

## Calculation of the photometric parameters in public lighting

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### Introduction

Calculation of performance parameters of public lighting are performed in a grid of points defined by the CIE publication 140 and European standard EN 13201-3. Calculation grid defined in these documents was created at a time of low powerful computers and less precise measuring technology. Distance between two adjacent calculating points may be a 3 m, depending on the geometry of the road. This arrangement is sparse view of the fact that the present used computer can cope with much more denser grid in a short time and the measurement can be performed by the luminance analyzers. Between the results of the calculation with different grid densities of calculation points may be significant differences. This fact may influence the new optical systems and some LED luminaires which as found by measurement may contain various local extremes in the luminous intensity distribution curve. In calculating of performance parameters of public lighting and given the current used grid density these extremes may fall between the calculation points and thus may not be included in the calculation. The solution is to propose a new density of calculation points which would be designed with respect to current possibilities of computer technology.

### Calculation of the photometric parameters

Calculation field has a exactly defined position in the transverse and longitudinal direction (Fig.1). In the longitudinal direction on a straight road, the field of calculation should lie between two consecutive luminaires in the same row. In the transverse direction, it should cover the whole carriageway width for roads without a central reservation, and the width of one carriageway for roads with a central reservation. Observer position is defined in the axis of each lane in height 1.5 m (it corresponding to the height of the observer eye in the car) and at a distance of 60 m before the first luminaire in the field of calculation which results from the application area of R-tables which are measured for the angle of observation  $\alpha = 1^\circ$ . R-Table may be used in the range of angle of observation from  $\alpha = 0.5^\circ$  to  $\alpha = 1.5^\circ$ . At a height of observer eye 1.5 meters, it represents observer distances from 57 m to 172 m. In the CIE 30.2 [3] was defined position of the observer in 1/4 of lane closer to the right side. Observer position by CIE 140 better reflects the real position. Calculation of the luminance is shown in Fig.2.

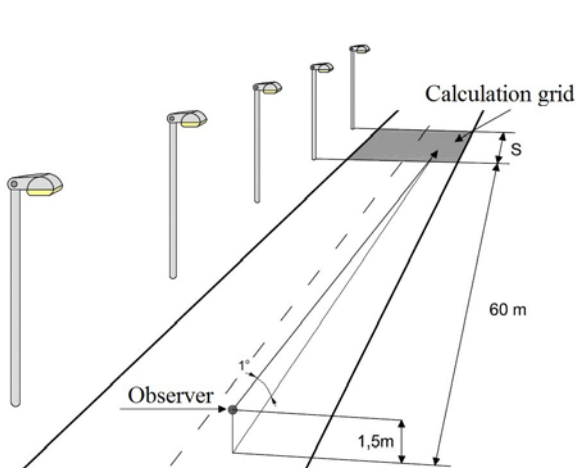


Fig.1. Location of calculation field LIDC

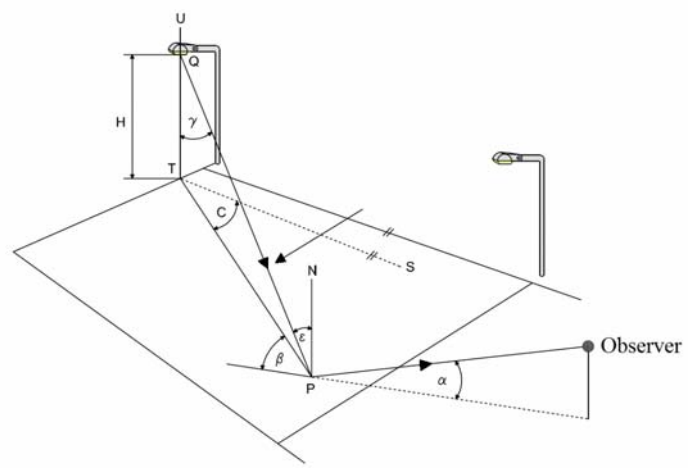


Fig.2. Calculation of luminance

ST is the longitudinal direction, Q is the photometric centre of the luminaire, QT is a vertical axis, PN is the normal at P to the road surface, C is the photometric azimuth,  $\beta$  is the angle of deviation,  $\gamma$  is the vertical photometric angle,  $\alpha$  is the angle of observation,  $\epsilon$  is the angle of incidence

Layout of calculation points is shown in Fig. 3. The number of calculation points in the longitudinal direction is defined by (1), in the transverse direction by (2).

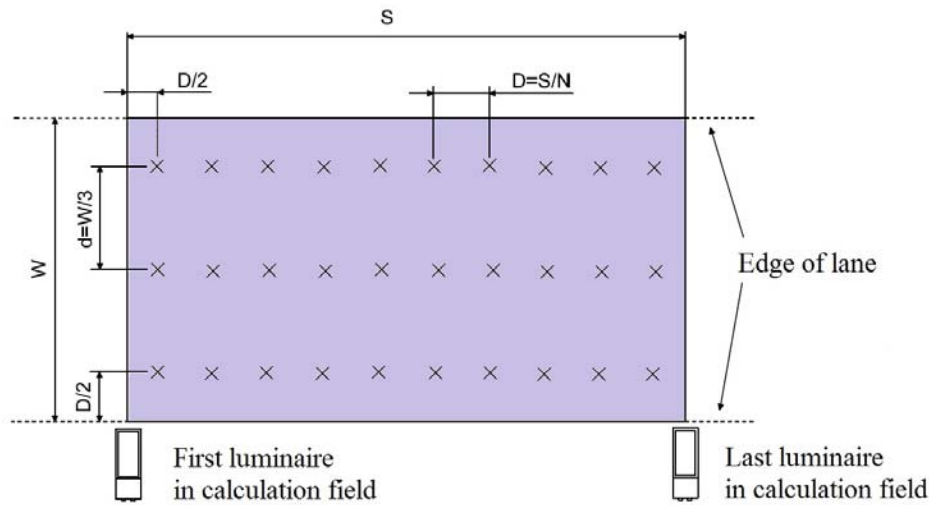


Fig.3. Calculation points

$$D = \frac{S}{N} \quad (1) \quad d = \frac{W}{3} \quad (2)$$

D is the spacing between points in the longitudinal direction,  
S is the spacing between luminaires in the same row,  
N is the number of calculation points in the longitudinal direction with the following values:  
for  $S \leq 30$  m,  $N = 10$ ;  
for  $S > 30$  m, the smallest integer giving  $D \leq 3$  m.  
The first transverse row of calculation points is spaced at a distance  $D/2$  beyond the first luminaire,  
d is the spacing between points in the transverse direction,  
W is the width of the lane, in metres

Currently, the number of calculation points in the field of calculation for lane is in the range  $3 \times 10$  to  $3 \times 14$  points, depending on the geometry of communication and luminaires arrangement. Given the progress in computer technology and automated measurement of photometric parameters of luminaires is currently used thicker angular interval. In CIE 140 are required measuring angular intervals in photometric azimuth (C) shall at most be  $5^\circ$  and in vertical photometric angle ( $\gamma$ ) shall at most be  $2.5^\circ$ . Currently used goniophotometers depending on the type are capable of measuring with the resolutions about  $0.5^\circ - 1^\circ$ . Using the thicker intervals have a major impact in modern LED luminaires which, depending on the optical system may include local extremes. Using a less dense interval would not be these extremes captured. When the local extremes are not included in the calculation we get misstatement results(Lav, U0, UI). These extremes in angular intervals can cause glare.

## Simulation

The simulation will be considered with the following assumptions:

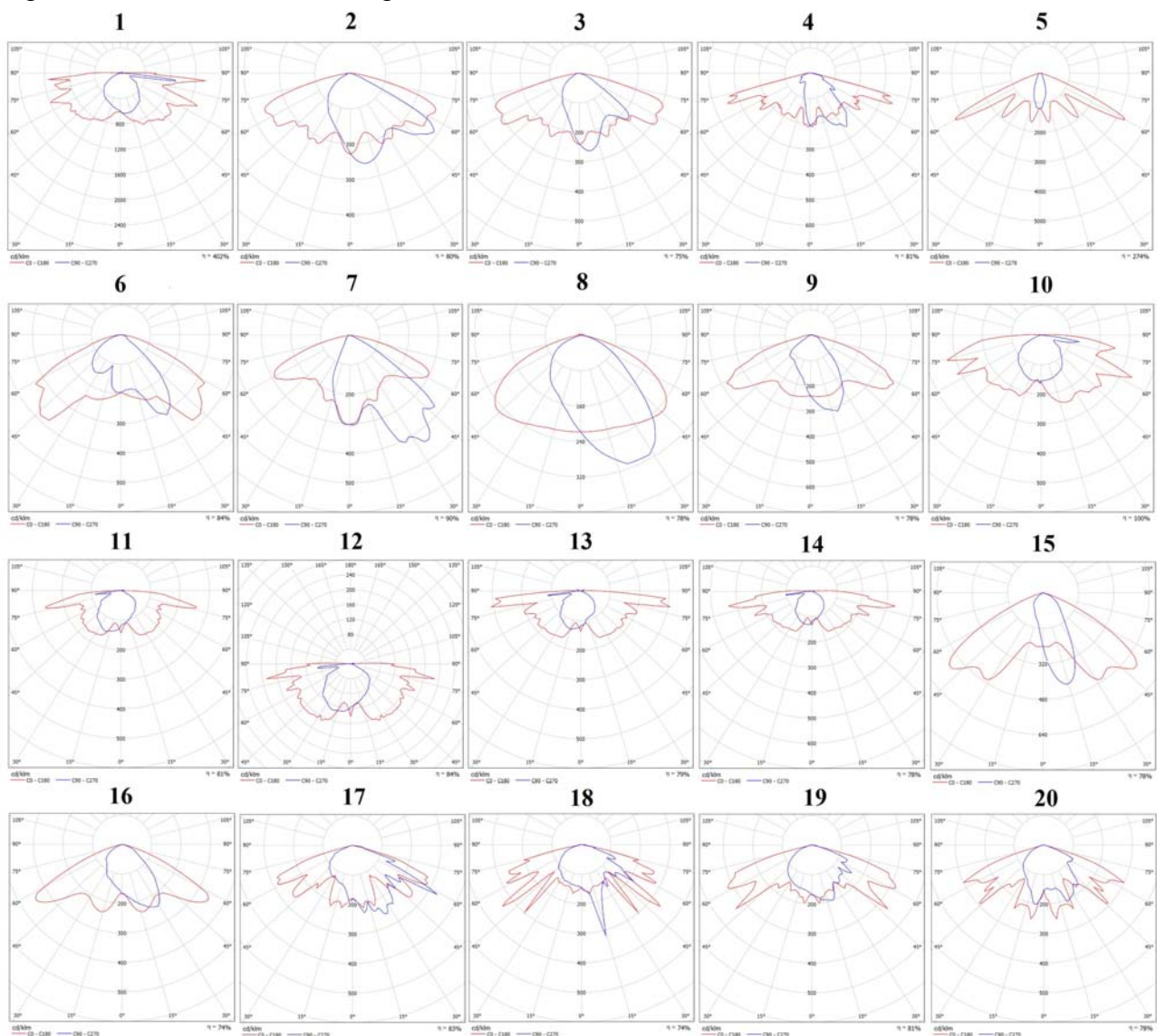
- not considering the lighting classes,
- the road surface is unified for all types of communication,
- Maintenance factor is equal to 1.

Lighting classes can be neglected due to the fact that in the simulations will examine the impact of various LIDC to the resulting photometric parameters. In the calculation will change the density of calculation points and types of LIDC, then investigated the influence of final density to the selected photometric parameters which are the average luminance (Lav), the overall uniformity (U0), the longitudinal uniformity (UI). For all calculations will use road surfaces R3 presenting asphalt surface with aggregate composed of a minimum of 60% gravel of size greater than 10 mm. Given that it will consider percentage change of individual parameters can be neglected the impact of the maintenance factor. For the simulation was selected geometry shown in table 1. LIDC were selected so that represent the widest possible range used LIDC in road lighting (Fig.4).

Table 1. Geometry using in simulation

Geometry	Calculation	
	1-4, 6-16	5
Road width	6 m	4 m
Number of lanes	2	1
Arrangement	single-sided left	
Mounting height	8 m	
Pole spacing	30 m	
Tilt angle	0°	
Overhang	0 m	

Fig.4. LIDC of luminaires using in simulation



In the calculations are used more settings of calculation grid. For each calculations are used calculation grid according table 2. The second (yellow) row of the table represents the basic layout of calculation points according to CIE 140, EN 13201-3. Other lines represent 0.5; 2; 4; 8 and 10-times densification points from the basic layout.

Table 2. Density of calculation points

Density	The number of calculation points in the transverse direction	The number of calculation points in the longitudinal direction
		$S \leq 30$ m
1	6	5
2	6	10
3	12	20
4	24	40
5	48	80
6	60	100

## Results of simulation

Calculated values of selected parameters of road lighting are shown in tables 3-5. In these tables are show values at various settings of density of calculation grid for each calculation. The geometry of the road and luminaire arrangement is shown in Table 1. Change of the resulting value of individual selected parameter is different and depends on the luminaire type and its LIDC. (Fig.4.) For luminaires containing a higher number of local extremes was the change of the individual parameters especially  $U_0$  and  $U_I$  greater.

Table 3. Calculated values of  $L_{av}$

Lav [cd/m <sup>2</sup> ]																				
Density	Calculation																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0,31	2,12	1,39	1,46	0,59	2,20	1,20	0,83	2,12	0,66	0,55	0,57	0,65	0,67	3,99	2,45	0,67	0,56	0,66	1,02
2	0,31	2,15	1,37	1,47	0,59	1,99	1,19	0,83	2,90	0,66	0,53	0,56	0,63	0,66	4,24	2,37	0,60	0,56	0,62	0,93
3	0,31	2,14	1,38	1,47	0,59	1,99	1,19	0,83	2,10	0,66	0,53	0,56	0,63	0,66	4,18	2,36	0,61	0,55	0,62	0,92
4	0,31	2,14	1,38	1,47	0,59	1,98	1,19	0,83	2,90	0,66	0,53	0,56	0,63	0,66	4,18	2,36	0,60	0,55	0,62	0,92
5	0,31	2,14	1,38	1,47	0,59	1,98	1,19	0,83	2,90	0,66	0,53	0,56	0,63	0,66	4,18	2,36	0,61	0,55	0,62	0,92
6	0,31	2,14	1,38	1,47	0,59	1,98	1,19	0,83	2,90	0,66	0,53	0,56	0,63	0,66	4,18	2,36	0,61	0,55	0,62	0,92

Table 4. Calculated values of  $U_0$

U0																				
Density	Calculation																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0,43	0,54	0,47	0,64	0,23	0,44	0,79	0,50	0,41	0,42	0,34	0,44	0,36	0,36	0,31	0,41	0,44	0,45	0,44	0,39
2	0,4	0,53	0,48	0,59	0,23	0,43	0,68	0,48	0,38	0,42	0,35	0,38	0,35	0,34	0,30	0,35	0,48	0,38	0,48	0,44
3	0,38	0,49	0,44	0,56	0,21	0,41	0,65	0,46	0,35	0,37	0,35	0,34	0,33	0,31	0,26	0,31	0,41	0,36	0,42	0,42
4	0,37	0,47	0,42	0,54	0,20	0,40	0,64	0,45	0,34	0,36	0,34	0,32	0,31	0,30	0,25	0,30	0,39	0,36	0,41	0,40
5	0,36	0,46	0,41	0,53	0,19	0,40	0,64	0,44	0,33	0,35	0,33	0,31	0,31	0,29	0,24	0,29	0,38	0,36	0,41	0,39
6	0,36	0,46	0,41	0,53	0,19	0,40	0,64	0,44	0,33	0,35	0,33	0,31	0,30	0,29	0,24	0,29	0,38	0,36	0,40	0,39

Table 5. Calculated values of  $U_I$

U_I																				
Density	Calculation																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0,86	0,83	0,85	0,68	0,23	0,51	0,68	0,59	0,70	0,71	0,70	0,85	0,80	0,84	0,40	0,48	0,60	0,51	0,58	0,58
2	0,81	0,75	0,75	0,68	0,22	0,45	0,58	0,59	0,64	0,70	0,67	0,76	0,79	0,78	0,38	0,39	0,39	0,55	0,43	0,46
3	0,78	0,74	0,7	0,67	0,20	0,45	0,56	0,58	0,61	0,71	0,66	0,70	0,72	0,74	0,38	0,38	0,34	0,54	0,47	0,40
4	0,76	0,72	0,7	0,65	0,21	0,44	0,54	0,58	0,59	0,70	0,65	0,69	0,73	0,74	0,37	0,36	0,34	0,51	0,44	0,36
5	0,75	0,72	0,7	0,64	0,20	0,43	0,54	0,57	0,59	0,69	0,64	0,68	0,72	0,74	0,37	0,35	0,34	0,49	0,42	0,36
6	0,75	0,72	0,69	0,64	0,20	0,43	0,54	0,57	0,59	0,69	0,64	0,68	0,72	0,74	0,37	0,35	0,33	0,49	0,42	0,36

In tables 6-8 and figures 5-7 are shown percentage changes of selected parameters. The results show that the density change in most cases does not have a major impact to the results of Lav. However have a not inconsiderable impact to U0 and UI. In 8 times densified of calculation grid will change resulting values of U0 approximately from 5 to 21% and UI approximately from 1 to 22%. It was found that a 10-times densification of calculation points has no effect on the resulting parameters and therefore is not necessary.

Table 6. Impact of changes the density of calculation grid to Lav

		$\Delta Lav$ [%]																			
Density	Calculation																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	0	-1,4	1,5	-0,7	0	10,6	0,8	0	-26,9	0	3,8	1,8	3,2	1,5	-5,9	3,4	11,7	0	6,5	9,7	
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
3	0	-0,5	0,7	0	0	0	0	0	-27,6	0	0	0	0	0	-1,4	-0,4	1,7	-1,8	0	-1,1	
4	0	-0,5	0,7	0	0	-0,5	0	0	0	0	0	0	0	0	-1,4	-0,4	0	-1,8	0	-1,1	
5	0	-0,5	0,7	0	0	-0,5	0	0	0	0	0	0	0	0	-1,4	-0,4	1,7	-1,8	0	-1,1	
6	0	-0,5	0,7	0	0	-0,5	0	0	0	0	0	0	0	0	-1,4	-0,4	1,7	-1,8	0	-1,1	

Table 7. Impact of changes the density of calculation grid to U0

		$\Delta U0$ [%]																			
Density	Calculation																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	7,5	1,9	-2,1	8,5	0	2,3	16,2	4,2	7,9	0	-2,9	15,8	2,9	5,9	3,3	17,1	-8,3	18,4	-8,3	-11,4	
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
3	-5,0	-7,5	-8,3	-5,1	-8,7	-4,7	-4,4	-4,2	-7,9	-11,9	0	-10,5	-5,7	-8,8	-13,3	-11,4	-14,6	-5,3	-12,5	-4,5	
4	-7,5	-11,3	-12,5	-8,5	-13,0	-7,0	-5,9	-6,2	-10,5	-14,3	-2,9	-15,8	-11,4	-11,8	-16,7	-14,3	-18,8	-5,3	-14,6	-9,1	
5	-10,0	-13,2	-14,6	-10,2	-17,4	-7,0	-5,9	-8,3	-13,2	-16,7	-5,7	-18,4	-11,4	-14,7	-20,0	-17,1	-20,8	-5,3	-14,6	-11,4	
6	-10,0	-13,2	-14,6	-10,2	-17,4	-7,0	-5,9	-8,3	-13,2	-16,7	-5,7	-18,4	-14,3	-14,7	-20,0	-17,1	-20,8	-5,3	-16,7	-11,4	

Table 8. Impact of changes the density of calculation grid to UI

		$\Delta UI$ [%]																			
Density	Calculation																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	6,2	10,7	13,3	0	4,5	13,3	17,2	0	9,4	1,4	4,5	11,8	1,3	7,7	5,3	23,1	53,8	-7,3	34,9	26,1	
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	
3	-3,7	-1,3	-6,7	-1,5	-9,1	0	-3,4	-1,7	-4,7	1,4	-1,5	-7,9	-8,9	-5,1	0	-2,6	-12,8	-1,8	9,3	-13,0	
4	-6,2	-4,0	-6,7	-4,4	-4,5	-2,2	-6,9	-1,7	-7,8	0	-3,0	-9,2	-7,6	-5,1	-2,6	-7,7	-12,8	-7,3	2,3	-21,7	
5	-7,4	-4,0	-6,7	-5,9	-9,1	-4,4	-6,9	-3,4	-7,8	-1,4	-4,5	-10,5	-8,9	-5,1	-2,6	-10,3	-12,8	-10,9	-2,3	-21,7	
6	-7,4	-4,0	-8,0	-5,9	-9,1	-4,4	-6,9	-3,4	-7,8	-1,4	-4,5	-10,5	-8,9	-5,1	-2,6	-10,3	-15,4	-10,9	-2,3	-21,7	

■ increase, ■ decrease

Fig.5. Impact of changes the density of calculation grid to Lav

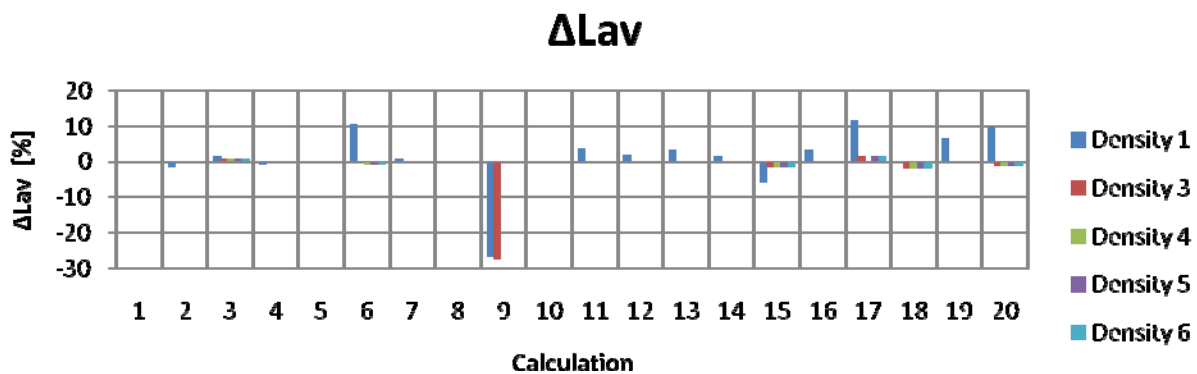


Fig.6. Impact of changes the density of calculation grid to U0

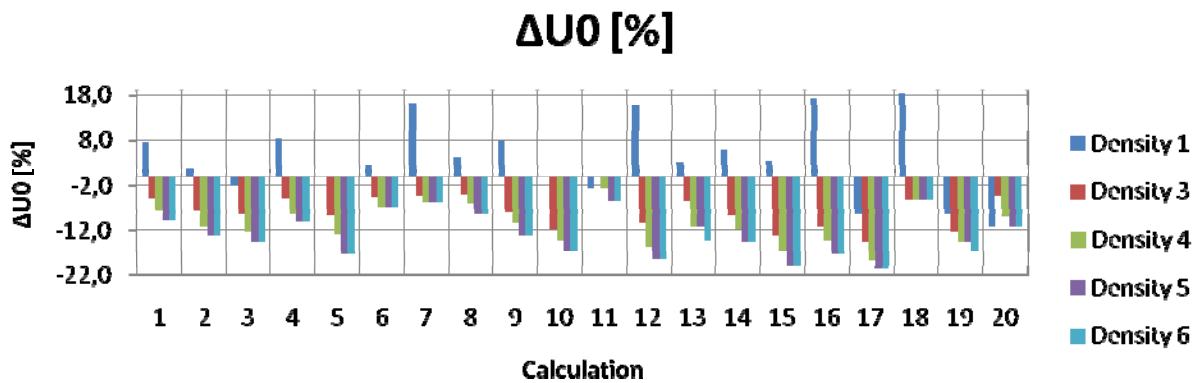
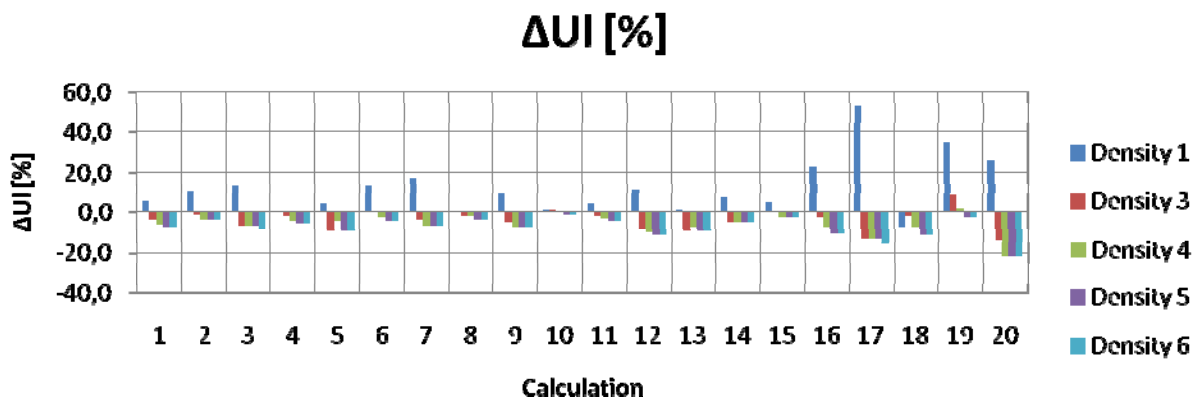


Fig.7. Impact of changes the density of calculation grid to UI



## Conclusion

It was found that the densification of calculation grid has impact on the resulting photometric parameters of public lighting. Calculation grid defined in standards was created at a time of less powerful computers and less precise measuring technology. Currently, the development of these devices has progressed and it is therefore necessary to consider the possibility of creating a new calculation grid with a greater density of calculation points. Creation of new calculation grid is necessary mainly because the new type of luminaires (LED, luminaires with faceted reflectors) contain local extremes in LIDC. If these local extremes are not included in the calculation we get inaccurate results (especially U0 and UI). Differences can be up to 22% as was shown in the simulation. In creation of new calculation grid can be considered 8 times densifying of calculation points, greater densification of points has not impact on the results. It is also necessary to think about densifying of measurement points because currently we can perform measurements by using luminance measuring camera.

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## References

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