# Measurement of surfaces according to the requirements of EN 12464-1

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## Abstract

At preparing of the lighting project is necessary to respect some normative requirements regarding with qualitative and quantitative parameters of light. According to these standards is necessary to design project properly to create appropriate lighting conditions for people who are staying in the workplaces. In 2011 was released by CEN 169 Workgroup 2 new version of standard EN 12646-1:2011 for indoor workplaces which replaced older version. There are implemented new requirements for photometric parameters in the workplaces which were not before. One of this new requirement is that people who are doing lighting projects should also consider properly photometric parameters of surfaces other than on task areas i.e. illumination of walls and ceiling. This paper describes work has done about measurement of these surfaces and presents preliminary results have performed measurements in the field. At the end of paper analysis of the possible errors and expression of the expanded uncertainty (for 95% confidence interval) of the measurement has been expressed for quantification how reliable measurement was performed.

*Keywords*: Indoor workplaces, Lighting project, Lighting simulation tool, Field trial

## Introduction

Due to unexpected errors in the lighting design to remove them can be too costly. Therefore designs should be made as good as possible to avoid these problems. After realisation of the lighting design appears another problem emerges how to verify photometric quanities of the lighting system in the workplace whether project was carried out properly or not. It influences health, performance and also well-being of persons present in workplaces. Verification of illuminance level at visual task level, surfaces in workplace i.e. walls and ceilings should be measured by field measurement. In Slovakia after realisation of lighting project is necessary to verify real photometric parameters by field measurement. It is necessary for allowance of owner of the building for permission of usage of the building from Public Health Authority in Slovakia.

**Figure 1 – Example of corridors with downlights on ceiling**

Practically it is sometimes difficult to measure illuminances of surfaces due to accessibility. For people who are doing lighting designs is difficult to achieve these illuminances in their lighting projects because for example for corridors it is necessary to have maintained illuminance level above 50 lx on the ceiling while normative condition for visual task area is 100 lx. It is very hard to achieve especially downlights are used in the corridors what can be seen on Figure 1. Illuminance level about 50 lx at the ceiling can not be achieved just by reflections from floor and walls. On Figure 1 it can be seen obvious contrasts between surfaces. Required maintained illuminance level according to EN standard for indoor workplaces is as follows:

$$\boldsymbol{E_m} > 30 \text{ lx – ceilings with uniformity } \boldsymbol{U_0} \geq 0{,}1 \tag{1}$$
$$\boldsymbol{E_m} > 50 \text{ lx – walls with uniformity } \boldsymbol{U_0} \geq 0{,}1$$

In some enclosed places such as offices, education, health care and general as entrance, corridors, stairs etc. should be walls and ceiling brighter and maintained illuminance level should be as follows:

$$\boldsymbol{E_m} > 50 \text{ lx – ceilings with uniformity } \boldsymbol{U_0} \geq 0{,}1 \tag{2}$$
$$\boldsymbol{E_m} > 75\text{lx – walls with uniformity } \boldsymbol{U_0} \geq 0{,}1$$

Measurements presented below were offices and laboratory places i.e. they should follow second condition (2) of EN standard. This paper concerns quantification of the differences between computed parameters in the lighting project proposal and the reality i.e. measured parameters by the stated procedure to respect requirements of the standard EN 12464-1:2011. Simultaneously work has been done for comparison of the lighting design performed by means of lighting simulation software before measurement what is very important information for people who are doing lighting designs. Paper brings results of first measurements of surfaces performed on four chosen already carried out indoor lighting designs with different luminaires. Investigation of accuracy of the measurement has been done with the vision what should be done in the future.

## Investigated indoor workplaces

Four places were chosen for investigation about illumination of surfaces in indoor workplaces. Three of them were offices and one was laboratory room were also brightener condition for people. In investigated rooms was installed different type of luminaires to compare influence of type of luminaire to the illumination of workplace surfaces. Before beginning of measurement was made simulation by two simulation software RELUX and DIALUX to see how computed values reflect real lighting conditions. However, from results of simulation it can be seen also reliability of very often used software for same geometry and input parameters. Reflectances of surfaces of each investigated room was measured before measurement with assumption that each surface is Lambertian i.e. follow formula

$$\rho = \frac{L_V . \pi}{E_V} \tag{3}$$

where

$L_V$ is the luminance emerging from surface element in cd.m$^{-2}$;
$E_V$ is the illuminance falling on the surface element in lx;

Transmittance of windows for each room was roughly estimated. Number and layout of measurement points in measurement grid corresponded with lighting design of each investigated workplace. Measurement and investigation of illuminance level was made only on the surfaces and measured values were compared to the computed values. Installed luminaires into rooms mostly covers usual used type of luminaires in offices or laboratories i.e. luminaires with grid with downward flux, luminaires with diffusors at the bottom and at the side of luminaires, luminaires with downward and upward flux for indirect illumination and typical square luminaires with grid mounted directly into the ceiling. Luminous intensity of each luminaire can be seen for each lighting design at computation of photometric parameters by lighting simulation software. Layout of investigated rooms with luminous intensity distribution of luminaires is depicted on Figure 2 to Figure 5. Measurement of illuminance on surfaces was performed by means of “L” shape holder where at the end of holder was mounted photometric head of illuminance meter. Holder was constructed to not shade of photometer head and thus it does not influence measured values. Also holder was sufficiently long to avoid impact of user of illuminance meter to influence results. Results of measurement and comparison of results with light simulation tools are presented in next section.

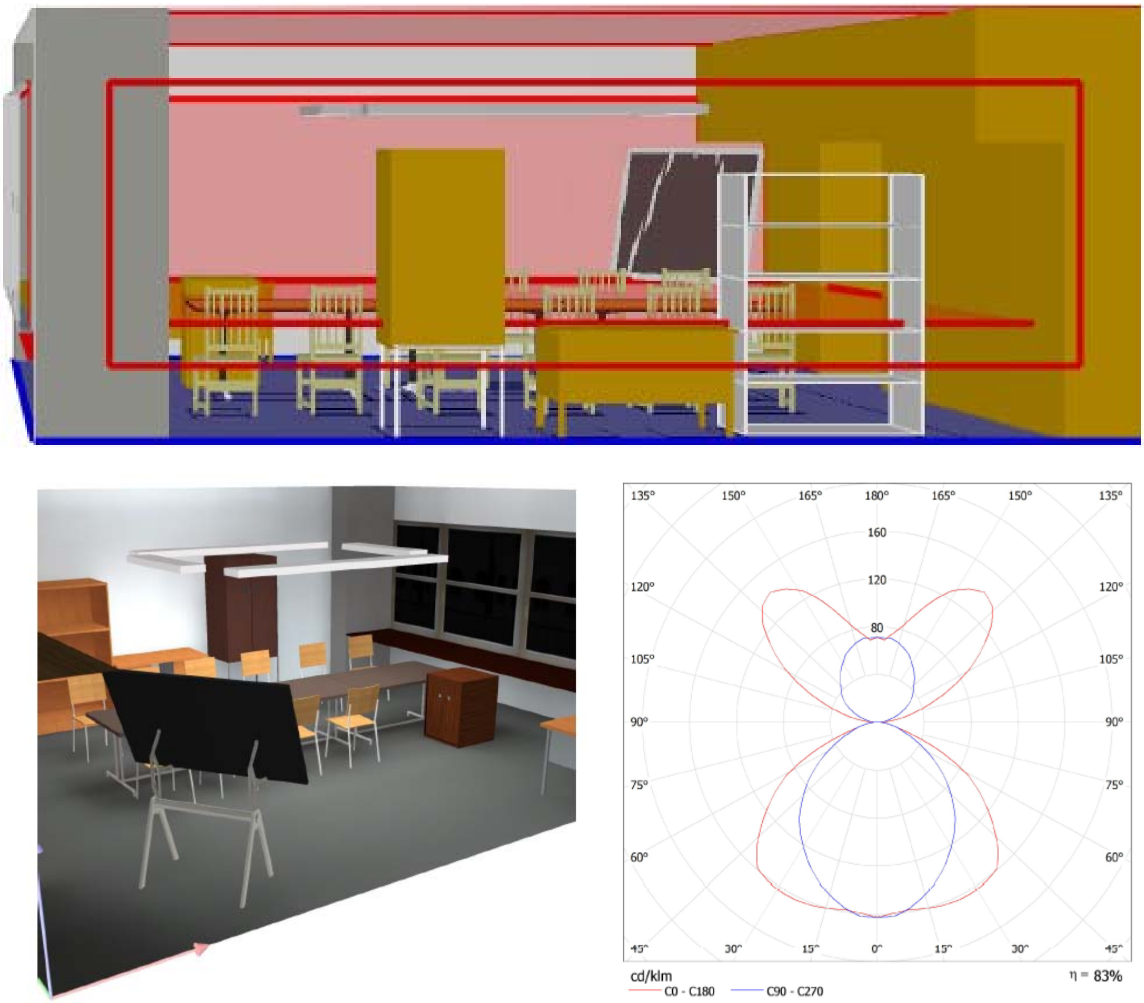



**Figure 2 – Room 1 - luminaires with downward/upward flux component**

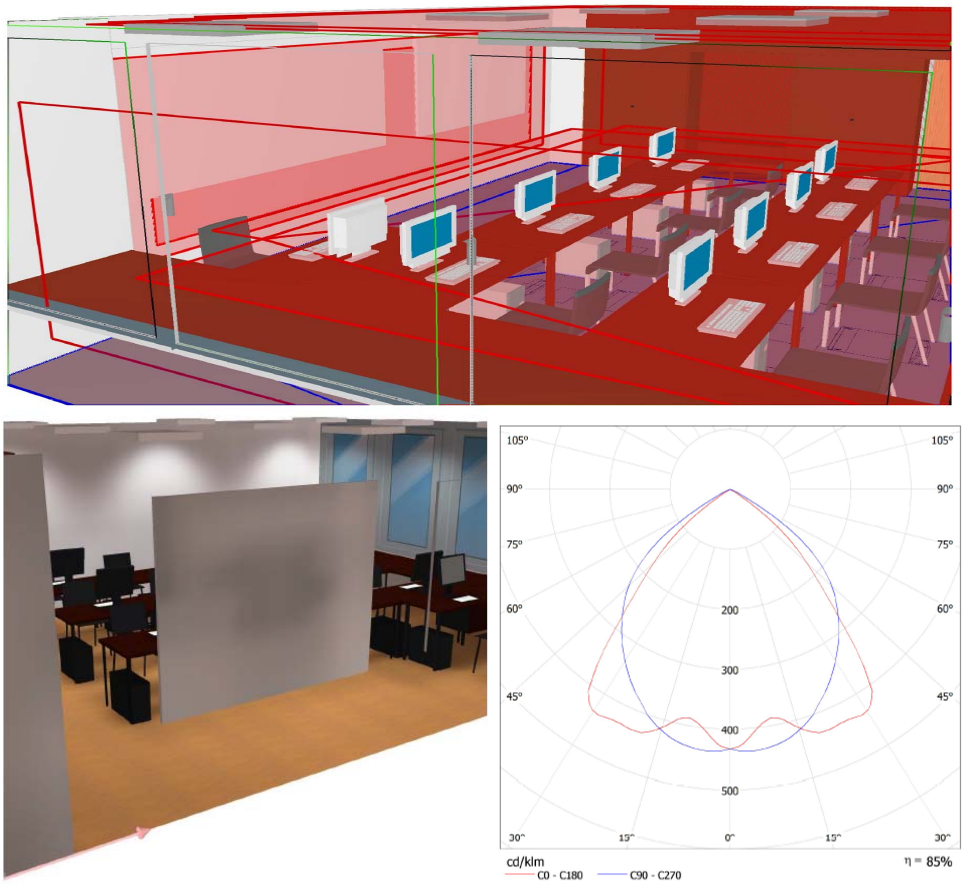



**Figure 3 – Room 2 - luminaires mounted into ceiling**

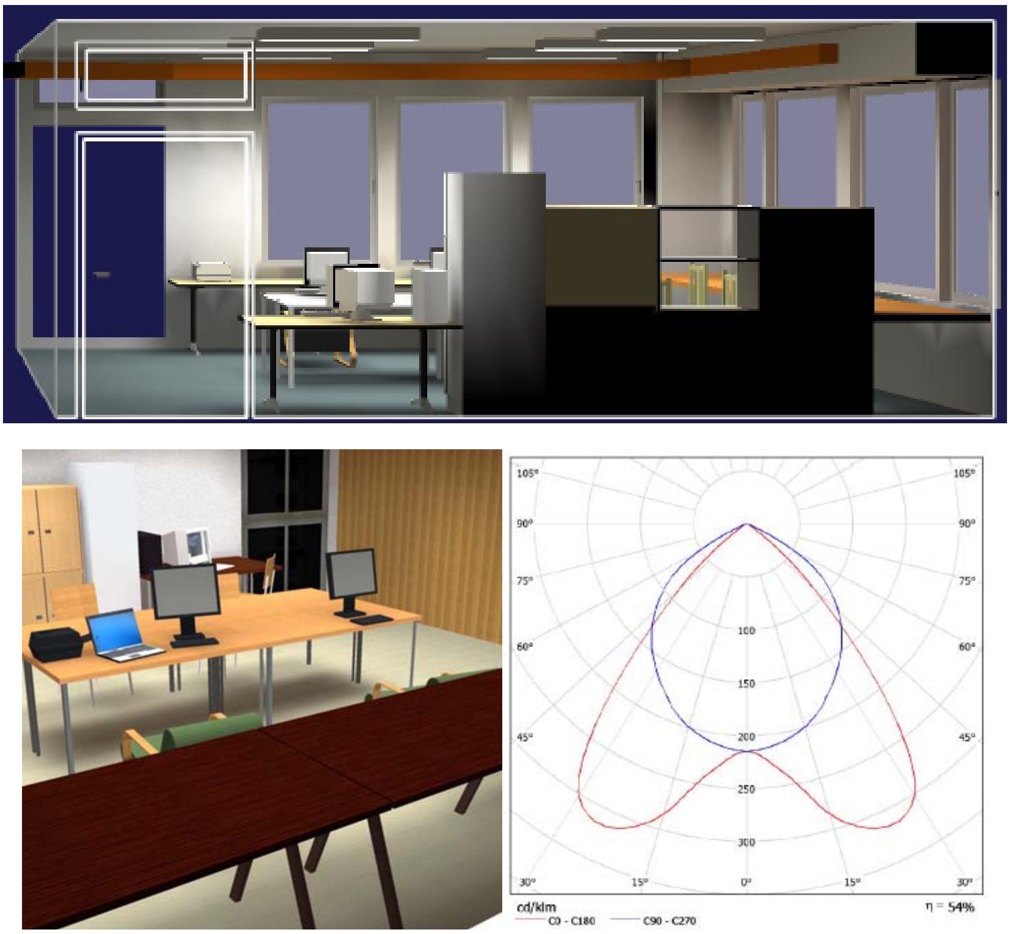



**Figure 4 – Room 3 - luminaires with grid / downward flux component**

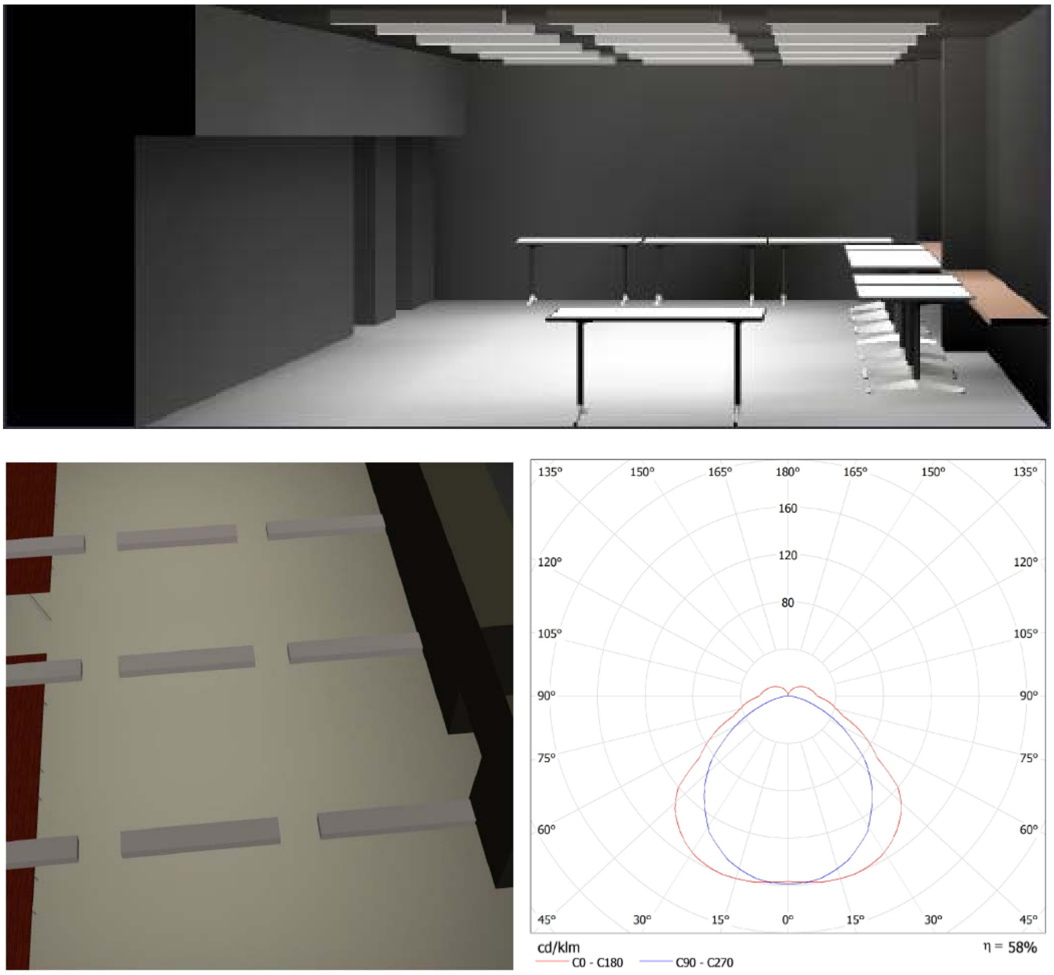



**Figure 5 – Room 4 – laboratory room with installed luminaires with diffusor**

## Results

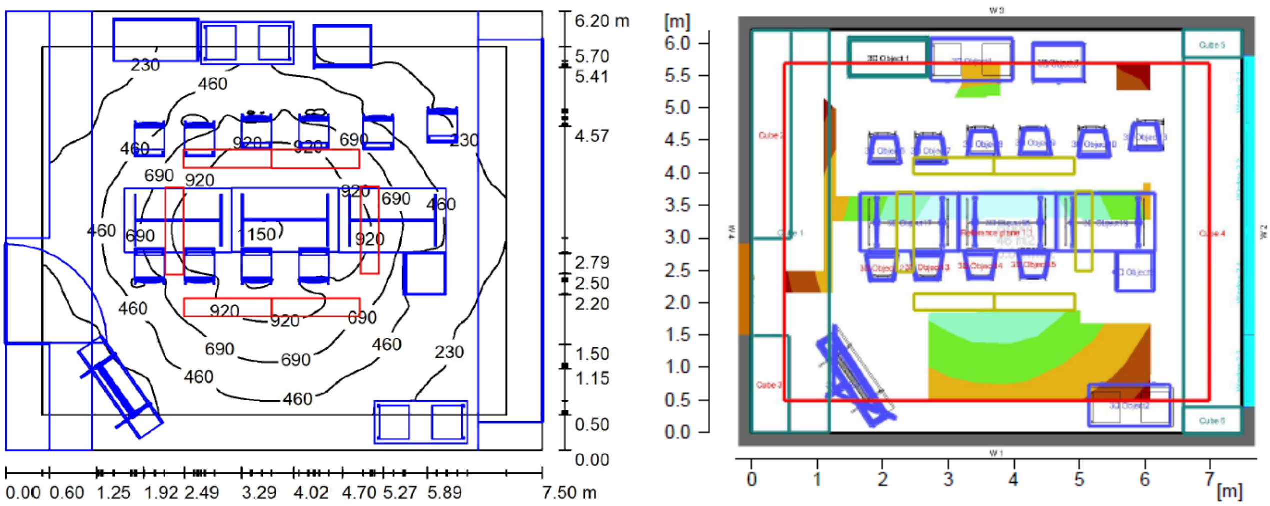
On the Table 1 it can be seen results of measurement of investigated rooms. Field trial was performed by illuminance meter classified in accordance DIN 5032-7. Measurement of reflectance of surfaces in the rooms was done by luminance meter MINOLTA LS-100 and illuminance meter. Reflectance of surfaces was stated by using formula (3). For distance measurement was used laser distance meter. All instruments were properly calibrated with traceability to national standards. Used instruments are shown on picture Figure 6. Maintanance factor of each room and also at simulation was assumed as 0,80.


**Figure 6 – Used instruments at the measurement**

| Room | $\overline{E}_m$ (lx) *Walls* | $\overline{E}_m$ (lx) *Ceiling* | $U_0$ *Walls* | $U_0$ *Ceiling* |
|---|---|---|---|---|
| **Room 1** | 63,2 | 150,0 | 0,10 | 0,23 |
| **Room 2** | 160,9 | 106,6 | 0,39 | 0,79 |
| **Room 3** | 120,3 | 85,7 | 0,19 | 0,22 |
| **Room 4** | 130,5 | 43,6 | 0,10 | 0,17 |

**Table 1 – Results of field trial**

On pictures Figure 7 to Figure 10 are shown results from simulations in light simulation tools DIALUX and RELUX.



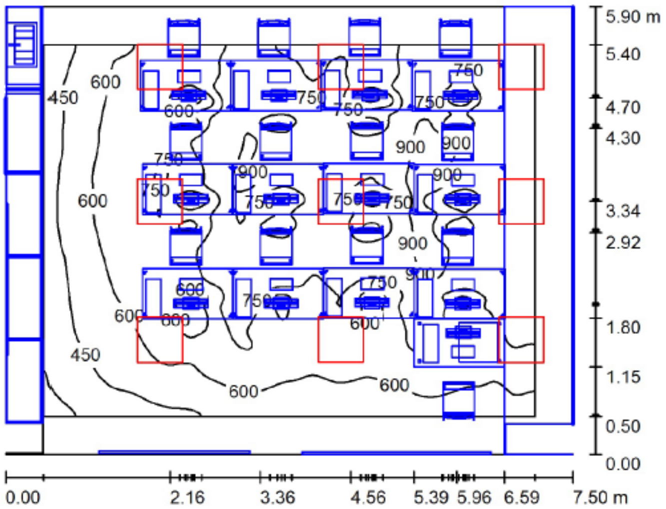

**DIALUX - Results**

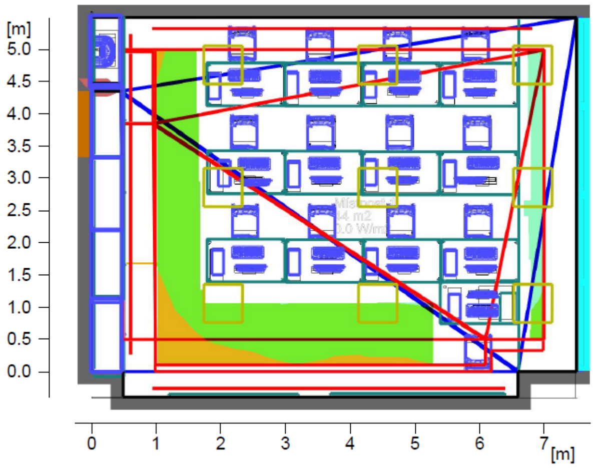
| Surface | ρ [%] | $E_m$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | $E_{min}$ / $E_m$ |
|---|---|---|---|---|---|
| Workplane | / | 521 | 27 | 1155 | 0.052 |
| Floor | 18 | 223 | 16 | 666 | 0.073 |
| Ceiling | 70 | 286 | 8.55 | 1147 | 0.030 |
| Walls | 59 | 67 | 5.23 | 286 | / |

**RELUX - Results**

| **Major surfaces** | Em | Uo |
|---|---|---|
| m 1.5 (Ceiling) | 501 lx | 0.17 |
| m 1.1 (Wall) | 200 lx | 0.38 |
| m 1.2 (Wall) | 117 lx | 0.05 |
| m 1.3 (Wall) | 110 lx | 0.01 |
| m 1.4 (Wall) | 25 lx | --- |

**Figure 7 – Results of simulation – Room 1 – DIALUX and RELUX**





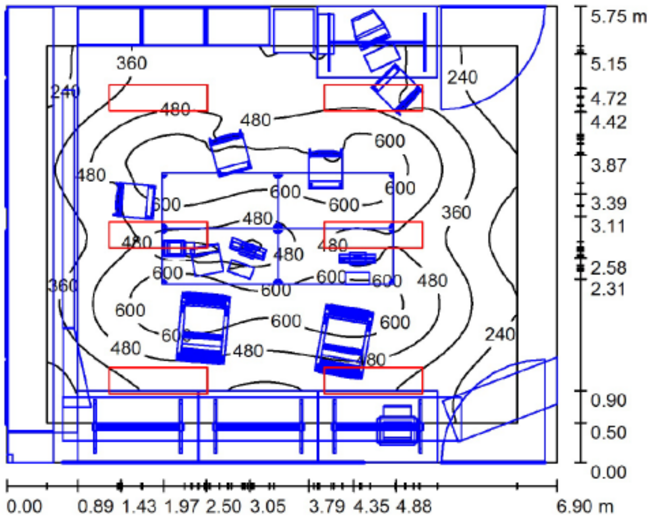
**DIALUX - Results**

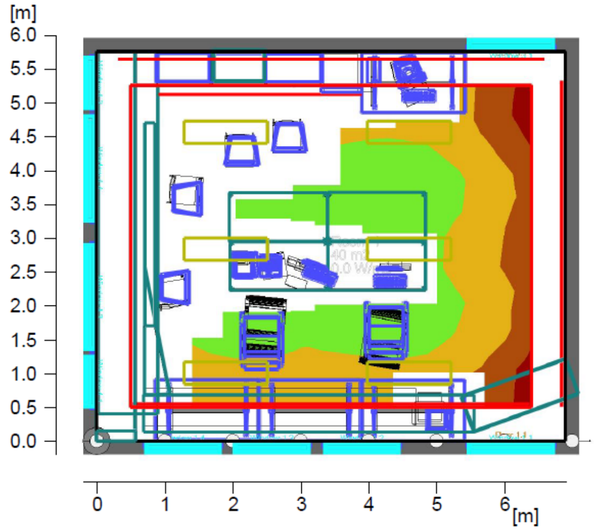
| Surface | ρ [%] | $E_m$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | $E_{min}$ / $E_m$ |
|---|---|---|---|---|---|
| Workplane | / | 692 | 245 | 979 | 0.354 |
| Floor | 42 | 266 | 27 | 585 | 0.103 |
| Ceiling | 70 | 131 | 35 | 240 | 0.265 |
| Walls | 85 | 171 | 1.41 | 769 | / |

**RELUX - Results**

| Major surfaces | Em | Uo |
|---|---|---|
| m 1.5 (Ceiling) | 156 lx | 0.77 |
| m 1.1 (Wall) | 111 lx | 0.00 |
| m 1.2 (Wall) | 517 lx | 0.48 |
| m 1.3 (Wall) | 337 lx | 0.18 |
| m 1.4 (Wall) | 0 lx | --- |

**Figure 8 – Results of simulation – Room 2 – DIALUX and RELUX**





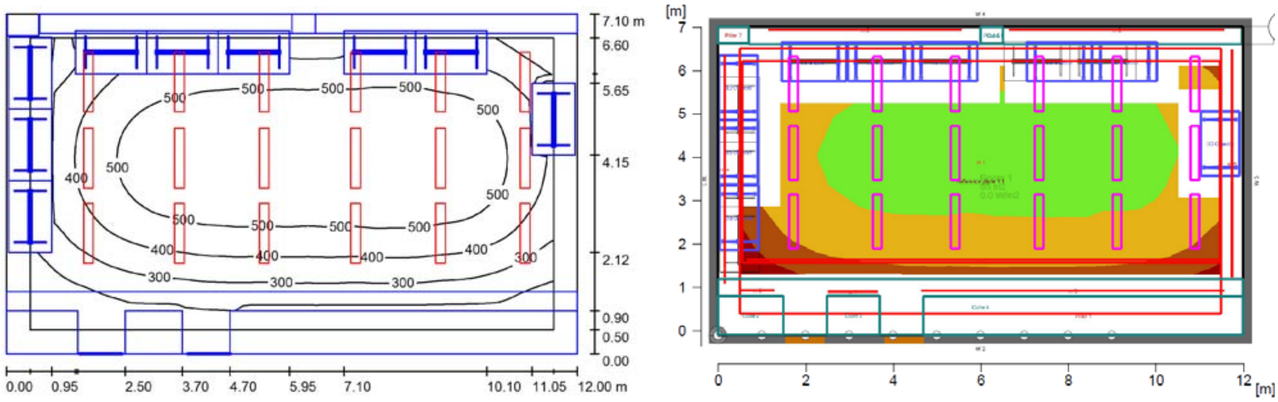
## DIALUX - Results

| Surface | ρ [%] | $E_m$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | $E_{min}$ / $E_m$ |
|---|---|---|---|---|---|
| Workplane | / | 446 | 136 | 693 | 0.306 |
| Floor | 18 | 193 | 6.26 | 453 | 0.032 |
| Ceiling | 68 | 36 | 9.56 | 59 | 0.265 |
| Walls | 48 | 56 | 4.34 | 265 | / |

## RELUX - Results

| Major surfaces | Em | Uo |
|---|---|---|
| m 1.5 (Ceiling) | 92 lx | 0.24 |
| m 1.1 (Wall) | 214 lx | 0.20 |
| m 1.2 (Wall) | 124 lx | 0.55 |
| m 1.3 (Wall) | 115 lx | --- |
| m 1.4 (Wall) | 151 lx | 0.15 |

**Figure 9 – Results of simulation – Room 3 – DIALUX and RELUX**




**DIALUX - Results**

| Plocha | ρ [%] | $E_m$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | $E_{min}$ / $E_m$ |
|---|---|---|---|---|---|
| Workplane | / | 433 | 108 | 600 | 0.249 |
| Floor | 16 | 313 | 66 | 508 | 0.210 |
| Ceiling | 3 | 88 | 16 | 817 | 0.185 |
| Walls | 4 | 152 | 40 | 350 | / |

**RELUX - Results**

| Major surfaces | Em | Uo |
|---|---|---|
| m 1.5 (Ceiling) | 109 lx | 0.42 |
| m 1.1 (Wall) | 192 lx | 0.04 |
| m 1.2 (Wall) | 5 lx | --- |
| m 1.3 (Wall) | 264 lx | 0.40 |
| m 1.4 (Wall) | 225 lx | --- |

**Figure 10 – Results of simulation – Room 4 – DIALUX and RELUX**

### Uncertainty of measurement

Relative expanded uncertainty ($k$=2) of maintained illuminance level $\overline{E}_{\mathrm{m}}$ assuming normal distribution was estimated on $U$ = 9,2 %. Uncertainty budget is shown on Table 2. At the estimation of measurement uncertainty were assumed uncertainties of all the most important parameters which could significant influence result of measurement with illuminance meter

- cosine error
- linearity
- fatigue of the photometer head
- spectral error of illuminance meter
- error of placement of photometer head
- deviation of photometer head from horizontal plane

- number of measurement points
- repeatability

Expanded uncertainty ($k$=2) of uniformity of illuminance in the room $U_0$ was estimated and calculated from equation (4) on $U$ = 0,05 assuming normal distribution and including covariance between maintained illuminance level and minimum illuminance level in the room. Both uncertainties was stated according to BIPM GUM publication.

| ***$x_i$*** ***contribution*** | ***distribution*** | ***Luxmeter Class A $u_{rel}$ / %*** |
|---|---|---|
| *Linearity* | normal | 2,2 |
| *Spectral error* | rectangular | 1,2 |
| *Cosine error* | rectangular | 0,75 |
| *Fatigue* | rectangular | 0,03 |
| *Resolution* | normal | 0,03 |
| *Drift from last calibration* | Rectangular | 0,8 |
| *Height of illuminance head* | Normal | 0,2 |
| *Error of placement of photometer head* | Rectangular | 0,7 |
| *Error of number measurement points* | Rectangular | 2,0 |
| *Deviation of photometer head from horizontal plane* | Rectangular | 0,7 |
| *Error of illuminance grid* | Rectangular | 2,7 |
| *Others* | Rectangular | 1 |
| *Repeatability* | Normal | 0,5 |
| ***$u_c$*** | | 4,6 |
| ***$U$ ($k$ = 2)*** | | **9,2** |

**Table 2 – Uncertainty budget of measurement**

For more details about uncertainty analysis for dfferent illuminance meters please refer paper [9].

## Conclusion

All results from lighting simulation tools and field trials in the rooms are summarized on the Table 3. From results can be seen non conformity between maintained illuminance level of ceiling, maintained illuminance level of wall and uniformity for both surfaces as well. In standard [4] it is not clarified how to people who do lighting designs should verificate computed values e.g. lighting simulation tools. Therefore average maintained illuminance level for walls was stated as arithmetic mean value from each wall and uniformity for walls stated assumed all walls in the room as one surface. Therefore it follows formula

$$U_0 = \frac{E_{\min}}{\overline{E}_{\mathrm{m}}} \quad (4)$$

where

$E_{min}$ is the illuminance of i-th measurement point of walls in lx;

$\overline{E}_{\mathrm{m}}$ is the maintained illuminance level of the walls in lx;

**FIELD TRIAL** / **DIALUX**

| Room | $\overline{E}_{\mathrm{m}}$ (lx) ***Walls*** | $\overline{E}_{\mathrm{m}}$ (lx) ***Ceiling*** | $U_0$ ***Walls*** | $U_0$ ***Ceiling*** | Room | $\overline{E}_{\mathrm{m}}$ (lx) ***Walls*** | $\overline{E}_{\mathrm{m}}$ (lx) ***Ceiling*** | $U_0$ ***Walls*** | $U_0$ ***Ceiling*** |
|---|---|---|---|---|---|---|---|---|---|
| **Room 1** | 60,1 | 150 | 0,1 | 0,23 | **Room 1** | 67 | 286 | *** | 0,03 |
| **Room 2** | 160,9 | 106,6 | 0,39 | 0,79 | **Room 2** | 171 | 131 | *** | 0,27 |
| **Room 3** | 120,3 | 85,7 | 0,19 | 0,22 | **Room 3** | 56 | 36 | *** | 0,27 |
| **Room 4** | 130,5 | 43,6 | 0,1 | 0,17 | **Room 4** | 152 | 88 | *** | 0,19 |

**RELUX**

| Room | (lx) ***Walls*** | (lx) ***Ceiling*** | $U_0$ ***Walls*** | $U_0$ ***Ceiling*** |
|---|---|---|---|---|
| **Room 1** | 113 | 501 | *** | 0,17 |
| **Room 2** | 241 | 156 | *** | 0,77 |
| **Room 3** | 151 | 92 | *** | 0,24 |
| **Room 4** | 171,5 | 109 | *** | 0,42 |

**Table 3 – All results – Measurement and Simulation**

For ceiling situation for computing both parameters $\overline{E}_{\mathrm{m}}$ and $U_0$ is more simple because this surface is not so ragged in comparison with walls. Even more in most cases it is flat surface where it is not doubt to compute parameters described in standard. Regardless of significant differences between results further it can be seen that maintained illuminance level from simulation tools are higher for each room except one DIALUX case for room 3 where further investigation should be done to uncover non-conformity between results. This fact support results from previous work [8] where comparison of lighting simulation tools with field trial has been done and also significant results has been found. At the end it should be emphasised that people who do lighting designs and want to follow EN standard [4] should be carefull about values which are computed from lighting simulation tools and should have some reserve about maintained illuminance level to be in accordance in described standard for indoor workplaces. For uniformity on ceiling results show more or less it is in accordance of lighting simulation tool even some significant differences between computed and measured values are observed. Unfortunately, for uniformity of illuminance level could not be stated walls from computed values. That cases should be investigated further and find some explanations for these non-conformities what is plan for future research work.

## Acknowledgments

**This publication is the result of the project implementation:**
**Research centre of light and lighting technology, ITMS 26220220150,**
**supported by the Research & Development Operational Programme funded by ERDF.**

Operačný program VÝSKUM a VÝVOJ

Agentúra
Ministerstva školstva, vedy, výskumu a športu SR
pre štrukturálne fondy EÚ

Podporujeme výskumné aktivity na Slovensku/
Projekt je spolufinancovaný zo zdrojov EÚ

Európska únia
Európsky fond regionálneho rozvoja

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