of the table. In the case of the greater complexity of the geometry or equipment in the room, this difference would probably be greater. Therefore, it is recommended that simulation calculations, using the best representation of the illuminated space, be performed.

Figures 6 and 7 present the results of the relative errors of the values of the individual parameters obtained as a result of the computer simulation, in comparison to the values of the parameters obtained as a result of measurements in a real room. It is noteworthy that, in the vast majority of cases (75%), negative relative error values were obtained. This means that the value obtained as a result of measurements is greater than that obtained as a result of the computer simulation of the lighting design. For the cases of assumed reflectance values (set A and set B), this error ranges from approx. -8% to over -22% for both average horizontal illuminance and uniformity. The simulation program used lowers the results obtained in comparison to the reality. On the one hand, this is an advantage, because the lighting designer can be more certain that the lighting design will meet specific normative requirements (in the case of simple rooms). On the other hand, one should be careful about the best representation of reality in the simulation program. It seems that such an underestimation can cause an oversizing of illuminance in reality and, as a result, greater, unnecessary consumption of electrical energy. This problem also exists for the measured reflectance values of the main surfaces (set C). In this case, there is usually an overestimation of the results, except that this is much smaller for the parameter of average horizontal illuminance (up to approx. 4%) than is the case for uniformity (even up to approx. 15%). Finally, it should be emphasized that the measurement results obtained and their analysis should be treated as general observations, rather than a restrictive design indicator. This is because the case analyzed is just one of the infinite number of cases that could occur in a lighting design reality. In addition, only one of the many programs for computer-aided lighting calculation was used for this analysis. Nevertheless, attention should be paid to this and lighting designs should be performed using good judgment and great experience.

Conclusion

This paper presents the results of a comparison of computer simulations and actual measurements of the lighting of the same simple office room. It was determined that lighting design simulation (in this case using DIALux 4.13) can be reliable. However, there are many factors that can cause it not to be reliable. These include issues of the reflectance values adopted, issues of room geometry complexity, issues of luminaire photometry and the performance of a photometric file. Therefore, it seems that the only guarantee of a lighting simulation that it is consistent with reality is the knowledge, experience and reliability of the lighting designer. Unfortunately, as is shown by design practice, in most cases the lighting designer is not able to verify his/her own design by means of measurements, be it due to workload, lack of time or measurement possibilities. Nevertheless, it is recommended that every person involved in the lighting design process should perform a verification measurement of their design at least once. This would certainly result in a greater design awareness and the better performance of lighting simulations and implementations in the future.

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