

Modeling the Light Parameters of The Measurement Station for Testing Small-Sized Objects by Luminance Method*

Łukasz KULIG¹, Krzysztof TERESZKIEWICZ¹, Agnieszka GALA-BLADZINSKA², Henryk WACHTA³

And Mateusz POLAR¹

¹Rzeszow University of Technology, Department of Computer Engineering in Management, Al. Powstańców Warszawy 12, 35-959 Rzeszow

²University of Rzeszow, Institute of Medical Sciences, Department of Nephrology and Endocrinology, ul. Warzywna 1A, 35-310 Rzeszow

³Rzeszow University of Technology, Department of Power Electronics and Power Engineering, ul. Wincentego Pola 2, 35-959 Rzeszow, Poland

ORCID: 0000-0001-8568-3709

ORCID: 0000-0001-6617-0852

ORCID: 0000-0001-6198-4128

ORCID: 0009-0006-1915-2612

Correspondence should be addressed to: Łukasz KULIG¹, lk@prz.edu.pl

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Abstract

The article discusses issues related to the design structure of a universal measurement environment using a luminance meter. The prepared simulations present different lighting variants allowing for an unambiguous selection of the best lighting parameters achieved on the test plane. The setting of lighting fixtures set in 6 variants was simulated: from the ceiling, simultaneous lighting from the ceiling and floor, only from the floor, hanging luminaires with mapping of photometric solids, luminaires suspended on a 40 cm line directing the light source towards the ceiling, lighting in a measuring tent with lighting of the calculation field. The simulation part was tested in the next stage in real lighting conditions and compared with the results obtained in theory. At both stages, the values were measured at 6 measurement points. Using the LMK meter, photos of the same white sheet of paper were taken to assess the uniformity of the measurement field lighting in real conditions and analyzed using specialized software. The luminance tested on the white measuring card ranged from 159 to 188 cd/m². The actual uniformity achieved during the measurement is 0.92, and the difference in relation to ideal conditions is 0.08. The discrepancy results from an imperfect representation of the lighting situation in reality compared to the exact conditions adjusted in the simulation environment. The difference of 0.08 compared to the value from the computer visualization is a very good result, illustrating an accurate representation of the station and acceptable uniformity for performing universal measurements.

Keywords: luminance, luminance measurement, matrix meter, test station.

Introduction

Based on an analysis of the literature and the existing knowledge of the lighting subject matter, it was concluded that the luminance measurement room must have constant lighting parameters [Andrea 2022, Kruisselbrink 2018]. The result of the work presented in the paper is the design, simulation and actual mapping of a universal measurement station for luminance analysis on the surface of the test items. The presented simulation solutions and mapping in the laboratory environment meet the assumption of universality of adaptation of rooms as measurement areas with maintenance of the assumed high value of the lighting uniformity parameter, provided that the guidelines described in the test methodology are implemented [Suk 2018, Kim 2014]. On the basis of this information, obtained during actual measurements and a series of simulation tests, it is possible to assess the suitability of the measurement room for conducting tests using the luminance method.

Lighting conditions simulation

A detailed description of the methodological procedure of the simulation calculations is included in the first part of the paper entitled “Light environment model for testing small-sized objects by luminance method” (in print). The most important features of the research environment are the dimensions of the room and the constant specified lighting. The room chosen for the measurement room is a square area of more than 30 square meters. The reflection coefficients for the floor, walls and ceiling are 0.3; 0.5 and 0.7, respectively [Żagan 2022]. The height of the measurement room is 2.8 meters, which is the standard height of office rooms constructed under current construction standards. In order to reduce the influence of reflections from other surfaces, all elements used in the simulation were centred (measuring table) or positioned at symmetrical distances from the centre of the room (luminaries). The light points used in the simulation of the measurement environment are high-end designs with reflective optical systems to reduce glare. All the light sources used are characterized by the same values of light parameters. Each luminaire generates 21.5 watts of power consumption and 1960 lumens of luminous flux, resulting in an efficiency of 91 lumens per watt. The selected colour temperature of the light is 4000 Kelvin.

Once the room’s features (dimensions and reflectivity) were introduced into the design area, several versions of the arrangement of this environment were made using luminaires mounted directly to the ceiling, suspended, mounted on the ground, and combinations of these variants. The luminaires in all variants were placed at equal distances from one another for uniform illumination distribution. The goal of presenting different combinations of illumination was to obtain as much uniformity as possible on the measurement surface. Were tested 6 systems in terms of lighting; from the ceiling, simultaneous lighting from the ceiling and floor, only from the floor, hanging luminaires with mapping of photometric solids, luminaires suspended on a 40 cm line directing the light source towards the ceiling, lighting in the measuring tent with lighting of the calculation field. Simulations using various methods of indirect and direct light are an important element influencing the lighting uniformity parameter. For this reason, the differences between the orientation of the light source for the uniformity parameter can reach even more than 20%, which is a significant change when examining small surfaces [Pracki, P. (2020)].

Simulations of different lighting layout options

An important parameter during conducting simulations is the selection of the arrangement of lighting fixtures and the direction of light distribution in relation to the tested surface. Adjusting the height and location of the lighting fixture and the direction of its distribution dynamically affects the lighting parameters obtained in the room. The purpose of regulating the above-mentioned variables is to achieve the highest possible uniformity of lighting at an acceptable intensity level, consistent with normative requirements. [Standard PN-EN 13201-2:2007, Pracki, P. (2021)]

In the case of variant 1 which is illustrated in Figure 1, mounting directly to the ceiling was simulated. The type of light point mounting shown is the most popular architectural solution in most office spaces currently being designed, making it the variant with the easiest way to replicate in reality. The advantage of variant 1 of the presented placement of light sources is high uniformity on a smaller measurement plane and the elimination of disturbances associated with the displacement of light sources.

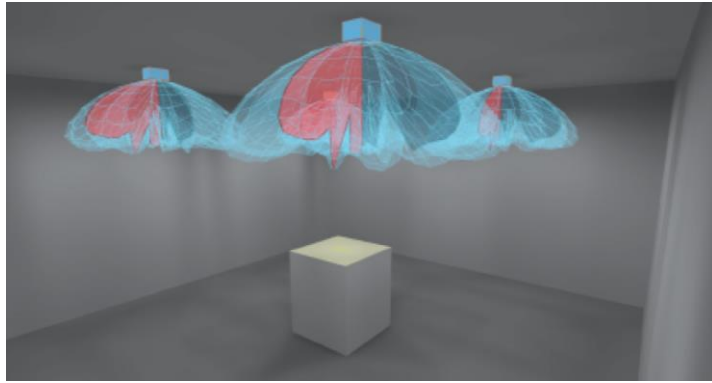


Figure 1. Simulation model using ceiling mounting with graphic representation of light distribution curves – variant 1 [own work]

In simulation model number 2 (Figure 2), where the luminaires were fixed directly to the ceiling and to the floor, it was possible to obtain the highest average illuminance value in the tested areas and a uniformity close to the value of 1. The disadvantage of luminaire placement in this variant is the discomfort during the positioning of the apparatus and the items to be analysed caused by the glare generated from light sources placed on the floor. Another disadvantage of such an application is the ease in disturbing the fixed position of luminaries on the ground. When carrying out measurements, the person operating the apparatus is exposed to damage to light-emitting elements and affects the safety of operating the measuring station.

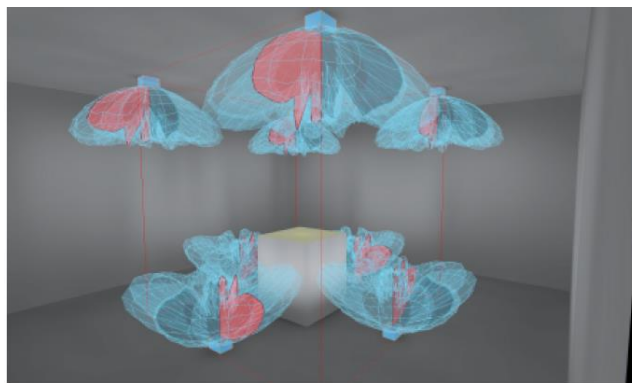


Figure 2. Lighting a room simultaneously from above and below with visualization of the shape of photometric solids – variant 2 [own work]

Another situation is variant number 3 (Figure 3), which involves the illumination of the test station by placing luminaires only on the surface of the ground. The biggest advantage of this variant is the illumination on the measuring surface only by indirect light, i.e. reflected from the walls, ceiling and ground. As a result, there is little amplitude in the illumination values, which results in good uniformity. In addition to the disadvantages mentioned in the description of variant 2, which are also present in variant 3, there are too low lux values in the design area. In order to correctly analyse samples, an intensity value close to the recommendations for the work surface specified in current standards is necessary.

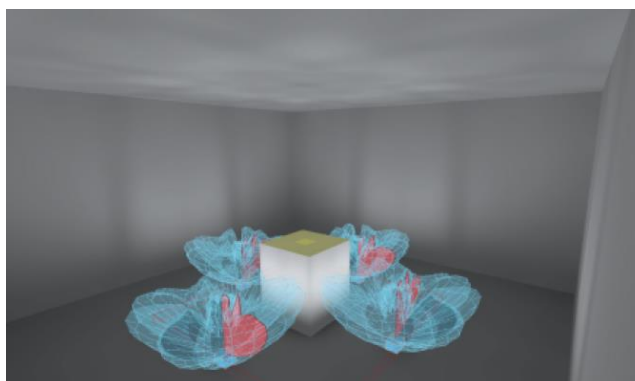


Figure 3. Lighting the room only from below with representation of the light distribution shapes of the luminaires used – variant 3 [own work]

The next case is hanging luminaires on mounting cables in simulation No. 4 (Figure 4). This solution allows for better uniformity and illumination on the measurement table. The negative effects of mounting with lowered light points is the possibility of a greater shadow effect cast by the light incident on the tripod holding the measuring apparatus. This can be prevented by moving the measuring arm accordingly, but this is an additional element of the station design changes to keep in mind. Also, due to the lack of permanent attachment to stationary elements of the room, the light points can be subjected to unwanted movement, which disrupts the stability of the lighting. Elimination of this disadvantage is also not complicated, due to the absence of any negative influences such as draft or vibration. The only thing to remember is to be careful when installing the measuring apparatus, so as not to disturb the luminaires suspended 2.4 meters above the ground.

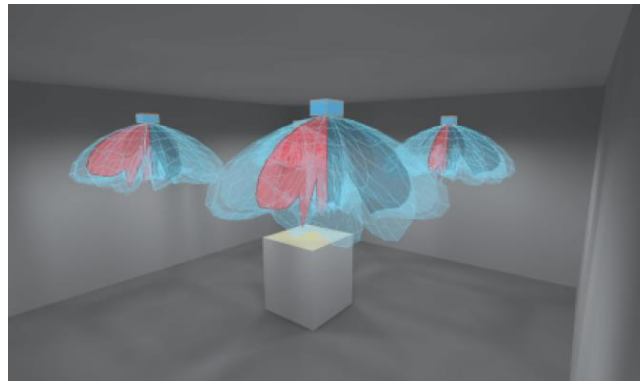


Figure 4. Lighting of the room by suspended luminaires with representation of photometric solids. (luminaires mounted below the ceiling) – variant 4 [own work]

Variant 5 of the measurement room in Figure 5 shows suspended luminaires providing illumination of the measurement area by indirect light, mostly reflected by the ceiling. Turning the light points so that they directly illuminate the ceiling is intended to reduce glare for station attendants and increase uniformity on the measurement planes. The disadvantages of this solution are analogous to the disadvantages presented in situations 2 and 3. The low value of the average illuminance and the possibility of interfering with the position of the light points by touching elements of the hanging structure disqualify this variant for use in measurements.

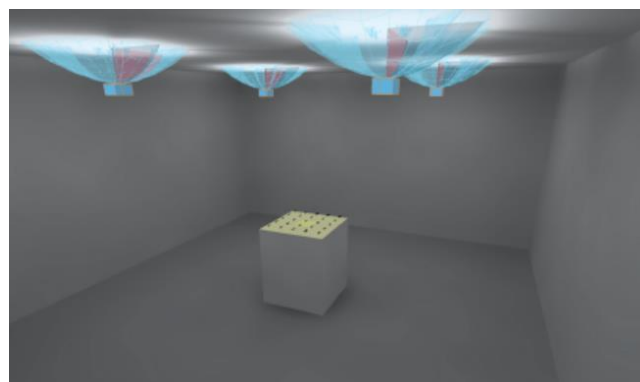


Figure 5. Simulation model using suspended luminaires on a 40 centimeter rope, pointing the light source towards the ceiling with representation of light distribution curves – variant 5 [own work]

The last option analysed is the measurement tent shown in Figure 6. The purpose of creating such a design was to reduce the impact of unpredictable situations on the measuring station, to focus all illumination on the computational surface, and to be able to accurately examine very small objects.

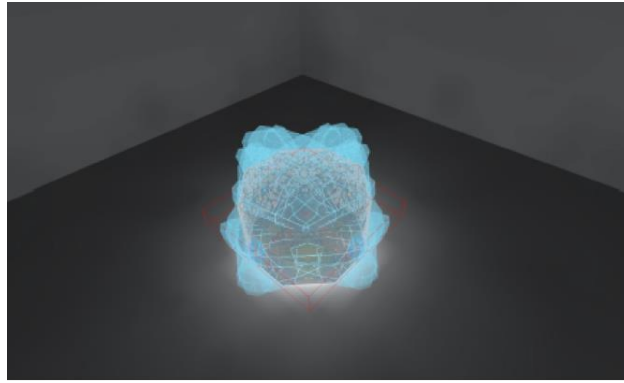


Figure 6. Simulation model of the measurement tent with computational field lighting with representation of light distribution curves – variant 6 [own work]

Thanks to the design of the tent with the use of scattering material, it is possible to achieve high values of average intensity inside the structure. Due to the small measurement area, the values of light parameters inside the tent are very high, resulting in deviations at the uniformity coefficient. In addition to the small measurement area, which disqualifies the possibility of analysing larger samples in this variant, there is a problem with increased temperature in the test space. Such a number of light points concentrated in a small space generates an increase in temperature, which can affect the surface of the test sample, generating skewed measurements. The unquestionable advantage of this solution is that there is no occurrence of possible shadowing by external objects, dealing with the operation of the measuring apparatus, and no possibility of disturbing the measurement by unwanted objects appearing on the path between the sample and the lens of the head of the luminance distribution testing apparatus.

Result Analysis

Evaluating each of the ways (variants) of illumination, the following were compared: the obtained uniformity of light incident on the CG2 measuring field (area of 20 x 20 cm), the values of illumination: where the position is most strongly illuminated (E_{max}), where it is least illuminated (E_{min}) and the average value of illumination of the working field $E_{\acute{s}r}$. In the end, variant No. 4 was selected as giving the most uniform illumination of the work field, the functionality of which offers the possibility of implementation in practice.

Table 1. Summary of light parameter values for the analysed lighting situations of the test station.

[own work]

Parameter	E_{min}	E_{max}	$E_{\acute{s}r}$	$G1_{CG2}$
Version 1	243 lx	246 lx	245 lx	0.99
Version 2	329 lx	332 lx	331 lx	0.99
Version 3	86.3 lx	86.7 lx	86.5 lx	1.00
Version 4	267 lx	269 lx	268 lx	1.00
Version 5	132 lx	145 lx	138 lx	0.96
Version 6	691 lx	773 lx	733 lx	0.94

When choosing the best version of the light point distribution, the utility of this type of lighting and its easy installation in reality were taken into account, as well as limiting the amount of shadow formation on the sample from the measurement head of the luminance meter. For the most advantageous version, lighting is directed directly towards the measuring field by four luminaires suspended from a 40-centimetre mounting cable. The illumination uniformity of the measurement field for this version is $G1_{CG2} = 1$. Despite similar uniformity, version No. 2 using a combination of ceiling-mounted and ground-mounted luminaires was rejected despite the fact that it achieves better illuminance performance. The argument to abandon this version was that the cost of the light installation was too high, with a disproportionate increase in performance relative to the previously selected

variant 4. Similarly, option No. 3 was rejected due to the marginally low illumination on the surface of the computational areas.

Checking the correctness of the selection of the light variant

In order to evaluate the most favourable lighting situation, cases were simulated that change the light distribution of the environment using the same lighting installation method, but with varying positions of luminaires and design surfaces. The selection check was divided into three segments: the first is a symmetrical change in the distance of the luminaires from the measuring surface along the room's diagonal lines, the second is moving the measuring surface by a fixed distance along the line of symmetry and one of the diagonals. The third method was to check the parameter values for one, two, three and four luminaires, respectively.

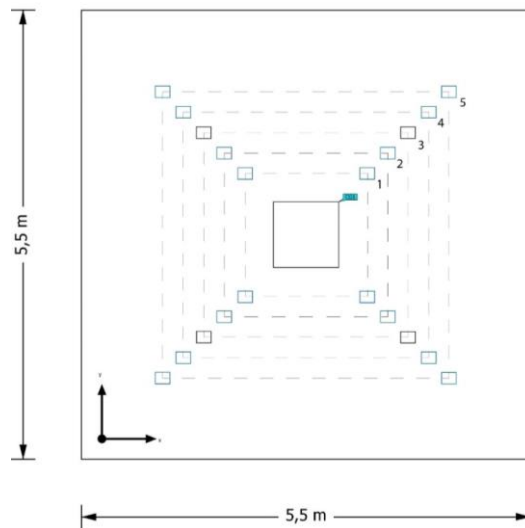


Figure 7. Change in distance of luminaires in the diagonal line of the measurement room [own work]

The first way to analyse the correctness of the selection of the lighting situation is to check the changes in the distance of the luminaires from the measuring table. Figure 7 shows lighting situation No. 4 in four additional variants of light point arrangement. Basically, the luminaires were placed symmetrically with a distance of 2.5 meters between their centres. The room visualization shows five luminaire arrangements starting with a distance of 1.5 meters between one another and jumping every 0.5 meters to a distance of 3.5 meters. The light points in black are the basic version of the arrangement of light structures in the room.

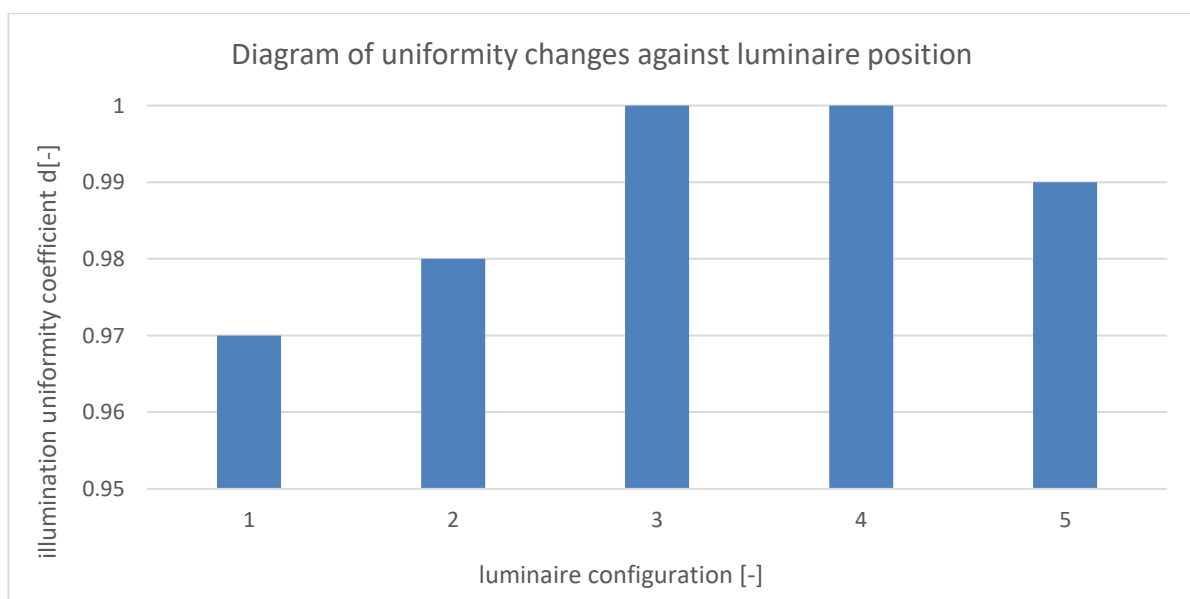


Figure 8. Diagram of changes in uniformity coefficient against luminaire arrangement [own work]

The lighting uniformity parameter on the computational plane depends on the distance of the light points used in the measurement room. Starting with the concentrated arrangement closest to the measurement table, the uniformity coefficient increases (Figure 8) until it reaches a peak in cases 3 and 4, showing a value equal to 1. Once the maximum is reached, the level of uniformity begins to drop, due to the light sources being too far away from the measurement surfaces. In the case of two variants reaching a value of 1 of the uniformity coefficient, it is necessary to check the illuminance they reach on the tested plane. The baseline variant with a distance of 2.5 meters between the centres of the luminaires represents a better average illuminance value on the tested planes, which keeps it in the classification of the best possible distribution of light points.

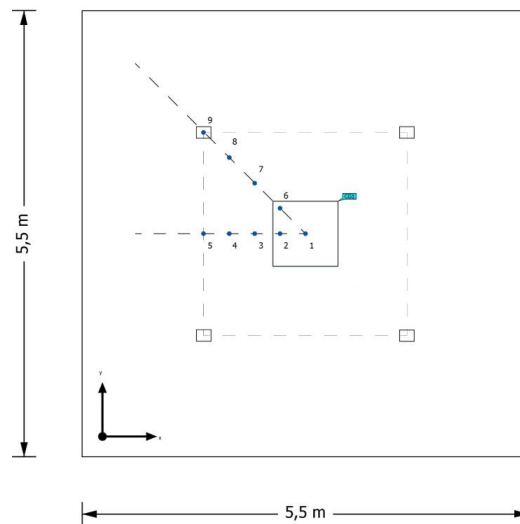


Figure 9. Location of the measurement plane [own work]

The next step in analysing the correctness of the lighting choice was to move the measurement table with monitoring the effect on the lighting uniformity parameter. The symmetrical spacing of the markers between each other shown in Figure 9 was intended to obtain stable measurements of the uniformity coefficient on the computational plane. To analyse these changes, the position of the measurement surface was routed through five points along the room’s horizontal axis of symmetry and through another four points along half of one of the room’s diagonals.

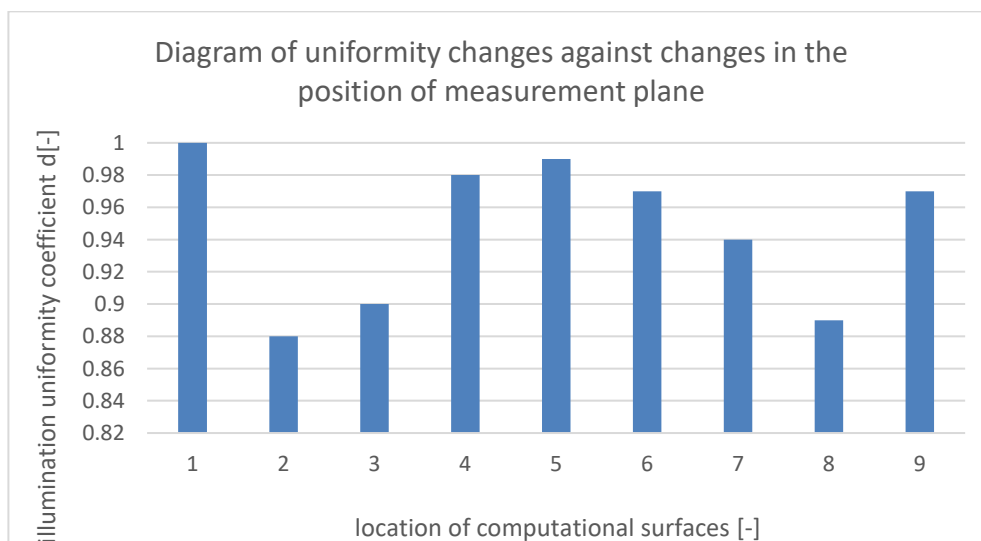


Figure 10. Diagram of changes in uniformity coefficient against the position of the measurement plane [own work]

The effects of simulating the orientation of the computational plane are shown in Figure 10. Item No. 1 corresponds to the base location of the computational surface. Moving the object to the left side, we get a sharp decrease in uniformity with an increasing trend until we reach position number 5. In this case, the computational

surfaces are exactly between the two light points, so the uniformity around this zone reaches a local peak. Moving the test table diagonally generates a downward trend in the uniformity parameter, due to approaching one lighting point while moving away from the other light sources. The last point in the analysis of changes in the position of the test surface represents a sharp increase in uniformity, due to direct illumination from a single luminaire. The cost of such an increase is a drastic decrease in illumination on the computational surface in this variant. Through the use of luminaires with a symmetrical photometric body and equal distribution of light points in the room, the light parameters achieved in the area intended for object testing are dependent on its location. After the analysis of changes in the position of the computational points, the choice of the baseline arrangement of the surface is the best of the cases studied.

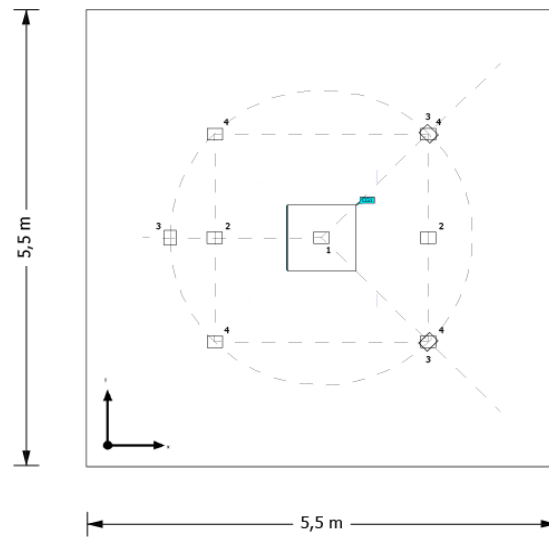


Figure 11. Change in the distribution and number of light points used [own work]

The final step in verifying the selection of test room lighting was to test variants with one, two, three and four light sources, respectively, symmetrically spaced from the centre of the measurement surface (Figure 11).

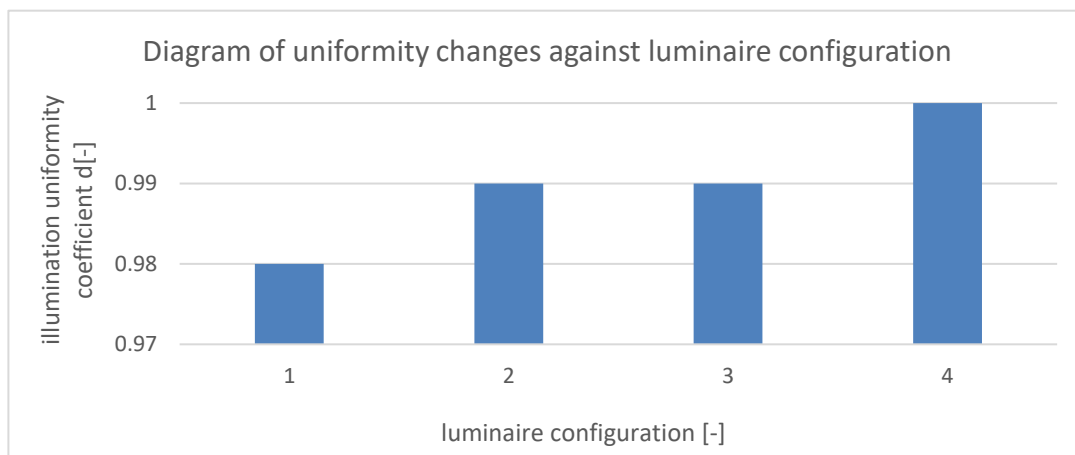


Figure 12. Diagram of changes in uniformity coefficient against luminaire configuration [own work]

A summary of the achieved uniformity coefficient values is shown in the diagram in Figure 12. As the number of light points increases, the uniformity of lighting on the test surface increases. The first option is to place one luminaire directly above the measurement table. This results in a very high uniformity, but on the scale of the measurements taken is a local minimum. The next two options were to place two luminaires away from the centre of the measurement table at the same distance as the luminaires in the baseline arrangement – a radius of 1.76 meters. For both cases, the uniformity is the same. The last option is to place luminaires in a square with a distance of 2.5 meters between light sources. This arrangement achieves the best results of light parameters, which translates into an optimal solution for conducting measurements in the selected test room.

All of the simulations conducted represented rooms created specifically for measurement purposes. Based on this assumption, the most favourable variant meeting the highest possible values of the uniformity parameter was selected. Given the slight differences between the uniformity values for the first three variants relative to the best choice (variant 4), they can be considered suitable for luminance measurements. Due to the goal of versatility of the test station, used in rooms where luminaires are already mounted, it can be assumed that differences of 0.01 are an acceptable reduction in uniformity values, without affecting the measurement results.

Simulation mapping in a real environment

Due to the reproduction of the measurement room concept in an existing room, some of the assumptions present in the simulation were modified. The reflectance of the walls may have deviated slightly from that entered in the assumptions, due to the furniture present in the room. Another modification is the elements that block the flow of natural light through the windows – instead of a black material that does not let the sun rays through, a standard roller shutter system was used. The roller blinds effectively suppress the inflow of external light, but the permeability of their material was slightly higher than that used in the simulations. The last change in the real measurement environment was the luminaires installed in the ceiling system.

In the real reflection of the simulation of the station, the following were used: a room with a length and width of 5 meters and a height of 2.8 meters, 4 identical lighting panels with a common power of 86 watts and a colour temperature of 4000K mounted directly to the ceiling, an LMK luminance meter, a tripod for mounting the meter, a table with a computer stand and a table forming a measurement plane on which the black material was placed. The measurement area was placed in the same way as in the simulations – at an equal distance between all the light points.

Calibration measurements of the real measurement room

In order to determine the differences between the results obtained by simulation and the values found in reality, test measurements were carried out. A sheet of white A4-size paper with a high weight of 250g/m² was placed on a test table covered by a light-absorbing black material. The sample material was tested for reflectance. The measurement consisted in illuminating the item with uniform natural light and completing two sections of measurements. The first step was to check the intensity of illumination incident on the sheet of paper at six equally spaced points. A Konica Minolta T-10A illuminance meter was used to perform the first section of measurements. The measuring apparatus was placed directly on the sheet of paper so that the measuring probe faced the light source measuring the incident illuminance (E_{pad}). The second step was to place the probe of the meter at a distance of 30 cm above the surface of the test object and point the sensor downward in such a way that it receives light streams reflected from the measurement area, measuring the reflected light (E_{odb}). The second section of measurements uses the values of the E_{pad} parameter measured in the first part, and in addition, a point measurement of luminance was made for the same locations where the incident illuminance was measured. A Konica Minolta LS-110 spot luminance meter was used for the test. The implementation of the measurements consisted of setting the meter one metre above the surface of the test item and aiming the lens at the areas designated for measurement. For both stages, values were measured at 6 measurement points (Tab. 2).

Table 2. Measurement of the reflectance of a sheet of paper

	E_{odb} [lx]	E_{pad} [lx]	L [cd/m ²]
Measurement 1	144	329	79.6
Measurement 2	143	337	82.6
Measurement 3	147	344	79.9
Measurement 4	144	337	84.3
Measurement 5	141	335	80.8
Measurement 6	144	342	84.4
Average value	144	337	81.9

From the measurements, average values were calculated for the parameters of incident light illuminance (E_{pad}), reflected light illuminance (E_{odb}) and luminance (L). Two methods were used to calculate the reflectance of the test item, the first being the ratio of the average E_{odb} value to the average E_{pad} value. Based on this relationship,

the calculated reflectance (ρ) is 0.43. Another way is to measure the luminance at the same points where the illuminance values on the surface of the item were read. Substituting the values into the formula $\rho = \frac{L_s r \times \pi}{E_s r_{pad}}$ the result of the coefficient is 0.76. The differences between the results of the calculated reflectance coefficients are significant. The reason for such differences is the accuracy associated with illuminance measurements. The probe of the lux meter apparatus has a very wide angle of measurement, so that light rays reflecting from other elements in the room reach the meter and significantly affect the measurement. When using a luminance meter, this problem does not occur due to the accurate spot measurement by the luminance apparatus and the use of a more detailed calculation formula. Taking into account the benchmark values of the reflectance of perfect white, which oscillate between 0.8 and 0.9, it can be assumed that the measurement with the LS-110 meter and the coefficient calculated on the basis of luminance of 0.76 is a real value and sufficiently approximate to theoretical values [Dorneless et al. 2006, Ketkar 2020].

The next step to verify the accuracy of the station's representation in reality was to measure the luminance distribution on the test station. Using the LMK meter, images of the same white sheet of paper were taken to assess the uniformity of the illumination of the measurement field under real conditions and analysed by specialized software. The measurement was carried out in a room with evenly spaced luminaries with a symmetrical photometric solid on a measuring table measuring 80 cm x 80 cm and 95 cm high.

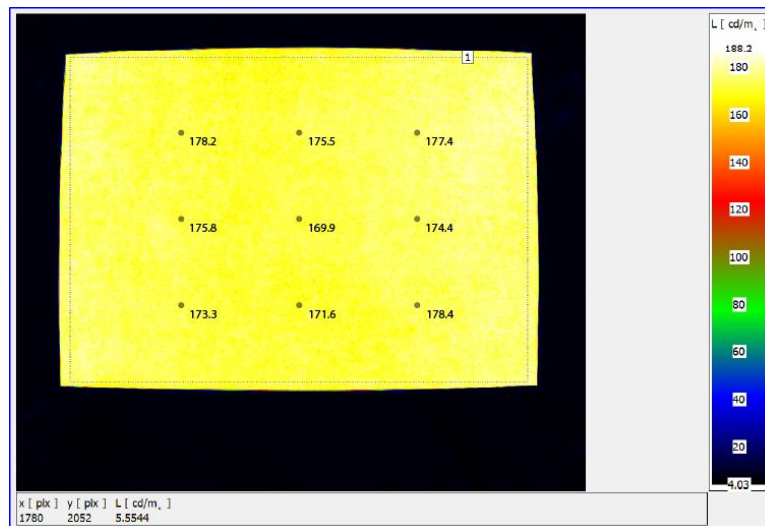


Figure 13. Luminance distribution on a sheet of paper with a mapped grid of values [own work]

The luminance tested on the white measurement sheet ranged between 159 and 188 cd/m². The actual uniformity that was achieved during the measurement shown in Figure 13 is 0.92. Comparing the value of the measured uniformity on the real test station and the value selected from the best simulation variant, a slight difference between the two can be observed. The discrepancy is due to the non-ideal representation of the light situation in reality compared to the precise conditions adjusted in the simulation environment. The difference of 0.08 compared to the value from the computer visualization is a very good result, illustrating a close representation of the station and acceptable uniformity for making universal measurements.

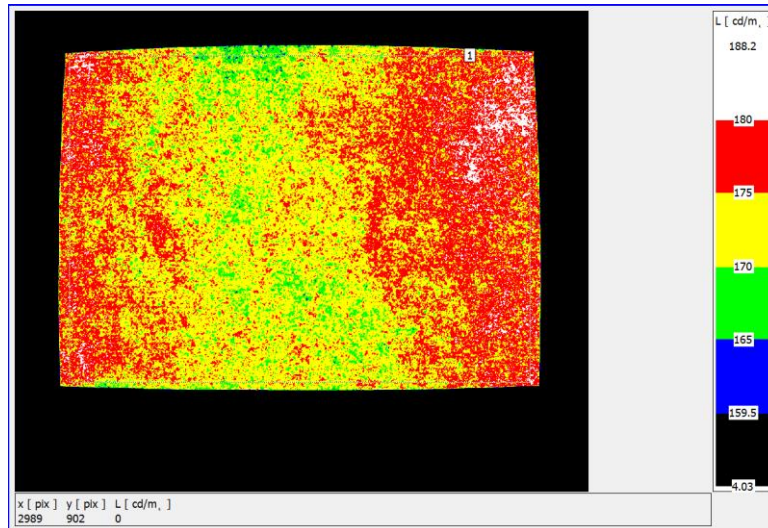


Figure 14. Luminance distribution on paper with representation in a larger colour range [own work]

The detailed distribution of luminance on the surface of the sheet of paper shown in Figure 14 provides a more accurate graphic representation of light reflections. The extreme values (white and blue colours) may have appeared due to the occurrence of shading by the tripod or illumination by unwanted light beams coming in from outside the covered windows and doors.

Summary

The station prepared for the analysis of luminance distribution with a matrix meter meets the assumptions of universality and uniformity of light parameters on the measurement planes. The lighting provided is intended not only to meet basic lighting properties, but also to introduce comfort at the test station. The methods used to analyze the existing lighting of the room and reflected in the simulations allows you to make decisions in terms of meeting the requirements of the test space selection and its modification. Thanks to the use of reflective optical systems that level the glare factor, colour temperature (4000K) and high colour rendering parameter (CRI>80), taking measurements is precise and comfortable for the user. Through the use of movable elements in the construction of the station, it is possible to modify the position of the measurement table and changes in lighting parameters by attached control modules in the luminaires. These treatments eliminate unwanted phenomena such as too much shadow or lack of symmetry of the photometric solids of the luminaires in the room.

Potential problems that may arise when measuring with this bench are increased ambient temperatures. The long operating time of luminaires causes LEDs and power supplies to heat up. Improper use of cooling methods and ventilation of the room can affect the results of the tests. Another of the problems arising from the creation of the station in reality is to seal all the places from which external light can enter. Unwanted beams of light negatively affect the uniformity maintained on the computational fields, disturbing the results of the samples. The same effect can cause inaccurate positioning of the measuring head, causing shadow effects on the measuring table. When preparing the station for analysing the item, one should focus on proper positioning of the tripod in relation to the light sources so as not to generate unnecessary shadows.

Considering all the advantages and disadvantages of the design, the presented measurement room using luminance distribution elements on the surface maintains the constant environmental parameters that are necessary for stable measurements.

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