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Classification of environmental zones in the Czech Republic

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Nowadays obtrusive light is discussed quite often and so this term has become well-known not only to professionals in the field of lighting but also to the public, designers and administrators. Quantification of obtrusive light depends on many factors. The biggest factor is the amount of the luminous flux directly emitted into the upper hemisphere. Other factors include the reflection qualities of illuminated surfaces and finally conditions in the atmosphere. Based on knowledge of the amount of luminous flux directly emitted into the upper hemisphere, depending on the surroundings (size of the agglomeration, protected landscape areas – national preserves, observatory, etc.), we can classify obtrusive light into several classes according to the standards EN 12464-2 and EN 12 193. These standards use only four environmental zones. For any outdoor lighting system it is possible to calculate the amount of luminous flux emitted into the upper hemisphere and determine if this potential source of obtrusive light is appropriate for the environmental zone. These calculations can also show if the lighting system is a significant contributor to the amount of obtrusive light. This paper tries to describe problems over larger areas where different environmental zones can exist side by side. Adjacent environmental zones should not differ by more than one level (for example E1 to E2 only). The aim of this paper is to establish methodologies for classifying environmental zones. A specific example of classification relates to a 420 kV outdoor electricity distribution substation, which is located in a selected area of the Czech Republic.

1. Introduction

The aim of this paper is to examine the classification of electricity distribution substations to the environmental zones listed in CIE 126-1997[1] and EN 12464-2.[2] Classification of selected areas to an environmental zone is carried out according to the type of residential area, distances from protected landscapes and distances from major observatories. The classification of environmental zones limits direct radiation to the upper hemisphere. In the above-mentioned references there are listed maximum values of direct radiation from outdoor lighting systems into the upper hemisphere. Obtrusive light is divided into four environmental zones. Table 1 shows the maximum percentage of luminous flux emitted directly into the upper hemisphere (ULR) as well as the maximum illuminance on objects (dominantly vertical) and the maximum luminous intensity of the luminaires for each environmental zone. The last two columns of Table 1 contain the maximum values of luminance on the facades of buildings and on traffic signs.

The four environmental zones are E1 to E4 where:

- E1 represents intrinsically dark areas, such as protected landscape areas or protected sites

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Table 1 Characteristics of environmental zones in terms of obtrusive light[2]

Environmental zone	Light on properties E_v (lx) Pre-curfew[a]	Light on properties E_v (lx) Post-curfew	Luminous intensity I (cd) Pre-curfew	Luminous intensity I (cd) Post-curfew	Upward light ULR (%)	Luminance L_b (cd·m^{-2}) Building facade	Luminance L_s (cd·m^{-2}) Signs
E1	2	0	2,500	0	0	0	50
E2	5	1	7500	500	5	5	400
E3	10	2	10000	1000	15	10	800
E4	25	5	25000	2500	25	25	1000

[a]Where no curfew regulations are available, the higher values shall not be exceeded and the lower values should be taken as preferable limits.

Table 2 Minimum distance between the reference point and the border zone[1]

Environmental zone	Minimum distance between the borders of neighbouring zones according to classification (km) E1–E2	E2–E3	E3–E4
E1	1	10	100
E2		1	10
E3			1
E4	No limit	No limit	No limit

- E2 represents low district brightness areas, such as industrial or residential rural areas
- E3 represents medium district brightness areas, such as industrial or residential suburbs
- E4 represents high district brightness areas, such as town centres and commercial areas

In larger surveyed areas different environmental zones may appear together. If so, environmental zones should not differ by more than one level. The boundaries between zones should not be sharp but gradual. Table 2 gives recommendations for minimum spacing between environmental zones. But it should be noted that the definition of the reference point is not fixed. This means that, especially for large areas (e.g. protected landscape areas), it is not clear whether the reference point is the centre of the area or its periphery. Some experts even believe that the distances between the zones listed in Table 2 should be doubled at least. At present neither designers nor the officials of construction authorities classify the environmental zones, because it is a relatively new issue in the Czech Republic. There is no standard which would regulate the classification. For these reasons it is not quite clear in which environmental zone an area is located. The following proposes a methodology for the classification of areas into environmental zones. This suggestion is based on the example of classifying an outdoor high-voltage distribution substation operating at 420 kV.

2. Proposal for classifying an outdoor distribution substation in Kletné

The above-mentioned area has been chosen as an example for a number of reasons. Distribution substations are usually built far from other sources of obtrusive light. This makes it possible to measure them while excluding the effects of other light sources and because we usually have their light-technical calculations available we can model direct luminous flux emitted into the upper hemisphere and indirect luminous flux reflected by the distribution substation into the upper hemisphere. Designers of outdoor lighting systems for such substations have to

Table 3 Boundary condition characteristics for particular zones

Zone E1	Zone E2
• national parks plus 1 km from its borders • protected landscape areas including 1 km environs • important observatories including 1 km environs	• at least 10 km from the borders of zone E1 • built-up area of villages and its surrounding 1 km • observatories of lesser importance including 1 km environs
Zone E3 • outer built-up areas of cities with their surrounding 1 km	Zone E4 • city centres – a zone is at least 1 km in diameter

respect the restrictions of direct luminous flux into the upper hemisphere.

In accordance with recommendations mentioned in literature sources[1,2] it is possible to base determination of environmental zones on distances from areas where environmental zone requirements have already been determined based on their functions. This mainly concerns observatories and protected landscape areas as well as industrial, commercial and residential areas. An area could be classified as zone E1 on the basis of the distance from astronomical and other observatories and protected landscape areas. An area could be classified as zone E2, E3 or E4 on the basis of the distance from residential areas and industrial and commercial areas.

In order to classify outdoor electricity distribution substations on the basis of the above information, the following boundary conditions have been set (Table 3). Figure 1 shows a map of the nearest critical areas to the distribution substation at Kletné.

In the distribution substation vicinity there are several protected landscape areas, an astronomical observatory, villages and towns. Distances of these features from the substation are given in Table 4. Figure 2 shows maps of the distribution substation with marked environs. The distribution substation is situated on the outskirts of a village Hladké Životice with a population of 959 inhabitants.

The classification of a zone of a distribution substation is based on:

- Direct surroundings of the distribution substation (Figure 2 left) and the surroundings of the distribution substation within a 10 km area (Figure 2 right)
- The distance from the nearest village Hladké Životice. This exceeds 1 km (see Figure 2), which means that it can be classified as zone E1–E3 based on distance.
- The distance from the nearest protected landscape area (nature preserve) at Bařiny. This is up to 10 km from the zone determined by the protected landscape area (see Figure 2), which means it can be classified as environmental zones E2–E1
- The distance from the nearest town Nový Jičín (see Figure 2). If we classify the centre of Nový Jičín as environmental zone E4, given its illuminated historical centre, then we cannot classify the distribution substation as environmental zone E1
- The distance from the nearest observatory of lesser importance does not influence the classification of the environmental zone of the distribution substation.

Based on the above partial classifications we can classify the 420 kV distribution substation in Kletné as E2 with a direct luminous flux into the upper hemisphere allowance of 5% of the total luminous flux produced by lighting system of the distribution substation.

Figure 1 Map of places of importance near the distribution substation[3]

Table 4 Distribution substation and distances from reference points

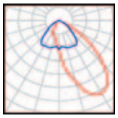
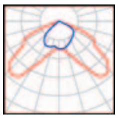
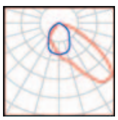
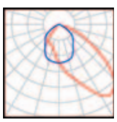
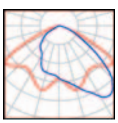
Observatories	Vřesina	24 km
Protected landscape areas – national preserves	Bařiny	5.2 km
	Bartošovický luh	5.9 km
Villages	Hladké Životice	1.3 km
Towns	Nový Jičín	9.8 km
	Příbor	15.5 km
	Studénka	10.9 km

3. Modeling the light into the upper hemisphere

The proposed lighting of the distribution substation at Kletné consists of several individual systems. Among the main ones are the service lighting of the distribution substation, the lighting of the transformers, the lighting of the road network and the security lighting. The lighting equipment used with its parameters is shown in Table 5. The total luminous flux produced by the metal-halide and high-pressure sodium lamps which are used in all luminaires is 2,127,502 lm. The direct luminous flux emitted into the upper hemisphere has been calculated using the DIALUX[5] program and the luminous intensity distributions of the luminaires. The calculated figure of 95,738 lm equals 4.5%

Figure 2 The direct surroundings of the distribution substation[3]

Table 5 Calculation of direct luminous flux into the upper hemisphere[4]

Luminous intensity distribution of luminaires used	Number of luminaires (pc)	Luminous flux of luminaire (lm)	Total luminous flux (lm)	Direct luminous flux to upper hemisphere (lm)	Total ULR (%)
	12	7207	2,127,502	95,738	4.5
	100	4101			
	64	14807			
	28	22728			
	14	3349			

of the total luminous flux. When we compare this figure to the requirements mentioned above we find that the technical proposal meets the requirements of environmental zone E2.

However, luminous flux emitted directly into the upper hemisphere does not describe real emissions into the upper hemisphere. As there is now no direct methodology for measurement of the overall luminous flux emitted into the upper hemisphere we present here a procedure how to obtain not only total luminous flux into the upper hemisphere but also the directional characteristic of the lighting of the whole distribution substation with the help of software designed for projecting lighting systems. Such a model can be used by astronomers or environmentalists when establishing new protected areas or building new observatories.

A network of calculation points placed in the upper hemisphere has been set up for the modeling of directional characteristics of the lighting of the distribution substation into the upper hemisphere with the DIALUX[5] program. The midpoint of this hemisphere is situated level with centres of the luminaires which are above the centre of the distribution substation. At the points situated on the surface of a hemisphere of 750 m diameter illuminances were calculated in the inwards direction (Figure 3). The diameter of 750 m is not five times the maximum size of the distribution substation (250 m), which means we cannot consider it as a point source. This issue is caused by the limitations of the software used. However, if we examine the distribution of lighting in the distribution substation itself, we can conclude that the maximum luminous flux takes place only over about a 150 m diameter, which is a size such that we can consider the distribution substation to be a point source of light.

The calculations are made for direct luminous flux emitted into the upper hemisphere (Table 6) as well as for different types of reflection characteristics of the terrain ($\rho = 0.15$–0.8) (Table 6). On the basis of such acquired figures we can model curves of luminous flux from the whole distribution substation in different directions.

Changes in the shape of the directional characteristic are caused by the increase in the reflected part of the total luminous flux with increasing reflectance of the surface (Table 7).

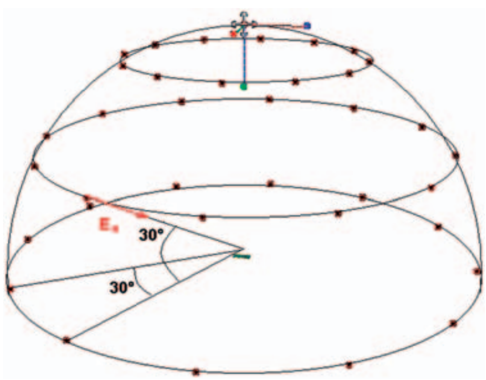


Figure 3 Position of illuminance measurement points[5]

4. Conclusion

This paper shows one possible way to approach the classification of large sources of obtrusive illumination into environmental zones. As an example, the suggested methodology of classifying such luminous sources, considering distances from residential areas, protected landscape areas, observatories and astronomical observatories, was used on the distribution substation in Kletné. In this

Table 7 Total luminous flux going into the upper hemisphere calculated from the directional curves (see Figure 4)

Reflectance	Luminous flux (lm)
0.15	222,305
0.30	356,150
0.80	806,145
0.00	95,738

Table 6 Calculated illuminances in the upper hemisphere – direct luminous flux for $\rho = 0.0$ and total luminous flux for $\rho = 0.15$

		Reflectance $\rho = 0$		Reflectance $\rho = 0.15$			
		Elevation		Elevation			
Illuminance (lx)		Horizon 0°	30°	Horizon 0°	30°	60°	Zenith 90°
Azimuth	**S 180°**	0.08	0.00	0.04	0.08	0.07	0.08
	210°	0.11	0.00	0.04	0.11	0.07	0.08
	240°	0.10	0.00	0.04	0.10	0.07	0.08
	W 270°	0.06	0.00	0.04	0.06	0.07	0.08
	300°	0.09	0.00	0.04	0.09	0.07	0.08
	330°	0.10	0.00	0.04	0.11	0.07	0.08
	N 0°	0.08	0.00	0.04	0.08	0.07	0.08
	30°	0.09	0.00	0.04	0.09	0.07	0.08
	60°	0.09	0.00	0.04	0.09	0.07	0.08
	E 90°	0.07	0.00	0.04	0.07	0.07	0.08
	120°	0.09	0.00	0.04	0.10	0.07	0.08
	150°	0.11	0.00	0.04	0.11	0.07	0.08

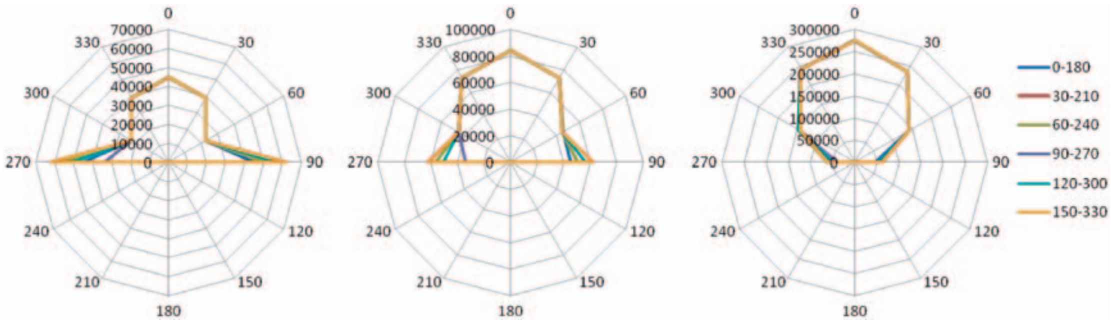


Figure 4 Directional characteristics of lighting of the distribution substation and direct and reflected luminous flux for surface reflectances of 0.15 (left), 0.3 (centre) and 0.8 (right)

example we classified it as a zone E2. Because its design and realization were carried out in accordance with this classification we continued with calculating luminous flux radiated into the upper hemisphere. Calculations were made not only for direct flux illuminated into upper hemisphere but also for the sum of direct and reflected luminous flux. Based on calculations of luminous flux entering the upper hemisphere from the lighting of the distribution substation in Kletné we determined that 4.5% of the total luminous flux produced by all the lighting is emitted directly into the upper hemisphere. This means that the lighting system of the distribution substation at Kletné complies with the requirements of environmental zone E2.

By modeling different types of surface reflectance we can see the changes in the behaviour of reflected flux into the upper hemisphere. These models can be used not only for investigating the effects of new lighting systems on their environment but also for verifying mathematical-physical models that describe the dispersive characteristics of the sky. With knowledge of the distribution of luminous flux in the sky, atmospheric properties and emitting characteristics we can verify models of the distribution of obtrusive light. After their verification it will also be possible to ascertain the effects of individual sources of obtrusive light on particular studied places on the grounds of measuring the luminance of the sky and the dispersive conditions in the atmosphere alone.

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Erratum

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The publishers would like to apologise for the omission of the above article in the special issue on Light Pollution for Lighting Research & Technology volume 46 issue 1 (February) for which it was specifically intended.

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