University of Ljubljana
Faculty of Electrical Engineering
Laboratory of Lighting and Photometry

WORKBOOK

FOR

LIGHTING ENGINEERING

UN2-1 - optional

Laboratory work

Student: ____________________________

e-mail: ____

Academic Year: 2016/17

Date of review:: ___________

The proposed grade for lab. work: ___________

Signature of evaluator: ___________

Workbook must be submitted at least one week prior to exam!

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Ljubljana, 2016

EXERCISE 1

Luminous intensity I [cd]

The term "photometry" refers to the measurement of variables, conventionally evaluated by visual impression caused by visible radiation (light). The basis for the measurement is physiological functioning of the human eye and its spectral sensitivity in photopic (day) vision.

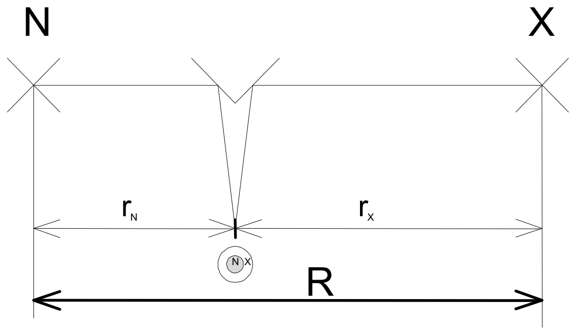
Photometry is divided according to the principle of the measurement to ***visual photometry*** and ***physical photometry***.

Visual photometry
is the optical measurement of photometric quantities with methods in which the human eye is directly involved in the measurement process. This type of photometry, also known as "subjective photometry", is based on the comparative method, in which we compare visually the unknown (measured) variable with a known (reference) variable. This comparison can be made on the basis of equal brightness, contrast or equal flickering. Measuring instruments that are used with this method are called visual photometers. The principle of operation is as follows: The eye is observing a "reference plane" - gypsum, which is alternately illuminated from known (reference) and unknown (measured) radiation. Based on the brightness, the contrast or flickering of both radiations we determine the value of the measured quantity.

The most common way of visual measuring of luminous intensity is with Lummer-Brodhun comparative method based on inverse square law: $E = \frac{I \cdot \cos \varepsilon}{r^2} \cdot \Omega_0 \quad \Rightarrow \quad I = E \cdot r^2 \quad \text{for } \varepsilon = 90^0 \text{ and } \Omega_0 = 1\,sr$

Comparison at rectangular light invasion: $\frac{E_X}{E_N} = \frac{{r_N}^2}{{r_X}^2}$

The principle of the measurement with method of weakening
Observing conditions: diffuse, reflective screen



$$\text{če x = n bo } L_X = L_N \Rightarrow I_X = I_N \cdot \frac{{r_X}^2}{{r_N}^2} \qquad I_X = I_N \cdot \frac{{r_X}^2}{\left(R - r_X\right)^2}$$

MEASUREMENT

Sources are attached to the bench (with a fixed distance between); we are moving only Lummer-Brodhun photometer (a box with the gypsum). When we see that the gypsum is equally illuminated by both sources, we measure the distance between the gypsum and the reference source and calculate the luminous intensity of a given resource.

Due to the different sensitivity of the eyes, perform a number of measurements, and from them calculate the average value.

When measuring, the stray light is limited with a shade.

The results of measurements

Measuring distance R= 200 cm Mains voltage U = 230 V Luminous intensity of reference I_N=

Test Lamp: ____

Unknown luminous intensity is calculated using the following equation:

$$I_X = I_N \cdot \frac{r_X^{\;2}}{(R - r_X)^2} \quad : \qquad \text{or} \qquad I_X = I_N \cdot \frac{r_X^{\;2}}{r_N^{\;2}}$$

No.	Person	r_N (cm)	r_X (cm)	I_X (cd)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
PV	Average value	---------------	--------------	

Results from the subjective method (mean) $I_{sub} =$

The average luminous intensity measured with personal measurements: $I_{pers} = \frac{I_{pers1} + I_{pers2}}{2} =$

$\Delta I = I_{sub} - I_{pers} =$

Deviation of personally measured values from the average value: $\Delta I\% = \frac{I_{sub} - I_{pers}}{I_{sub}} \cdot 100\% =$

COMMENTS

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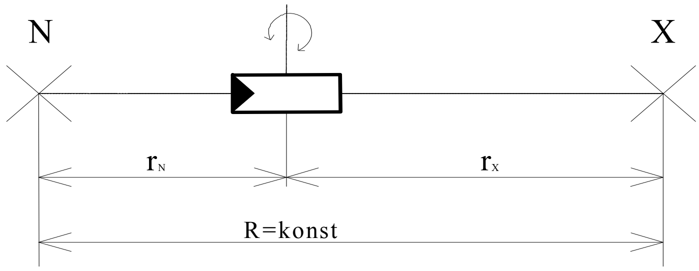
Physical photometry

is the measurement of optical (photometric) quantities with physical detectors. These are specific elements which under the influence of radiation cause measurable physical effects. This method differs from visual photometry because the human eye is replaced by the physical receiver that is sensitive to light.
Measuring instruments and devices used in physical photometry are called physical photometers. The basic element of every physical photometer is the so-called physical receiver or detector. When measuring the optical quantities photo-elements are mainly used physical receivers. These receivers have a feature to turn visible radiation (light) into electrical current. Phenomenon that accompanies this change is called the "photoelectric effect". In the physical sense is defined as the interaction between radiation and matter, which causes the absorption of photons and the formation of free electrons.

In previous exercises we used our eyes to identify where the gypsum is equally illuminated from reference and unknown sources. In this exercise we will replace our eyes and gypsum with photo-element, which will be inserted between the reference and the measured source. An output of photo-element is an electric current which is directly proportional to the illuminance of the detector. The current is extremely small, therefore, measured by μA meter. With fixed reference and unknown source, move a trolley with a photo-element in both directions and read the distance.

$$E_N = E_X$$

$$I_X = I_N \cdot \frac{r_X^2}{r_N^2}$$



Measuring the distance R between the reference and unknown source is constant.

The results of measurements

Measuring distance R= 200 cm Mains voltage U_{omr}= 230 V

Luminous intensity of reference I_N=_____ cd

No.	r_N (cm)	r_X (cm)	I_X (cd)
1			
2			
3			
4			
5			
PV	----------	----------	

The result of objective method I_{obj} = _______ cd

Results from the subjective method (the result of Exercise 1a) I_{sub} = _______ cd

Comparison of subjective to objective method: $I_{sub} - I_{obj}$ = _______ cd

Deviation of subjective method from objective method $\frac{I_{sub} - I_{obj}}{I_{obj}} \cdot 100\% =$ _______ %

COMMENTS

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EXERCISE 2

Luminous flux Φ (lm) and luminous efficiency η (lm/W)

Each light source emits energy in the space around. Luminous flux is the total emitted power of radiation of a light source, which is evaluated by human eye as a light.
Luminous flux is measured in lumens (lm). Lumen is a derived unit from international measurement units (SI) and is defined as a luminous flux of a point light source with luminous intensity in all directions equal to 1 cd (Candela) to a solid angle of 1 sr (steradian).

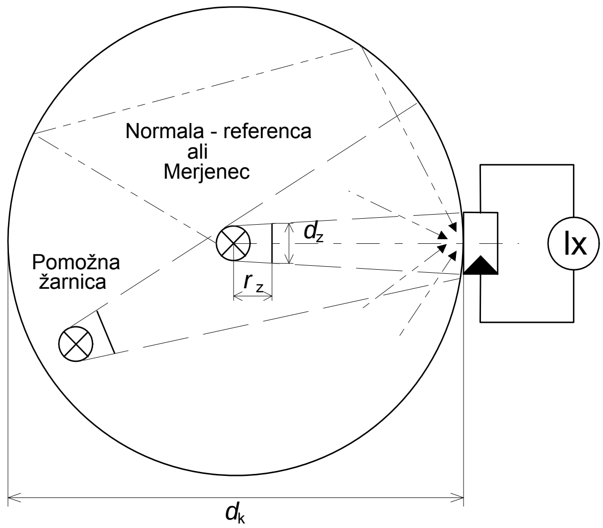
Luminous flux is measured using an integrating sphere and photometric equipment.

Integrating sphere has an inner wall coated with a special coating. On the sphere there is an opening, which accommodates a photoelectric detector. In the interior of the sphere there is also installed a screen, which prevents the light from a light source to be emitted directly to the detector.
Photoelectric detector measures illuminance, which in certain circumstances is directly proportional to the luminous flux of the source. In this way, we can measure the unknown flux, if the device is calibrated to a normal light (reference light source).

Photometric equipment is lx - meter or in our case photo-element and μA - meter

Illuminance on the inner walls of the sphere is proportional to luminous flux if ρ (reflexivity) is constant throughout the interior of the sphere and the surface is ideal diffuse. In addition, the equations assume that the sphere is completely empty, and that the reflected light from walls comes freely to detector. The presence of a light source of finite size in the interior of a sphere or a violation, breach of these terms and conditions. In addition, the violation is also a window for installation the detector and a screen, which prevents the direct flux to photo-element. To override these disorders we add extra bulb into the sphere.

In luminaries we use a variety of lighting sources. Sources differ in performance, light color and light efficiency. For public lighting are used mainly sources with high luminous efficiency. At the exercise we will measure the luminous efficacy of the following sources: incandescent lamp, halogen lamp, fluorescent lamp, LPS lamp, HPS lamp, HP Mercury lamp, metal halide lamps, a mixed light source and LED. Luminous efficiency is the ratio of emitted luminous flux and the consumed electrical power. Calculated with next equation: $\eta = \frac{\Phi}{P}$



The measurement of luminous flux should be done prior to the luminous efficiency calculation
Since we have a photo-element connected to μA-meter will be operated with the current and not illuminance. We know that the current through photo-element and illuminance are linearly dependent. When doing measurements we should be careful of the voltage, which is connected to a light source to keep in nominal values.

The measurement procedure luminous flux:

In integrating sphere switch on the reference lamp with known luminous flux ϕ_{norm} and measure the current i_{norm} through photo-element, then switch off and remove the reference lamp. Insert the measured lamp, wait until it comes stabile and measure the current through photo-element.
Then we can start calculating the luminous flux of the measured lamp:

$$\Phi_{mer} = \Phi_{norm} \cdot \frac{E_{mer}}{E_{norm}} = \Phi_{norm} \cdot \frac{i_{mer}}{i_{norm}}$$

Make sure that the light source is heated to the nominal value. In addition, we also measure the electrical parameters (voltage, current, power).

Results of the measurements

$\phi_{norm} =$ lm Luminous flux of reference lamp

$i_{norm} =$ μA Current through photo-element with lit reference lamp

Light source	Light source / name, type, power
incandescent lamp	
halogen lamp	
fluorescent Lamp	
HP Mercury lamp	
LPS lamp	
HPS lamp	
Metal-halide lamp	
Mixed light lamp	
LED	

Light source	Voltage	The current through the light source	Total Harmonic Distortion-current	Apparent Power	Active power	Power factor	Current through photoelement - measurand	**Luminous flux**	**Luminous efficiency**
	U [V]	***I*** [A]	***THDI*** [%]	***S*** [VA]	***P*** [W]	***cos*** φ	i_{mer} [μA]	ϕ [lm]	η [lm/W]
incandescent lamp	230								
halogen lamp	230								
fluorescent Lamp	230								
HP Mercury lamp	230								
LPS lamp	230								
HPS lamp	230								
Metal-halide lamp	230								
Source for mixed light	230								
LED	230								

COMMENTS

EXERCISE 3

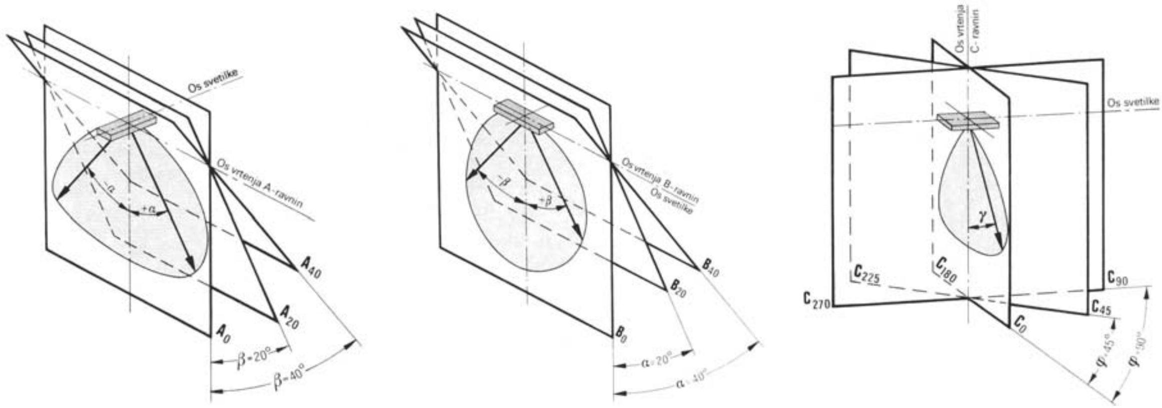
Angular distribution of intensity

For the evaluation of photometric properties of luminaires these photometric characteristics are most important: the distribution of luminous flux, the angular distribution of luminous intensity, the distribution of luminance and light efficiency. For us the most important is the spatial distribution of luminous intensity.

The spatial distribution of luminous intensity

To display light distribution of luminous intensity in photometric practice the following types of diagrams: the polar diagram, iso-candel diagram and Rousseau diagram.

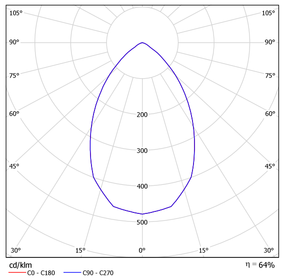
Polar diagram represents the most common form of presentation of the angular distribution of luminous intensity. In use are three systems of displaying: A-system of planes, B-system of planes and C system of planes. Among all the most widely used is internationally agreed system of C-planes. Individual half-plane C-system are labelled according to their angle of rotation of 0^0 to 360º.



a b c

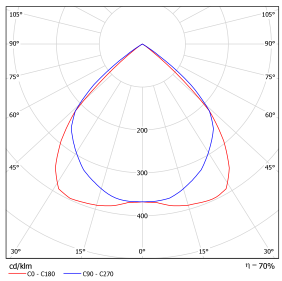
The polar diagram of A-system of planes (a), B-system of planes (b) and C-system of planes (c)

Angular distribution of the luminaire can be rotationally symmetric or asymmetric. Diagram of the light distribution for the first type of luminaire is illustrated by a single curve (right picture above). Diagram for the second type of luminaires contains several curves, with each relating to a certain C-plane. In luminaire symmetrical distribution to two main planes (for example, fluorescent luminaires), a diagram contains of two main curves, wherein each relating to one principal plane or. half-plane (right picture bottom).



All polar diagrams of the light distribution are reduced to 1,000 lumens luminous flux. In this way it is possible to use the same diagram for the light sources of the same dimensions, but different value of the luminous flux.

Rousseau diagram *serves for the calculation of the total luminous flux of the luminaire. The basis of the Rousseau diagram is a polar diagram.*



MEASUREMENT:

With a goniophoto meter measure the light distribution diagrams for the main C-planes (C0, C30, C60 and C90). To measure the luminous intensity distribution measure illuminance in points with different gamma - vertical angles (0^0 to 90^0) according to the lamp and at various positions (rotation) of the lamp. Calculate luminous intensity from illuminance, but we have to take into account the correction factor, since luminaire is not a point source and the scaling factor, because the flux source in the lamp more than 1000 lm.

The results of measurements

Input data:

Luminous flux of the light source (lamps) in luminaire	ϕ_V=	lm
Measuring the distance light – photometer head	r_m=	m
Diameter (largest dimension of luminous part) of the lamp	p=	m

Luminous intensity I (cd) is expressed by the equation:

$$E = \frac{I \cdot \Omega_0}{r_m^{\;2}}$$

Taking into consideration the correction factor, which is the result of non-point lighting:

$$\mathrm{F_{kor}} = 1 + \left(\frac{p}{r_m}\right)^2 =$$

Scaling factor:

$$\mathrm{F_{norm}} = \frac{1000\ lm}{\phi_v} =$$

Specifically referenced intensity perpendicular under the lamp, which is not normalized:

$$I_0 = F_{kor} \cdot r_m^{\;2} \cdot E_{y=0} = \qquad \text{cd}$$

Normalized luminous intensity:

$$I_{\gamma 1000}\,(\text{cd}) = F_{kor} \cdot F_{norm} \cdot r_m^{\;2} \cdot E$$

Calculate the product of constant coefficients and with it (in the table) multiply the measured illuminance:

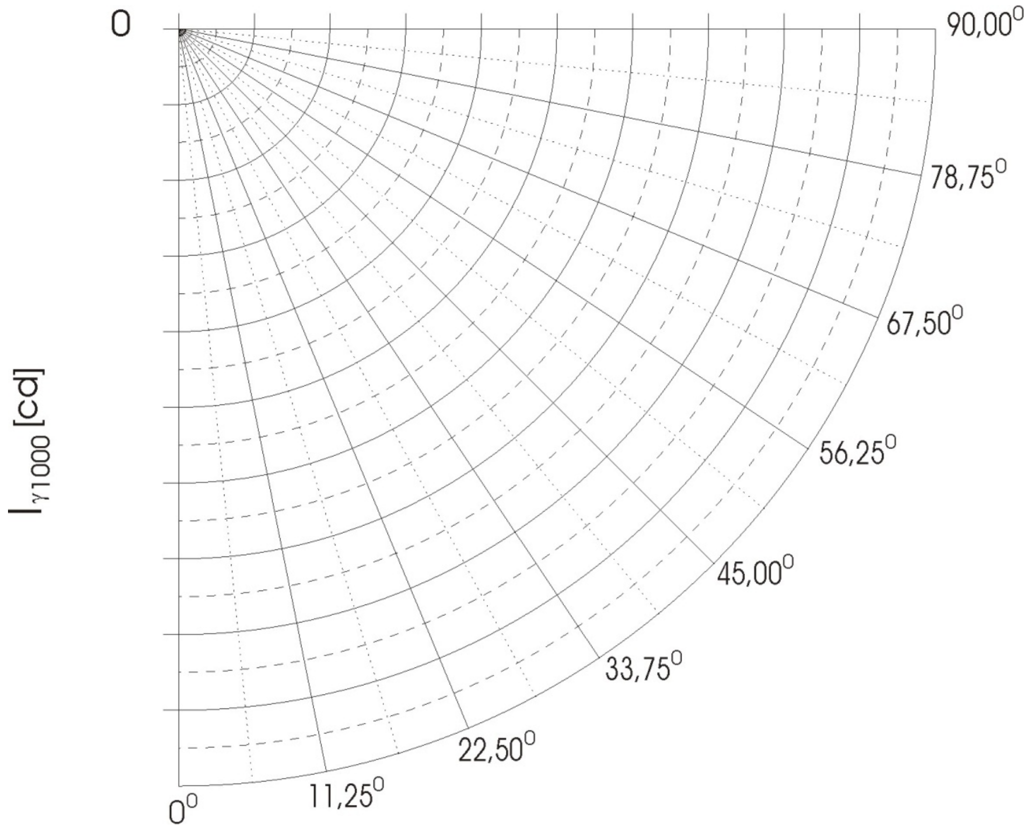
$$F_{kor} \cdot F_{norm} \cdot r_m^{\;2} =$$

Table of measurements

Fill in the table. Gray columns are measured values and the other are calculated according to the formula above.

γ (^{0})	E_{C0} (lx)	E_{C30} (lx)	E_{C60} (lx)	E_{C90} (lx)	$I_{\gamma 1000\text{-}C0}$ (cd)	$I_{\gamma 1000\text{-}C30}$ (cd)	$I_{\gamma 1000\text{-}C60}$ (cd)	$I_{\gamma 1000\text{-}C90}$ (cd)
0,00								
5,63								
11,25								
16,88								
22,50								
28,13								
33,75								
39,38								
45,00								
50,63								
56,25								
61,88								
67,50								
73,13								
78,75								
84,38								
90,00								

Draw all 4 curves in polar diagram. Read the data from the table above.



COMMENTS:

EXERCISE 3 - HOMEWORK

Luminous flux of the luminaire

Flux, which is emitted from the light source or luminaire, is equal to the product of luminous intensity and solid angle through which the light is emitted, bearing in mind that the intensity depends on the angle of observation (spatial distribution of luminous intensity).

$$\Phi = I \cdot \Omega$$

Where:

Φ luminous flux [lm]
I luminous intensity [cd]
Ω solid angle [sr]

Example:
What flux is emitted by a candle, where its luminous intensities in all directions are the same and are 1,2 cd?

$$\Phi = I \cdot \Omega = 1.2 \text{ cd } \cdot 4\pi = 15{,}08\ lm$$

Example:
The light source emits light with a luminous intensity of 60 cd only in the lower hemisphere. What is the luminous flux of the source?

$$\Phi = I \cdot \Omega = 60 \text{ cd } \cdot 2\pi = 377{,}0\ lm$$

In general, the luminous intensity depends on the angle of observation and therefore, for calculation of the total luminous flux is necessary to integrate product of luminous intensity and solid angle:

$$\phi = \int I \cdot d\Omega$$

As mentioned above it's possible to calculate total luminous flux from angular distribution of luminous intensity.

Rousseau's diagram allows the determination of the total luminous flux of the luminaire. Surface element (area) on a sphere within the solid angle corresponding to the peak in the centre of the sphere (lamps) covers in Rousseau diagram the area:

$$\Delta A_k = 2 \cdot \pi \cdot r \cdot s$$

Luminous flux is by definition $\Phi = I \cdot \Omega$, can be assembled from parts $\Phi = \sum I_{\Delta\Omega} \cdot \Delta\Omega$, where $\Delta\Omega = \frac{\Delta A_k}{r^2}$.

Luminous flux is therefore obtained from the equation:

$$\Phi = \sum I_{\Delta\Omega} \cdot \frac{2\pi \cdot r \cdot s}{r^2}$$

Where $I_{\Delta\Omega} = v_{sr} \cdot s$ and v_{sr} - average height and s - width of the column luminous intensity I (cd) of Rousseau chart.

Taking into account the scale of luminous intensity M_{cd}:

$$M_{cd} = \frac{cd}{mm}$$

and the radius of the polar diagram, r = 100 mm, the luminous flux of the luminaire can be calculated with:

$$\Phi = \sum v_{sr} \cdot s \cdot \mathrm{M}_{\mathrm{cd}} \cdot \frac{2\pi}{r}$$

The above equation is valid if we have a rotationally symmetrical light, as we anticipate that the same angular distribution is repeated for all the C plane (2π). If the lamp is not rotationally symmetrical, plot Rousseau diagram for each C-plane and calculate the proportion of luminous flux for a plane or half-plane.

Insert the data into Rousseau diagram. From the diagram we can read the average height and width of columns. For greater accuracy average height and width should be calculated.

$$s_i = (\cos\gamma_{i-1} - \cos\gamma_i)\cdot 100$$

$$s_1 = (\cos 0^0 - \cos 5{,}63^0)\cdot 100 = (1 - 0{,}9951)\cdot 100 = 0{,}48\ mm$$

$$v_{sr_i} = \frac{(I_{\gamma 1000_i} + I_{\gamma 1000_{i-1}})}{2}\cdot\frac{1}{M_{cd}}$$

γ (^{0})	E (lx)	$I_{\gamma 1000}$ (cd)	v_{sr} (mm)	s (mm)	$v_{sr}\cdot s$ (mm^2)
0,00			-----------	-----------	-----------
5,63				0,48	
11,25				1,44	
16,88				2,38	
22,50				3,31	
28,13				4,20	
33,75				5,05	
39,38				5,85	
45,00				6,59	
50,63				7,27	
56,25				7,88	
61,88				8,42	
67,50				8,87	
73,13				9,24	
78,75				9,52	
84,38				9,71	
90,00				9,80	
				$\Sigma\ v_{sr}\cdot s$	

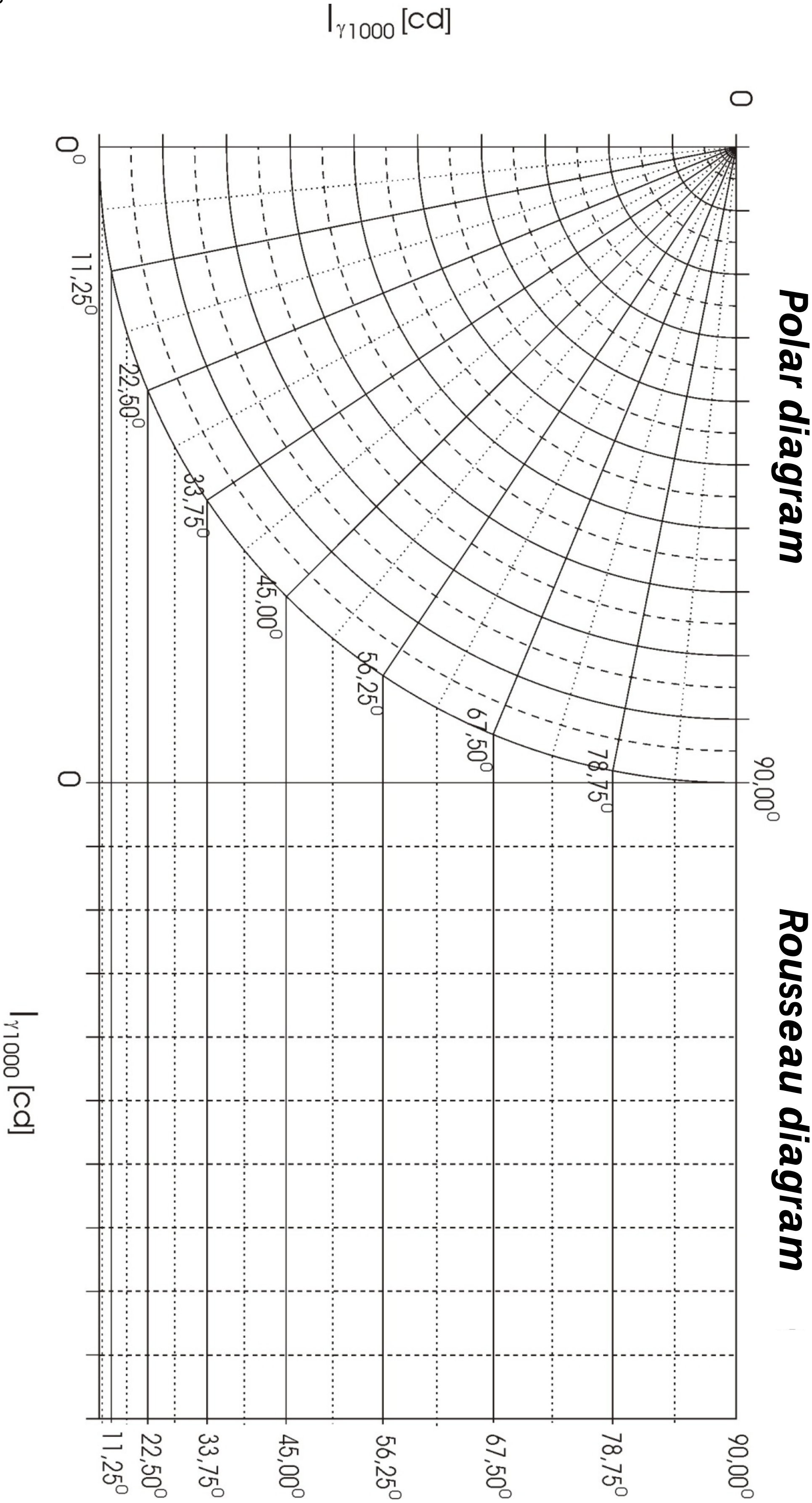
The first two columns can be copied from the previous table (e.g. data for C0), and the third column is calculated according to the formula above. Make the same table for the other three C planes and calculate the area of a area, which is a limited by a function of luminous intensity in Roussou chart.

Homework should be done with computer. Send your results via e-mail of via Echo e-classroom. Send original files (.xlsx or similar). In case I get two or more apparently similar files, then positive grade goes only to the first student.

Task:

- Draw the polar diagrams for measured C-planes. Keep in mind that the half-planes C0-C180, C90-C270 should be combined.
- Draw a Rousseau diagram for all measured half-planes (keep an eye on the y axis).
- Calculate the flux for each C plane and the whole luminaire, if you know that the quadrants of C planes are symmetrical to each other (the luminaire is symmetrical in axis C0-C180 and C90-C270).
    - All graphs must have (on the graph) your name and student number! Homework without this will be automatically rejected!

Our diagram:



Graphs in Excel must follow the shape of the above graph.

Calculation of the luminous flux of one C plane:

$$r = 100 \;\; mm \;\; (radius of \;\; diagram)$$

$$\phi_{C0}' = \sum v_{sr} \cdot s \cdot M_{cd} \cdot \frac{2\pi}{r} = \qquad \text{lm}$$

Thus, we calculated the luminous flux of the luminaire in the lower half space, if the lamp is rotationally symmetrical, and if installed light source would have a luminous flux 1000 lm.

In the same way it is necessary to calculate the luminous flux of the other C-plane (C30, C60 and C90)

C plane	*Area in Rousseau diagram [mm²]*	Luminous flux of a plane *[lm]*
C0		
C30		
C60		
C90		

Determine the total luminous flux of the lamp by the equation below:

$$\phi = \frac{\phi_{C0}' + \phi_{C30}' + \phi_{C60}' + \phi_{C90}'}{4} = \qquad \text{lm}$$

Our luminaire are equipped with any light source, so we have taken into account the scaling factor. Luminous flux of our luminaire is:

$$\phi_{sv} = \frac{\phi}{F_{norm}} = \frac{\qquad}{\qquad} = \qquad lm$$

Calculate the efficiency of the luminaire. Keep in mind that we have normalised the luminous intensity in a polar diagram to the luminous flux of 1000 lm.

$$\eta_{sv} = \frac{\phi}{\phi_z} \cdot 100 \;\; \% = \frac{\qquad lm}{1000{,}00 \;\; lm} \cdot 100\% = \qquad \%$$

The technical characteristics of the luminaire

Characteristics	Symbol	value
Nominal operating efficiency luminaire	η_{sv}	
Luminous flux of the luminaire	ϕ_{sv}	
Power consumption of the luminaire	P_{sv}	
Operating voltage	U_{obr}	

COMMENTS

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Reference:

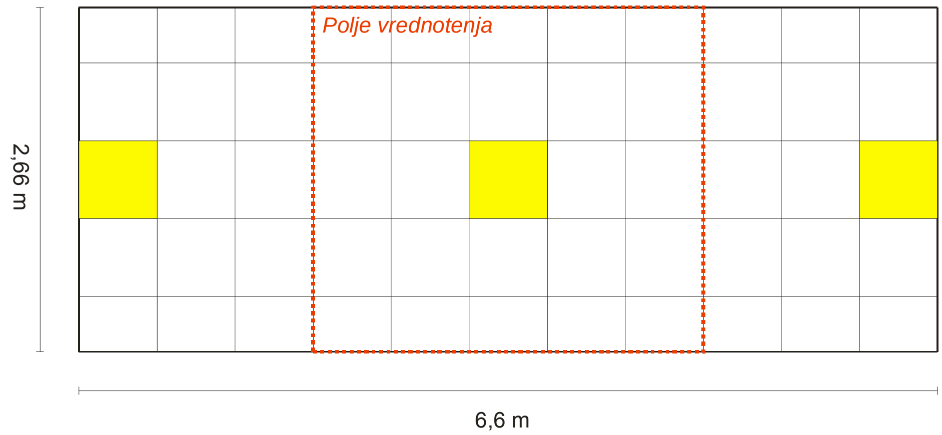
- http://www.ies.org/PDF/100Papers/012.pdf
- http://books.google.si/books?id=M24776VXDUgC

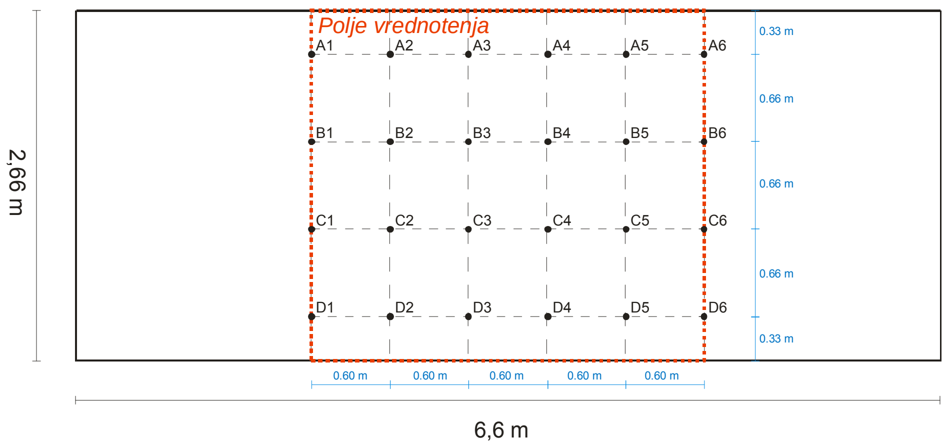
EXERCISE 4

MEASUREMENT OF ILLUMINANCE

After the installations of the luminaries in a newly constructed or renovated building it is necessary to carry out measurements of the illuminance and to determine if the whole installation is in compliance with the needs of users and the standard.

In the hallway, which was recently renovated, carry out measurements of the illuminance on the ground in 24 points. Due to the presence of daylight it is necessary to carry out the measurements twice, first with the lighting switched on and in the second measurements with the lighting switched off. With artificial lighting we should provide adequate visual environment in total darkness. Therefore, from the values measured with artificial lighting and daylight subtract values measured with only daylight present. When doing so, care must be taken that the weather conditions do not change!





For comparison check what is written in the standard ***EN 12464/1 Light and lighting – Lighting of work places, Part 1: Indoor work places***

Spaces for education					
Type of interior, task or activity	$\bar{E}_{vz}$ lx	GR_L -	U_0 -	R_a -	**Remarks**
Classrooms, tutorial rooms	300	19	0,6	80	Lighting should be controllable.
Classroom for evening classes and adults education	500	19	0,6	80	Lighting should be controllable.
Lecture hall	500	19	0,6	80	Lighting should be controllable to accommodate various A/V needs.
Black board	500	19	0,7	80	Specular reflections shall be prevented. Presenter/teacher shall be illuminated with suitable vertical illuminance.
Demonstration table	500	19	0,7	80	In lecture halls 750 lx.
Art rooms in art schools	750	19	0,7	90	T_{cp} > 5000 K
Technical drawing rooms	750	16	0,7	80	

Practical rooms and laboratories	500	19	0,6	80	
Circulation areas, corridors	100	25	0,4	80	
Student common rooms and assembly halls	200	22	0,4	80	
Teachers rooms	300	19	0,6	80	

Values given in the standard are always maintained average values in this case spatial average values, because the illuminances in different parts of corridor are different. To avoid excessive differences between light and dark areas, uniformity is also defined in the standard. The required uniformity of lit task areas can be found in the fourth column.

Measuring data

Measuring point	Artificial + Daylight [lx]	Daylight [lx]	Artificial lighting [lx]
A1			
B1			
C1			
D1			
A2			
B2			
C2			
D2			
A3			
B3			
C3			
D3			
A4			
B4			
C4			
D4			
A5			
B5			
C5			
D5			
A6			
B6			
C6			
D6			

Calculate the spatial average value of illuminance:

$$E_{mean} = \frac{\sum_{i=1}^{n} E_i}{n} =$$

and uniformity: $u = \frac{E_{\min}}{E_{mean}} =$

Compare the measured values with the values in the standard!

COMMENTS:

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