Determining the Lamp Location in the Optical System of a Street Luminaire

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1. Introduction.

The computer design of luminaires privides vast possibilities for studying and optimization of their power and light characteristics.
The companies manufacturing luminaires combine modifications having light sources varying in type, power and size, housed in one body with a definite optical system.
The paper presents studies on the effect of the location of various light sources mounted in a single luminaire upon its efficiency and characteristics. The studies are conducted on the basis of the types of street luminaire construction common in Bulgaria, with an aluminum body functioning as a reflector.

2. Modelling. Settings.

The 3D model of the luminaire optical system is designed in AutoCAD. The luminaire model is imported into the software product for optical analysis Photopia [3], where the photometrical characteristics of reflector and the light source are assigned.
The parameters of the optical analysis following the probabilistic raytracing method are chosen in order to obtain most accurate results.
The main raytracing settings are:

- *Initial Source Rays.* Defines the total number of rays that will be emanated from the light source. Eight variants of modifying the initial source rays have been developed, from 10 000 to 20 000 000. The luminaire efficiency in not changing when the number of rays is of the order of 100 000 and above. To achieve an accurate and stabilized light intensity distribution, 500 000 rays and above are required.
- *Number of reflections*. Determines how far a ray will be followed before it is discarded and used as a criterion for terminating rays which interreflect many times. A number of calculations are performed with a rise in the number of reflections, the aim being to minimize the number of number of lumens lost in the luminaire (Unaccounted lumens), due to rays having reached their reflection limit. Unaccounted lumens percent is less than 0.1 % when the number of reflections is greater than seven.
- *Lamp Shadowing*. When the lamp shadow check is enabled, all rays emanating from the light source are checked to see if they intersect with any other surfaces on the lamp which block light. The 3D models of high pressure lamps used in the present work have the actual geometrical dimensions of the elements in their structure. Therefore, it is necessary to activate lamp shadowing check with 200 retries.
- *Spawn Limit*. Refers to the number of rays that are spawned upon a reflection or transmission of light. The results of the calculations performed while varying the spawn limit from 1 to 8 show that with the diffusing materials used in the given optical system no significant differences in the light characteristics of the individual versions are obtained.

- *Magnitude Threshold*. Sets the percentage of the initial ray magnitude at which a ray will be terminated. Photopia looks at both the magnitude threshold and the number of reflections when determining if a ray should be continued. Calculations have been performed about eight variants of modifying the magnitude threshold, and the results show that when magnitude threshold is equal to 1 %, the number of lumens lost in the luminaire is less than 0.1 %.

After analyzing the influence of the raytracing parameters on the correctness and accuracy of the results, the following final settings have been determined:

- Initial Source Rays 500 000
- Number of reflections 8
- Lamp Shadowing Enabled. Number of retries - 200
- Spawn Limit 1
- Magnitude Threshold 1 %

3. Analysis.

The paper presents studies aiming to extend the application and to improve the efficiency of this type of luminaries by varying the location of the lamp in the optical system. Two typical sizes of high-pressure sodium lamps are positioned in the street luminaire – 50W; 70W and 100W; 150W.

The photometrical analysis yields results about the following indicators in accordance with IES Roadway Classification of luminaire light distributions:

- Vertical light distribution - short, medium, long
- Lateral light distribution - Type I, II, III, IV, V
- Control of distribution above the maximum light intensity - full cutoff (FCO), cutoff (CO), semi cutoff (SCO), non cutoff (NCO)
- Maximum light intensity – value Imax (cd), vertical angle V (deg), horizontal angle H (deg).

The normal working position of lamps 100 W and 150 W in the luminaire determines the positioning of the coordinate system XYZ, the origin of which coincides with the centre of the lamp burner (x=0, y=0, z=0). The working position of lamps 50 W and 70 W correspond to coordinates of the centre of its burner (x=0, y=-50, z=0) – Figure 1.

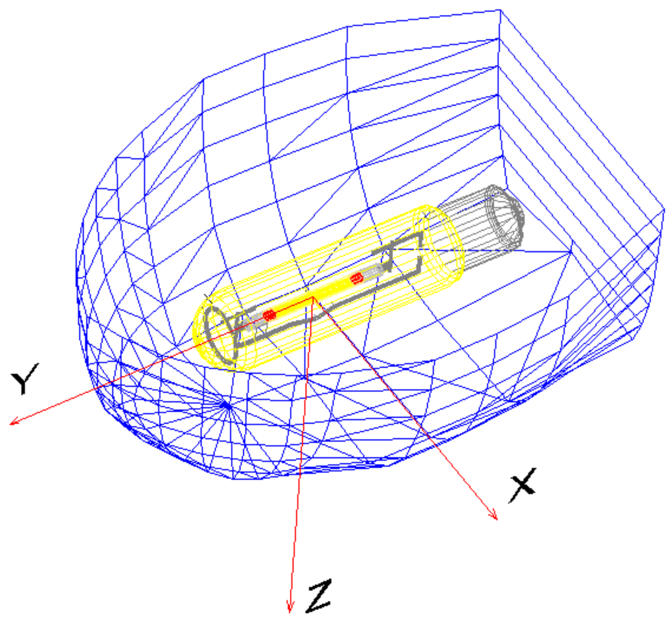

Figure 1

Table 1

	Y		-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50
Z= +10	IES Classification	Type	I	I	I	I	I	I	I	I	I	I	I	I	I
		Vertical	short	short	short	short	short	short	short	short	short	short	short	-	-
		Control	CO	CO	CO	CO	CO	CO	CO	CO	CO	FCO	CO	CO	CO
	Maximum Intensity	Imax	736	788	817	836	845	887	924	957	978	1037	1048	1108	1162
		V	52.5	55	55	55	55	57.5	55	55	55	55	52.5	52.5	52.5
		H	75	80	80	90	95	100	105	110	115	115	125	130	135
Z= 0	IES Classification	Type	II	I	I	I	I	I	I	I	I	I	I	I	I
		Vertical	short	short	short	short	short	short	short	short	short	short	short	short	short
		Control	CO	FCO	FCO	FCO	CO	CO	CO	FCO	CO	CO	CO	CO	FCO
	Maximum Intensity	Imax	778	802	831	834	918	901	917	959	1009	1016	1101	1073	1078
		V	60	60	60	60	60	60	60	60	60	60	60	57.5	60
		H	70	80	80	90	95	100	105	110	110	115	125	130	135
Z= -10	IES Classification	Type	II	II	I	I	I	I	I	I	I	I	I	I	I
		Vertical	short	short	short	short	short	short	short	short	short	short	short	short	short
		Control	CO	CO	FCO	CO	CO	FCO	CO	CO	CO	CO	CO	CO	CO
	Maximum Intensity	Imax	771	804	781	793	864	871	900	902	931	949	969	985	974
		V	65	65	62.5	65	65	65	65	65	65	65	65	65	65
		H	75	75	85	90	95	100	105	105	110	115	120	125	130
Z= -20	IES Classification	Type	II	II	II	I	I	I	I	I	I	I	I	I	I
		Vertical	medium	medium	medium	medium	medium	medium	medium	medium	medium	short	short	medium	short
		Control	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO
	Maximum Intensity	Imax	700	740	736	729	724	751	777	767	768	777	822	834	794
		V	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	70	67.5
		H	75	80	80	85	95	100	100	105	110	115	120	125	135
Z= -30	IES Classification	Type	III	II	II	II	I	I	I	I	I	I	I	I	I
		Vertical	medium	medium	medium	medium	medium	medium	medium	medium	medium	medium	medium	medium	medium
		Control	SCO	SCO	SCO	SCO	SCO	NCO	NCO	NCO	NCO	NCO	NCO	NCO	NCO
	Maximum Intensity	Imax	599	604	609	589	602	620	595	602	604	604	655	641	617
		V	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5
		H	70	75	80	85	95	100	100	105	110	115	120	125	130

Table 2

	Y		-60	-50	-40	-30	-20	-10	0	10	20	30	40	50
Z= +10	IES Classification	Type	I	I	I	I	I	I	I	I	I	I	I	I
		Vertical	short	short	short	short	short	short	short	short	short	short	-	-
		Control	CO	CO	CO	CO	CO	CO	CO	CO	FCO	CO	CO	FCO
	Maximum Intensity	Imax	717	752	764	796	823	867	849	875	910	919	950	942
		V	55	55	55	57.5	55	57.5	55	57.5	55	55	52.5	52.5
		H	80	85	95	95	100	105	110	115	120	125	130	140
Z= 0	IES Classification	Type	I	I	I	I	I	I	I	I	I	I	I	I
		Vertical	short	short	short	short	short	short	short	short	short	short	short	short
		Control	CO	CO	CO	CO	CO	CO	CO	FCO	FCO	CO	CO	CO
	Maximum Intensity	Imax	715	735	750	800	837	847	864	881	863	916	898	847
		V	57.5	60	60	60	60	60	60	60	57.5	60	60	60
		H	80	85	95	100	100	105	110	115	120	125	125	135
Z= -10	IES Classification	Type	II	II	I	I	I	I	I	I	I	I	I	I
		Vertical	short	short	short	short	short	short	short	short	short	short	short	short
		Control	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO
	Maximum Intensity	Imax	701	710	738	780	805	782	788	784	814	839	826	795
		V	65	65	65	65	65	65	65	65	65	65	65	65
		H	80	85	90	95	100	105	105	110	120	125	125	135
Z= -20	IES Classification	Type	II	II	I	I	I	I	I	I	I	I	I	I
		Vertical	medium	medium	medium	medium	medium	medium	medium	medium	short	medium	short	short
		Control	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO	CO
	Maximum Intensity	Imax	632	643	638	641	688	666	692	642	668	684	685	647
		V	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	70	67.5	70
		H	80	80	90	90	100	105	105	110	120	125	125	130
Z= -30	IES Classification	Type	III	II	II	I	I	I	I	I	I	I	I	I
		Vertical	medium	medium	medium	medium	medium	medium	medium	medium	medium	medium	medium	medium
		Control	SCO	SCO	SCO	SCO	SCO	SCO	SCO	SCO	SCO	SCO	SCO	NCO
	Maximum Intensity	Imax	534	528	510	540	527	538	527	507	499	538	538	524
		V	70	72.5	72.5	72.5	72.5	72.5	72.5	72.5	75	72.5	72.5	72.5
		H	80	80	85	95	100	100	105	115	115	125	125	135

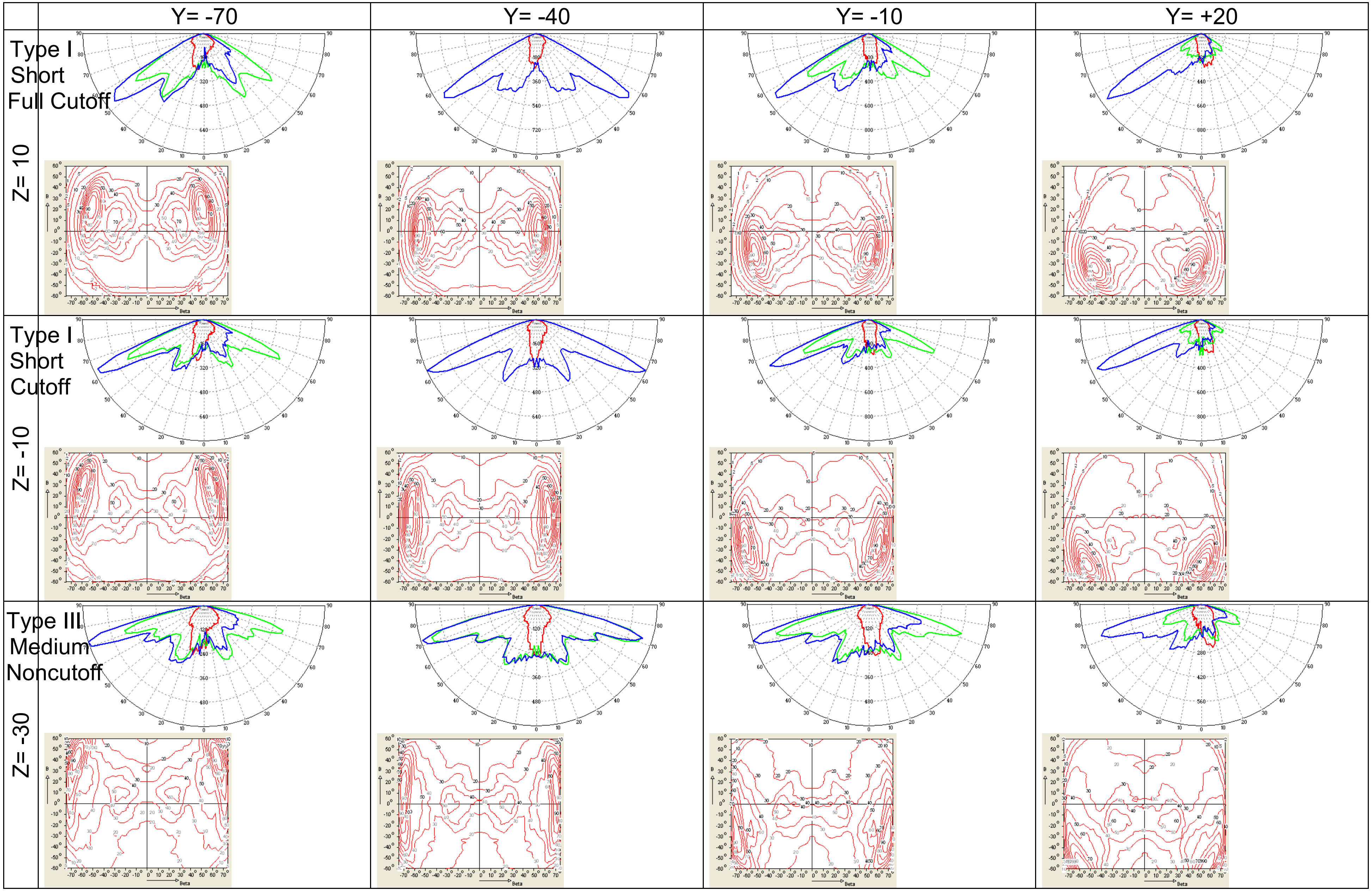

Figure 1. Light Distributions and Relative Isocandela Diagrams for luminaire model with SON-T 70 W lamp when changing the location of the lamp along axes Y and Z

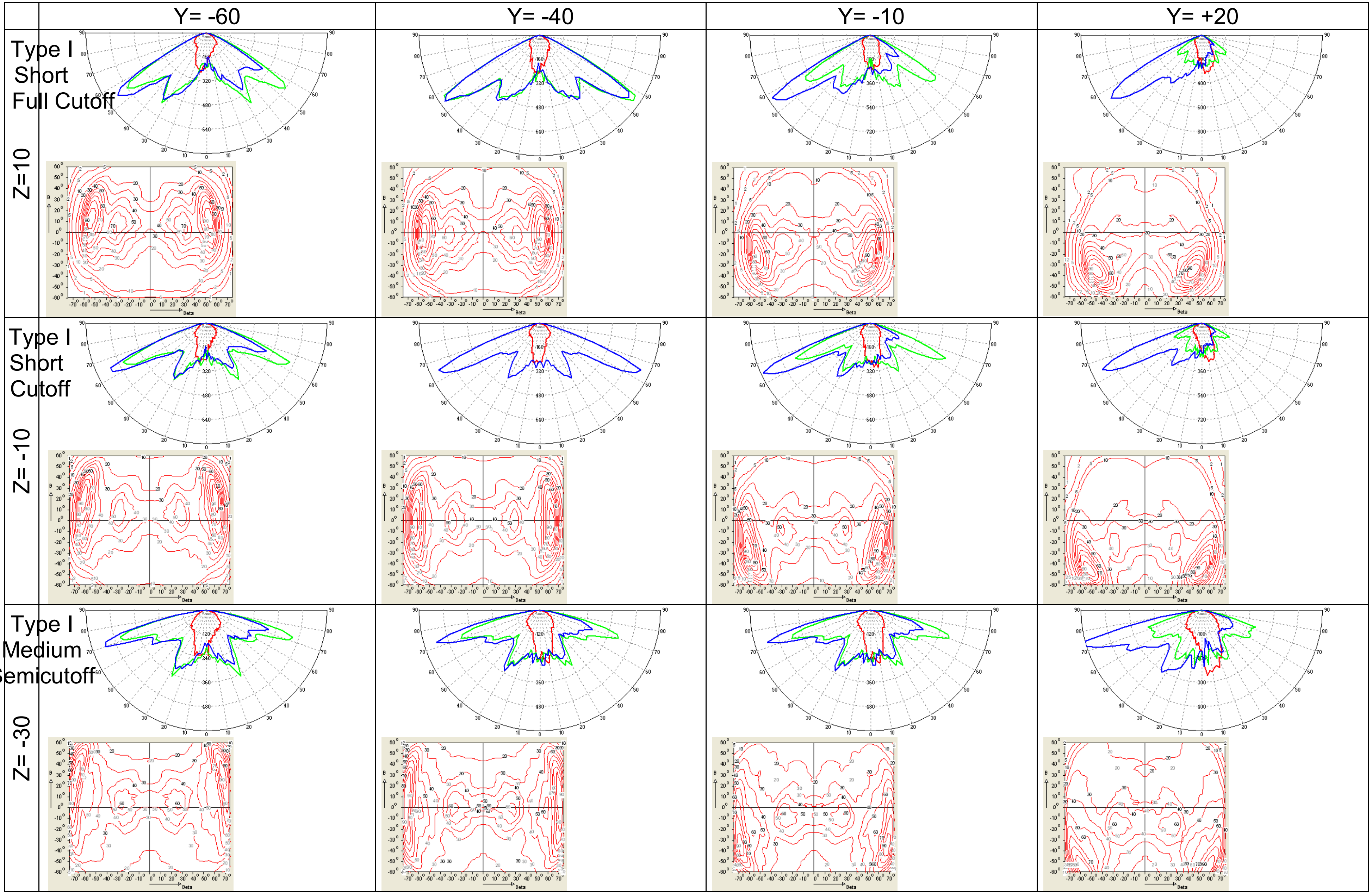

Figure 2. Light Distributions and Relative Isocandela Diagrams for luminaire model with SON-T 150 W lamp when changing the location of the lamp along axes Y and Z

Tables 1 and 2 present the results of the optical analysis of the liminaire for the two typical sizes of the lamps (50W, 70W) and (100W, 150W). Each of the lamp has been positioned for 5 different locations along axis Z = +10, 0, -10, -20, -30 mm and for 13 locations along the longitudinal axis of the luminaire Y = +50, +40, +30, +20, +10, 0, -10, -20, -30, -40, -50, -60, -70 mm. A total of 5 × 13 = 65 variant solutions have been studied for each lamp. The type of luminaire studied with the two lamps 70W and 150W, as it is available from the manufacturers, is classified according to IES Roadway Classification for the existing positions of the lamp as Type I, short – Table 1 and Table 2. This means that from a light engineering point of view it is only suitable for a certain configuration of the street lighting system. With the substitution of luminaries having high-pressure sodium lamps for luminaries having mercury lamps that is going on in Bulgaria now, luminaries having an optical system similar to the type studied must be mounted on various street lighting systems that are available, with existing spacing and mounting height. The light engineering calculations performed on the quantitative and qualitative indicators of street lighting in accordance with the recommendations of the European Norms EN 13201 prove that when mounted in most of the other configurations (spacings and mounting heights), this type of luminaries does not satisfy the recommendations for Lave, U0, Ul, TI [4].
The results in Tables 1 and 2 have shown that when the position of the lamp in the luminaire changes along axis Z from Z = 0 to Z = -30, the new liminaire that has been modeled passes gradually from short to medium vertical light distribution. Short distributions are not used extensively for reasons of economy, because extremely short spacing is required. The medium distribution is predominantly used in practice, and the spacing of luminaries normally does not exceed five to six mounting heights. As a result of the analysis done, this change in the lamp mounting is recommended, so that medium vertical light distribution would be achieved.
Imax has maximum values at the original position of the lamp – Z = 0 and Z = +10. When moving the lamp to Z = -10, -20, -30 mm, the direction of Imax on the vertical plane changes from V = 60º at Z = 0 to V = 72.5º at Z = -30 mm, the value of Imax decreasing by about 30÷35 % - Figures 1 and 2, Tables 1 and 2.
In the individual variant studies the luminaire optical efficiency changes slightly by 2÷3 %.

4. Conclusion

The application of the conclusions drawn from the studies conducted to a widely used type of luminaries, used in the renovation of street lighting in Bulgaria can improve the energy efficiency and the quality of lighting in renovated street lighting systems in Bulgaria.

References

[1] Illumination Engineering Society (IES) Lighting Handbook
[2] AutoCAD User's Guide
[3] Photopia 2.0 User's Guide
[4] EN 13201 Road Lighting