Light Technology Lab
Far field goniometry

Institute of Light Technology

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Group L09

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1. Theory

1.1 Photometry

Photometry is a science of light measurement. These measurements are restricted to the visible range of the electromagnetic spectrum, the range that is perceived by the human eye (380 nm – 780 nm). The sensitivity of the human eye can be seen on the *figure 1*. The human eye is most sensitive at the wavelength of 555 nm in daylight (red curve on the *figure 1*) and most sensitive at the wavelength of 505 nm at night (black curve on the *figure 1*).

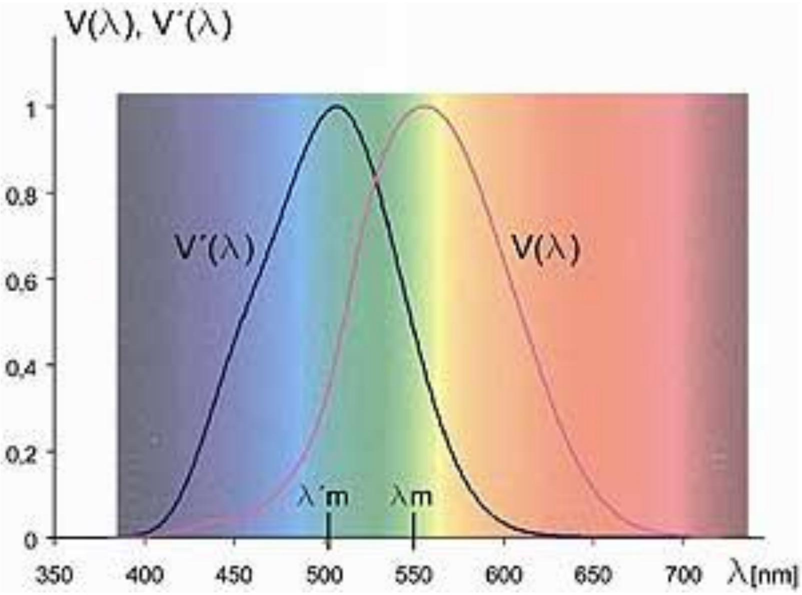

Figure 1 The sensitivity of the human eye. Red line: photopic curve. Black line: scotopic curve. [3]

Basic photometric quantities, that represents different kinds of light measurement, will be explained.
Luminous energy per unit time is called luminous flux Φ and its unit is lumen [lm]. This quantity describes how much light is emitted from a source.
To evaluate the amount of light in some specified direction, we need the luminous intensity *I* which is luminous flux per solid angle Ω:

$$I = \frac{\Phi}{\Omega}$$

The unit of *I* is candela. [cd $=\frac{lm}{sr}$]
The third important photometric quantity is illuminance *E*, that describes the luminous flux incident on a surface *A*:

$$E = \frac{\Phi}{A}$$

Its unit is lux [4]. [lx $=\frac{lm}{m^2}$]

1.2 Photometric law of distance

To measure correctly the luminous flux, only light perpendicular to the surface of the luminaire is supposed to be detected. For an extended light source, the receiver detects also light which comes under a certain angle.

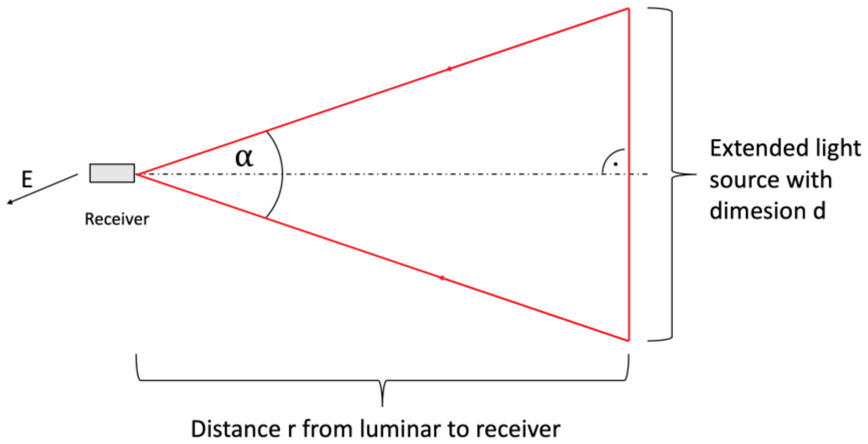

Figure 2 Angle the receiver "sees" under certain distance

In order to avoid the receiver to detect light coming with angle α, the distance r is enlarged tremendously. So, α becomes very small thus the light rays incident on the receiver are almost parallel to the optical axis.

To achieve reliable data, it is important at which ratio r/d the illuminance is measured. In the norm DIN-13032 Part 1 it is defined: the r/d ratio has to be at least 5. Luminaire with a luminous intensity distribution strongly different from lambertian, the ratio r/d hast to be at least 10. [2]

Indeed, a more reliable way of setting the r/d correctly is used in practise by the photo metric law of distance.

$$I = E * r^2$$

In theory the illuminance E is inverse proportional to r^2.
As measuring E of a luminaire for different distance ratios r/d, it is observable that the function E(r/d) is not proportional to r^{-2} before a certain point.
The far field condition is, that E(r/d) hast to be proportional to r^{-2} within a tolerance ε = ±1%.
The distance r which fulfils this for a certain luminaire of size d, is called *Photometric distance*.
All measurements not fulfilling the condition are considered as nearfield measurements.

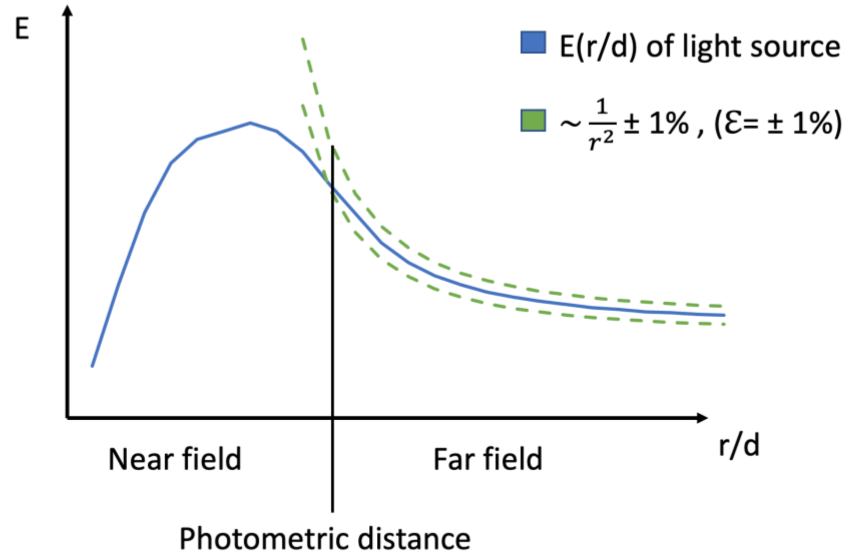

Figure 3: Schematic representation of the photometric law of distance

Measuring in the far field allows to approximate the luminaire as a point light source. Hence the light rays reaching the receiver are coming from the center of light.
By measuring the illuminance E and knowing the distance r from light source to receiver, it is possible to calculate the luminous intensity I.

The parameters for the Photometric distance are:

- Size of the light source
- Size of the receiver
- Gradient of luminous intensity distribution

1.3 Far field goniophotometer with turning mirror

Far field goniometer with mirror basically consists of a rotatable lamp holder, a rotating mirror and a photometer. The measurement procedure is to guide the lamp with constant orientation but on a radius round the rotating mirror, which directs the light towards the receiver, which measures illuminance. The centre of the mirror is at the pivotal point. The photometer is set up in a fixed position, 14.56 meters far from the source of light. In case of measuring bigger lamps or lamps strongly different from lambertian sources, there is possibility to change to a receiver with longer distance over 22 meters. The distance is connected with photometric law of distance. Scattered light is reduced by changeable size aperture and shutters in the measuring space.
The goniometer has three axes of rotation. The first is a horizontal, theta axis which follows the optical axis and has the rotating mirror centrally upon it. This axis rotates the mirror and at the same time the arm on which the second theta axis is fixed by means of the lamp or luminaire arm. The second theta axis rotates in the opposite direction to the first, always through the same angle, in order to compensate for the tilting. The light source being measured is rotated solely on the phi axis on the horizontal [1]. Measurements are always compromised between time, precision and amount of data. The Goniometer measures directly illuminance. Software sketches the polar diagram of luminous intensity distribution using data of illuminance and the orientation of the luminaire as well as given distance from light source to the receiver.

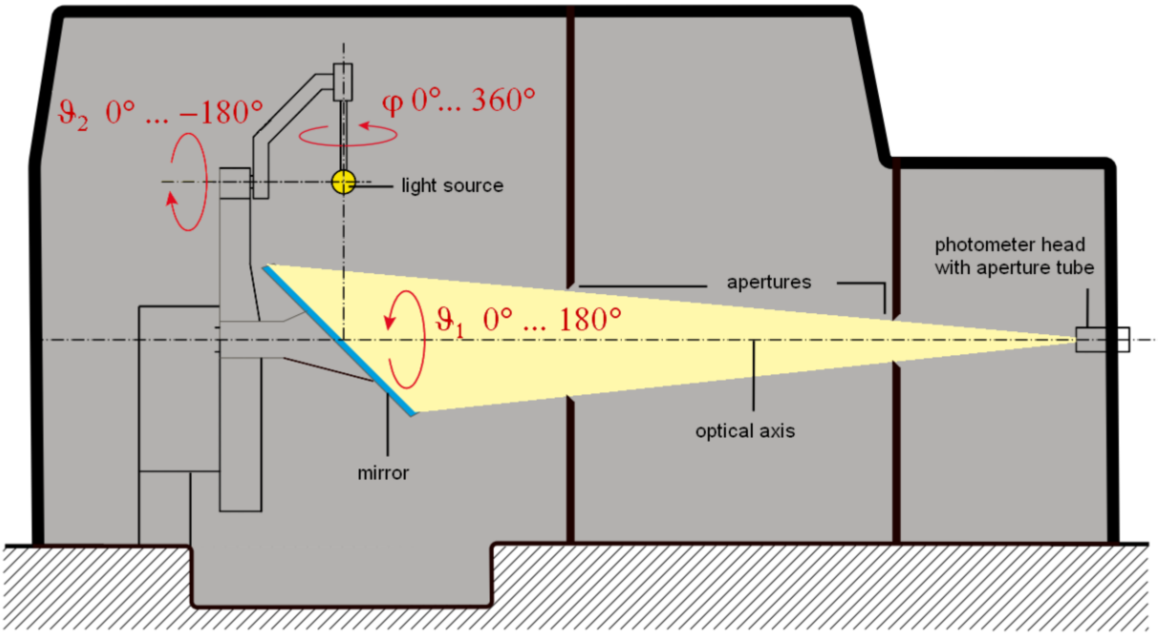

Figure 4 Schematic sketch of a mirror far field goniometer [1]

2. Method

The measured object was incandescent 100 Watts RADIUM light bulb (see *figure 5*):

- free burning
- with flat mirror plate
- with flat matt plate

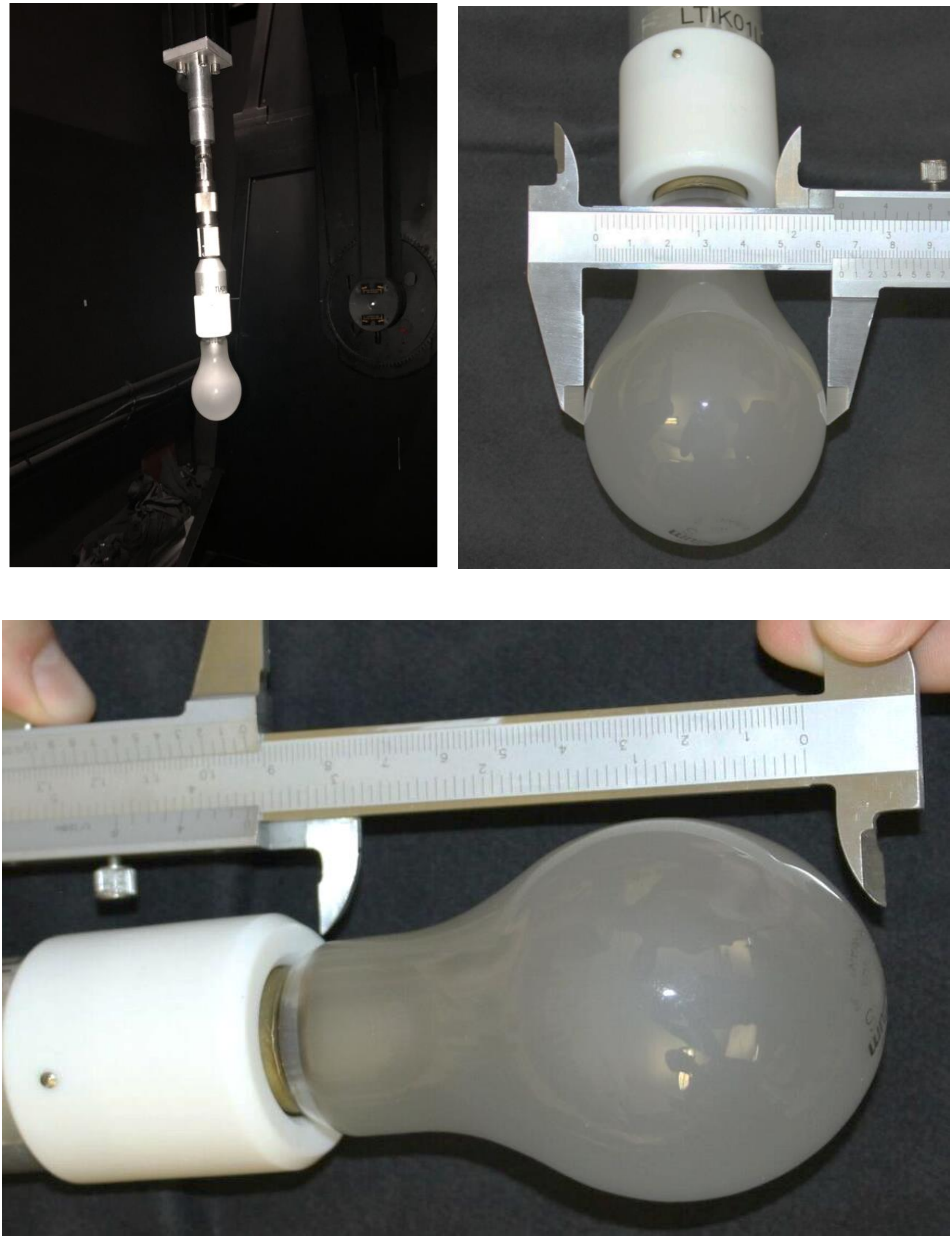

Figure 5 Incandescent light bulb RADIUM 100 W. Left top: installed in the goniometer. Right top: Measurement of the light bulb's diameter. Bottom: Measurement of the light bulb's height.

Size of the lamp:

- diameter: 65 mm
- height: 120 mm
- height with plate: 270 mm
- diameter of plate: 300 mm

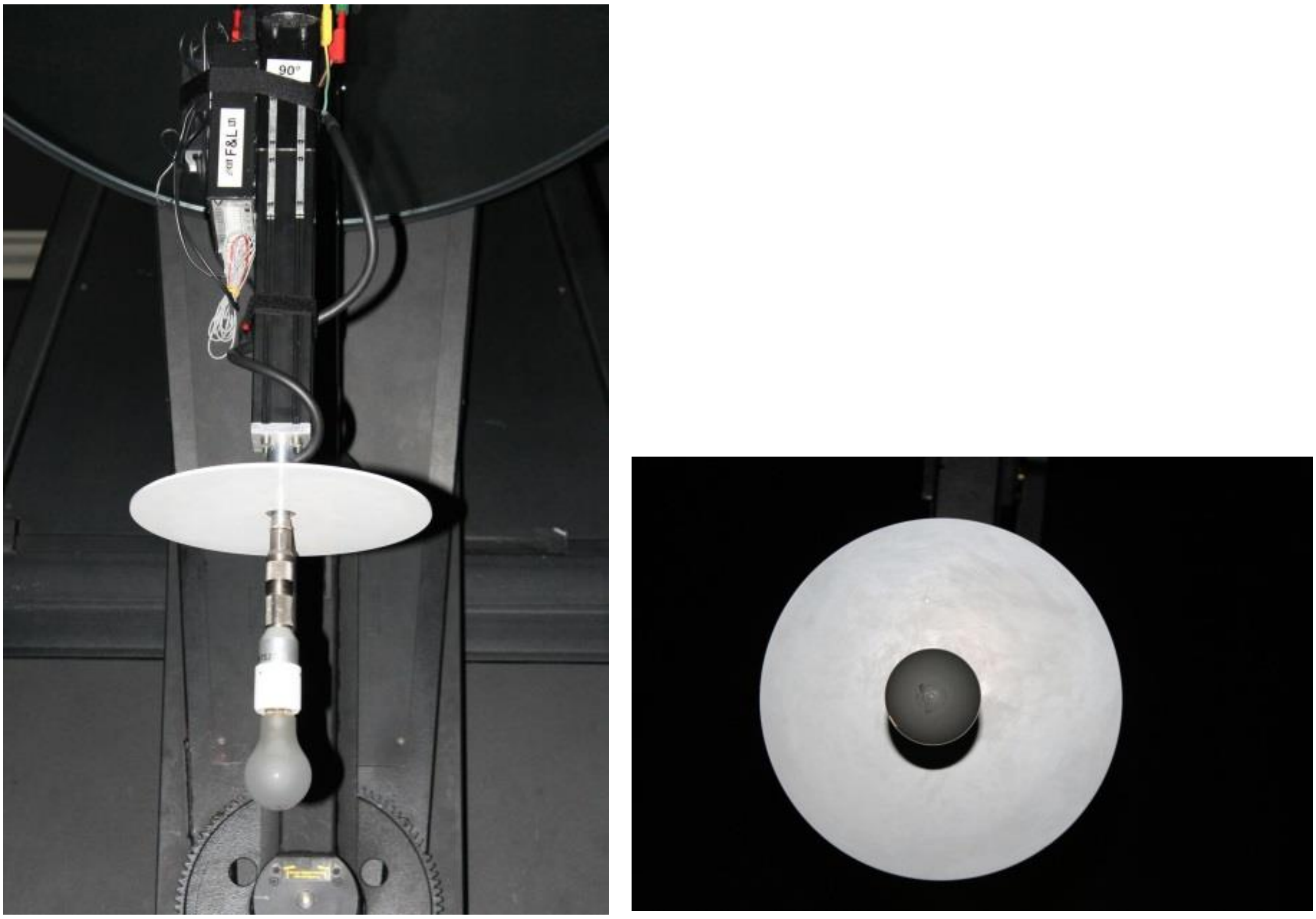

Figure 6 Reflector luminaire with matt plate. Left: installed in the goniometer. Right: bottom view.

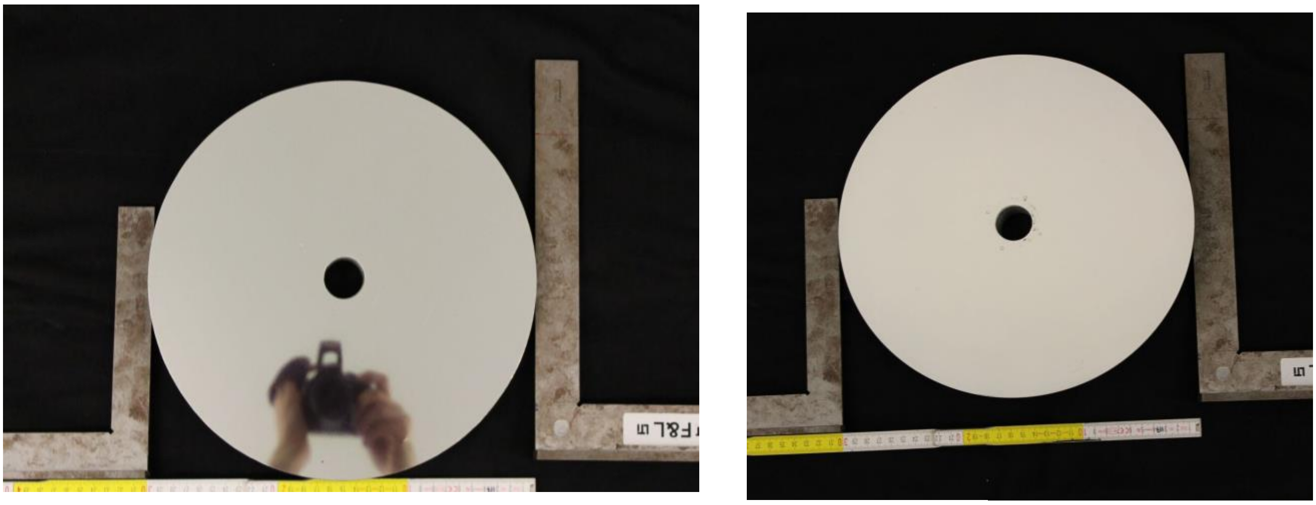

Figure 7 Left: Mirror reflector. Right: Matt reflector.

The light bulb was positioned by laser, according to the light center. In this case, it was in the middle of the light bulb.

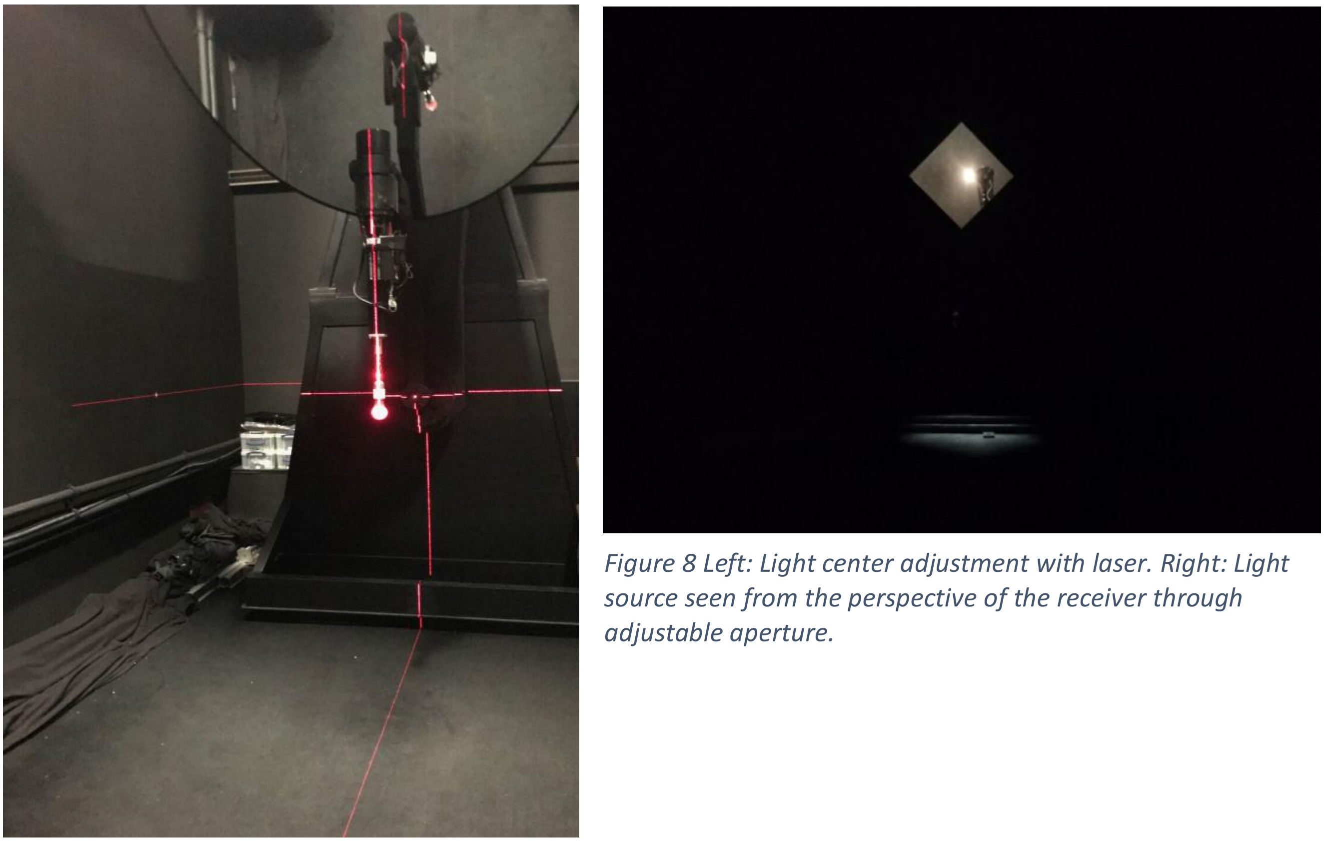

Figure 8 Left: Light center adjustment with laser. Right: Light source seen from the perspective of the receiver through adjustable aperture.

The temperature in the room has to be 25 ^{o}C ± 1 ^{o}C. During measurements, it was 25.6 ^{o}C. The aperture was 30 cm wide. The *figure 8* shows how the receiver sees the light source. The distance from source to receiver was 14.56 m. Based on the size of the light source and the distance from it to the receiver, the photometric law of distance is fulfilled hence the lamp can be considered as point source.
Before starting the measurement, the incandescent lamp was burned-in for 10 minutes in order to reach stable working point. The burn-in takes usually about 1 hour [2].
To avoid any kind of uncertainties due to an unstable power supply an external power supply is used to run the luminaire.
Additionally, the Roxxane Home Desk LED luminaire of a customer has been analysed (see *figure 9*).

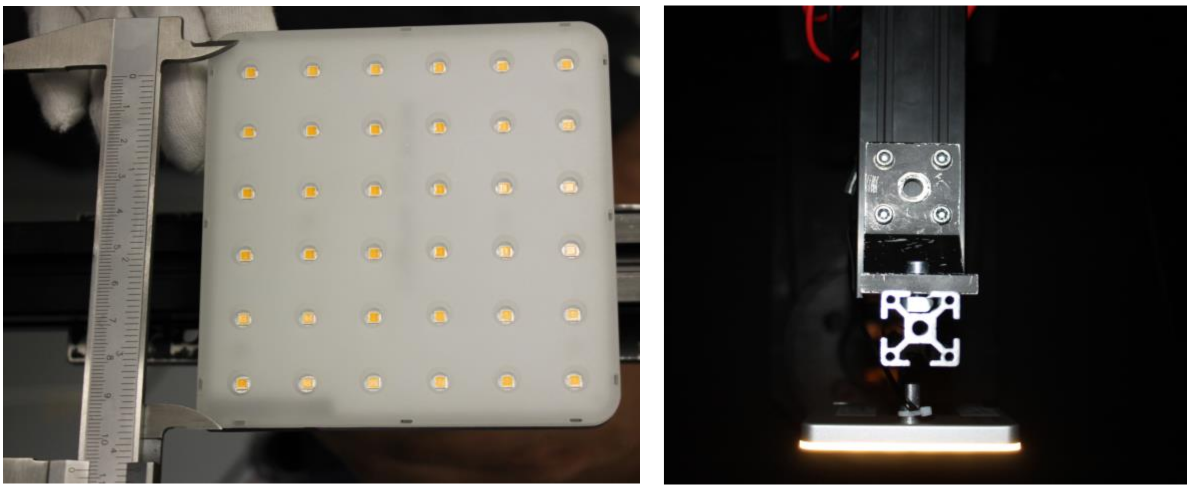

Figure 9 Left: Roxxane Home LED luminaire with area of 10 cm x 10cm. Right: installed in the goniometer.

3.Data analysis

3.1 Incandescent lamp

In the first part of measurements, the tungsten lamp was investigated, the goal was to determine the luminous flux of the lamp. The light bulb was installed into the goniometer. To avoid stray light, reflective objects were removed from measuring room and additional light was turned off. The measurements of the goniometer were based on the rotation of the light source and turning of the mirror. In this way, the luminous intensity distribution was obtained with the software *(see figure 10).*

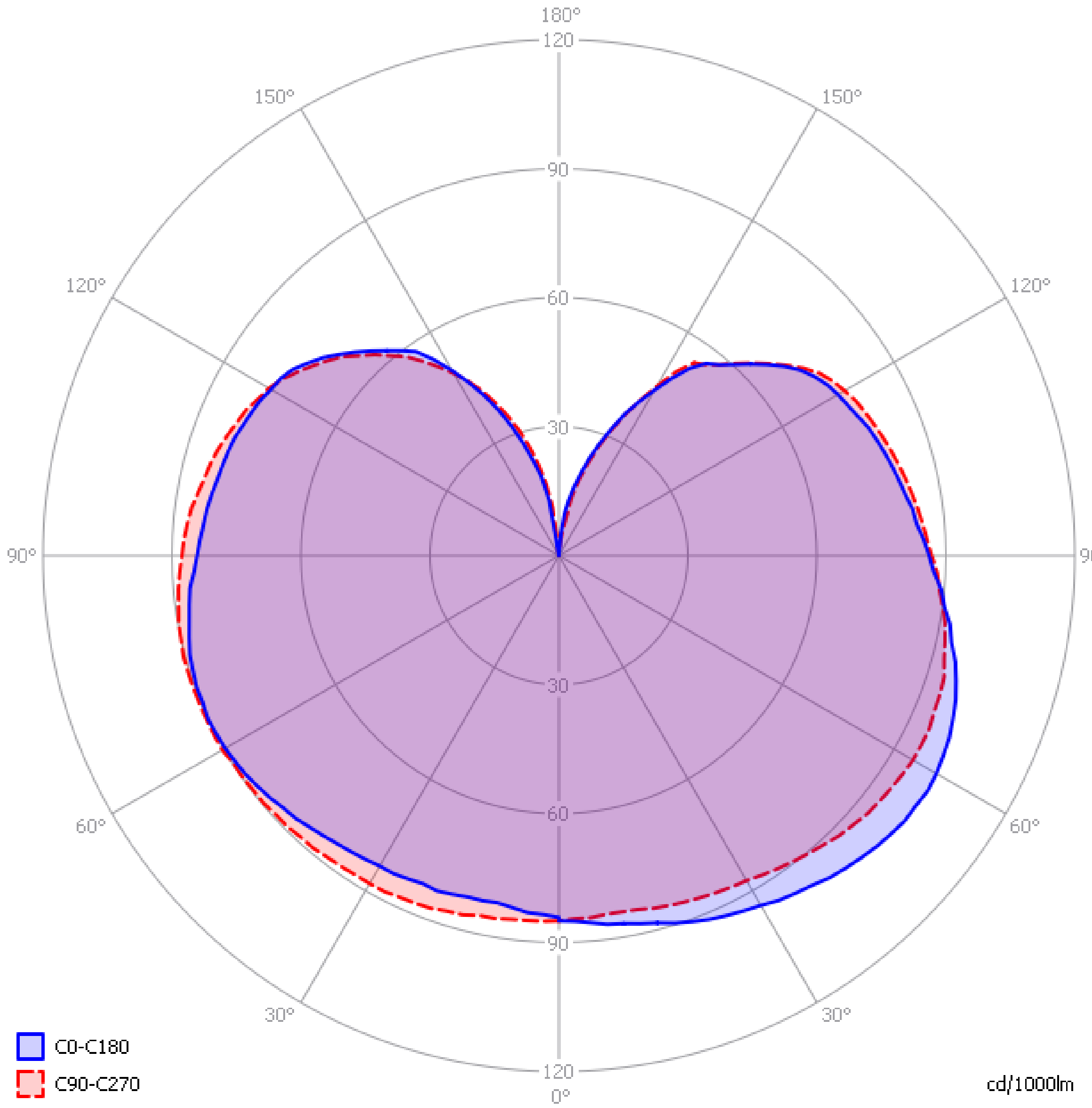

Figure 10 Luminous intensity distribution of the incandescent lamp.

The distribution was evaluated for two C-planes combinations:

- $C_0 - C_{180}$ plane
- $C_{90} - C_{270}$ plane

The angles on the polar diagram determine the turning of the mirror. The luminous intensity was measured in intervals of 2.5 degree. As can be seen on the graph, the distribution shows that incandescent lamp is approximation of lambertian light source. The small deviation from the symmetry of the C planes (the distributions in both planes do not overlap entirely) can result from the fact, that the light bulb's socket is positioned slightly off center in the

goniometer, so by turning the C plane the light bulb rotates off axis. The visible indent on the top of the graph is also due to the socket.
The luminous flux can be obtained by integrating the luminous intensity over solid angle. The electrical parameters during the measurement were:

- Voltage: 230.19 V
- Current: 454 mA
- Power: 104.44 W

The resulting luminous flux was 1083.2 lm.

3.2 Reflector luminaires

In this experiment a reflector was installed 27 cm above the center of light of the light bulb. Two different types of reflector were evaluated: a flat mirror *(see figure 11)* and a white plate *(see figure 12)*. The measurement procedures were the same for both reflectors. The goniometer arm drives continuously while the luminaire holds still. The procedure was made for four different orientations (c-planes) of the luminaire.

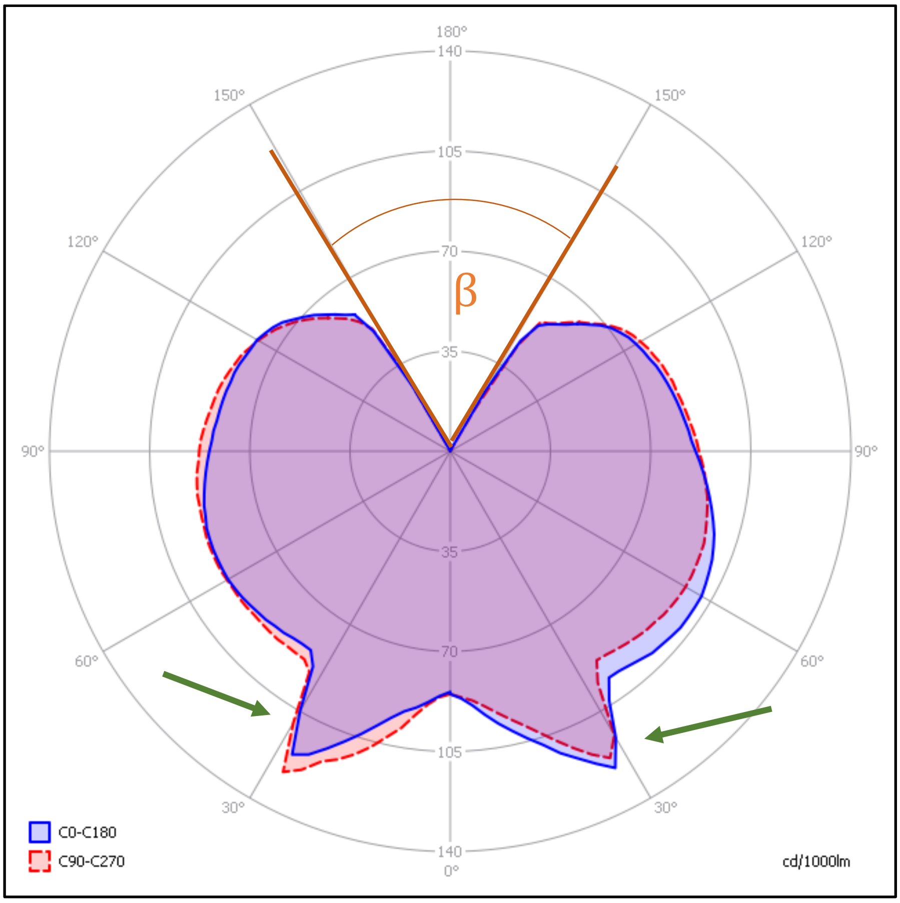

Figure 11 LID of luminaire with a flat mirror reflector

Because of the mirror reflector the angle β has zero luminous intensity, all light within this solid angle is reflected. The reflected light appears in the opposite direction and causes the peaks (marked by green arrows).
The luminaire efficiency for the luminaire with mirror reflector, according to the measurement, is 99,88%.

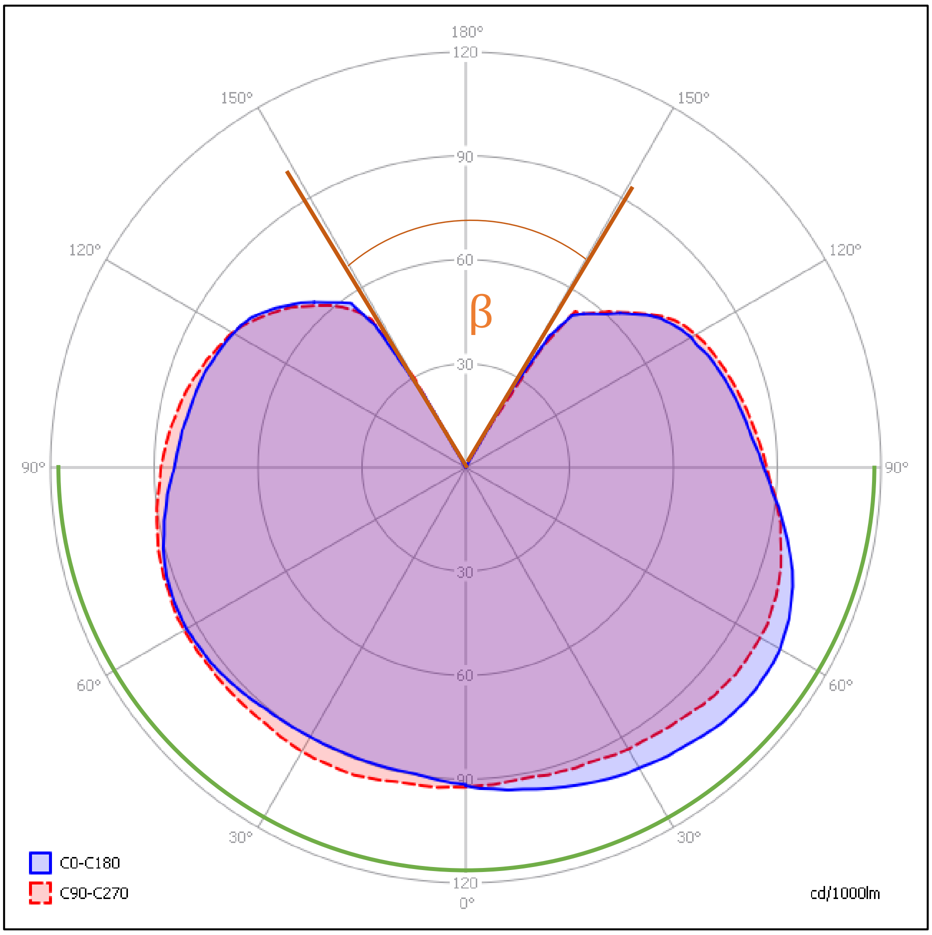

Figure 12 LID of luminaire with a white plate reflector

Also, the white plate blocks all light of the angle β. In terms of a white reflector the light is isotropically distributed. So, the luminous intensity for the bottom half of sphere (marked by green line) is higher compared to the pure light bulb.

The luminaire efficiency for the luminaire with white plate, according to the measurement, is 99,6%.

3.3 Custom luminaire

As last part of measurements, LED luminaire Roxxane Home has been investigated. Electrical parameters that were used during the measurements were:

- Voltage: 8.47 V
- Current: 88 mA
- Power: 7.45 W

The resulting luminous intensity distribution can be seen on *figure 13.*

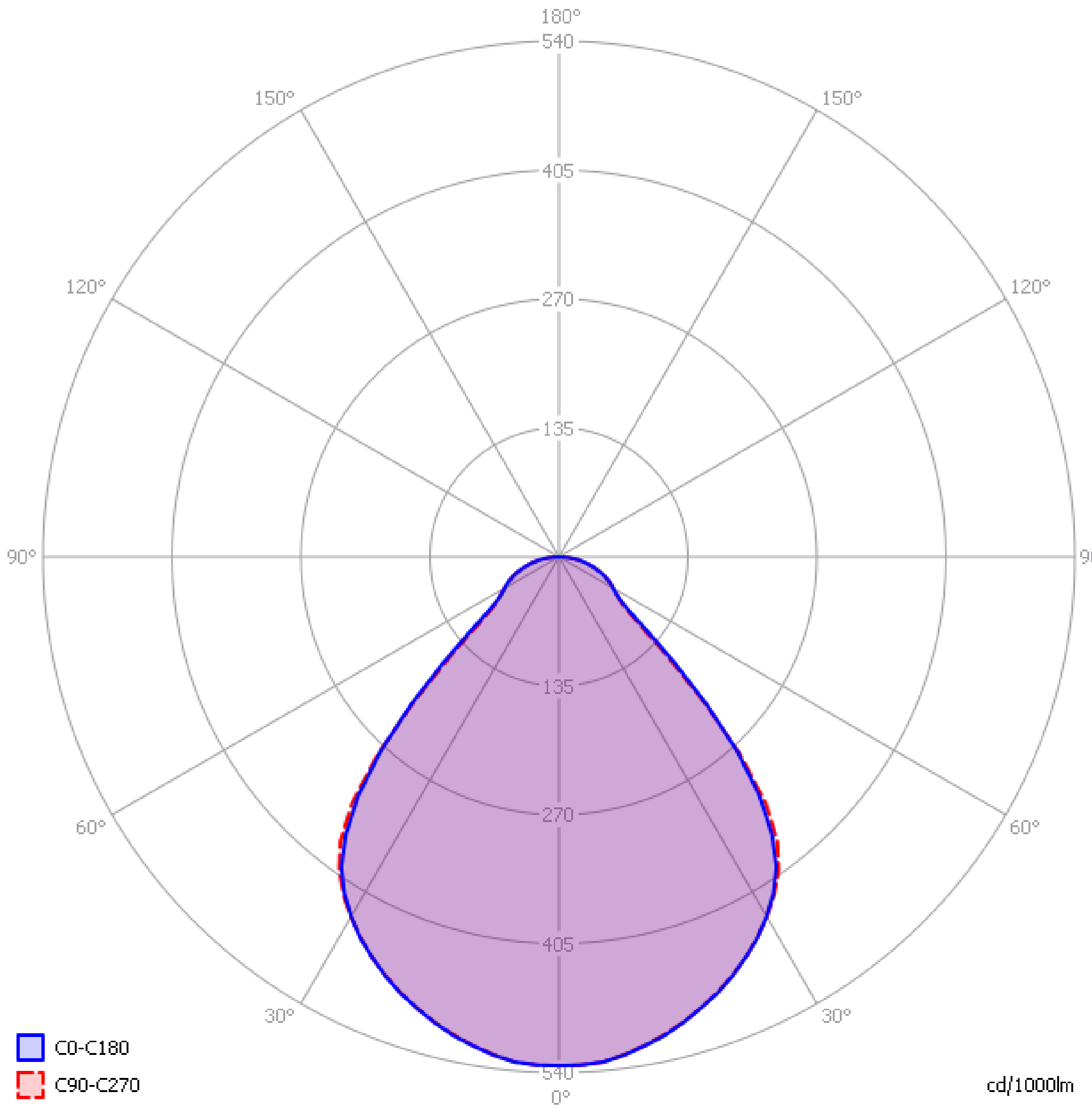

Figure 13 Luminous Intensity distribution of the LED luminaire.

The luminaire was measured in the same planes as previous light sources (C0-C180 and C90-C270). The LID is symmetrical and maximum luminous intensity corresponds to the normal direction. Luminaire's diffuser surface directs the light downwards. Such distribution can be explained by the purpose of the luminaire, since it is designed for desk office work [5]. The luminous flux resulting from integration of luminous intensity over the whole space, that was estimated by the software, equals 917.31 lm. The luminaire efficiency could not be determined, since luminous fluxes of individual LEDs in the luminaire have not been measured.

4. Conclusion

Far field goniophotometry is an adequate way to measure the luminous intensity distribution and luminous flux of lamps and luminaires. Measurements rely on the photometric law of distance. The luminous intensity is calculated based on the directly measured illuminance and the distance between the receiver and the light source. Due to the appropriate distance, the light source is considered as point source in the far field measurements. Luminous intensity can be measured in different intervals and the compromise between the time and the precision of measurements must be made. Outcome of the analysis depends strongly on the ambient temperature deviations and electrical parameters. Additionally, any potential stray light should be avoided.

According to the measured LID, the incandescent lamp approximates a lambertian light source. Luminous efficacy of the lamp is 10,4 lm/W, that only slightly differs from the expected value of 10 lm/W.

In theory, a perfect white and perfect mirror have a luminaire efficiency of 100 %, since they reflect whole the incident light. However, in practice, there are intensity losses in form of absorption. Based on the results, luminaire with mirror plate shows better luminaire efficiency (99,88 %) than the luminaire with white plate (99,6 %).

Last measured LED luminaire shows the luminous intensity distribution, that confirms its application in office desk lighting.

References

[1] Dipl.-Ing. Chr. Schwanengel "Comparison of techniques for measuring luminous intensity distribution overall and across segments"

[2] Prof. Dr. Cornelius Neumann "Light Technology Lab Farfieldgoniometry" Karlsruhe Intistute of Technology - Light Technology Institute, 2016

[3] https://light-measurement.com/spectral-sensitivity-of-eye

[4] https://en.wikipedia.org/wiki/Photometry_(optics)

[5] https://nimbus-lighting.com/en/products/families/roxxane/roxxane-home-tischleuchte