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LIGHTING INSTALLATIONS**

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MEASUREMENT OF OBTRUSIVE LIGHTING OF OUTDOOR LIGHTING INSTALLATIONS

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Abstract

Outdoor lighting systems excluding road lighting and public lighting e.g. LED screens, sports lighting systems, lighting systems of parking zones and industrial zones, illumination of buildings, decorative lighting of buildings etc. are a potential sources of obtrusive lighting. Light emerging from luminous areas of these installations have sometimes significant impact to the surrounding environment. Therefore, in practice it is needed to control of measure obtrusive lighting by means of on-site or laboratory photometric measurements in respect of particular outdoor lighting installation and environment where lighting installation is situated. This paper deals with recommendation of on-site or laboratory photometric measurement methods to control measure of obtrusive lighting from real installed outdoor lighting systems by means of photometric devices i.e. luminance meters, illuminance meters and image luminance meters according to limits prescribed by standards and CIE document.

Keywords: Obtrusive lighting, Outdoor lighting, Photometry

1 Obtrusive lighting

The maximum permissible limits of photometric parameters from the outdoor lighting systems depend on the environmental zones defined by standards and CIE recommendation where lighting systems are installed. The values of limits luminances, illuminances levels or TI values are defined in the national standards and CIE documents treating obtrusive lighting. In some countries are these limits implemented in the law to minimize obtrusive lighting in outdoor environment. Practically operation of outdoor lighting installations often does not meet the standards or recommendation requirements. Too high luminance from these sources can cause visual discomfort mainly to the car drivers, to pedestrians or even more habitants in ambient residential buildings by obtrusive lighting. Potential obtrusive lighting from outdoor lighting installation should be controlled in some way. LED screen panels are a source of information that they mediate to the surrounding environment. The maximum permissible values of luminances emerging from the screen and illuminances on the buildings of immediate surround buildings depending on the environment in which they are installed. The allowed values of luminances and illuminances levels are defined in the European standard STN EN 12464-2. In some countries are implemented in the law. In case of Slovak republic the decree of ministry of health of Slovak republic No.539/2007 Z. z. prescribe these requirements for light sources e.g. adverts boards, LED screens etc. Practically operation of these devices often does not meet the standards requirements. Too high luminance from these sources can cause visual discomfort mainly to the car drivers, to pedestrians or even more habitants in ambient buildings. The LED screen panels are still increasingly used article installed in the outside environment. They consist from LED modules which are mounted together to create big boards which depend on application. The most common application for these screens is advertising. They are source of possible light pollution when the screen is installed in the particular environmental zone prescribed by standard EN 12464-2. When LED screen is installed the measurement of luminance and illuminance should be performed to assess which level is appropriate for operation as information for the owner of the LED screen. The user can control the screen by computer or electronics where it can be adjusted level of the luminance. The luminance level is more critical in the night time after sunset when due to the increasing contrast with dark background of the screen may cause obtrusive light. The field trial is sometimes very difficult performed because the measurement can be

performed in the night without daylight. Usually in the time of measurement it is negatively influenced both habitants of near buildings situated around the screen or even more there occur a big risk of accident in the traffic what brings another complication when on-site measurement is performed. Therefore it should be found another way how to measure photometric parameters of LED screen panels in connection with luminance level control. The easiest way appear to measure one or more specimen of LED modules from which LED board consists under laboratory conditions. After that it can be calculated photometric parameters by means of well-known relations. In the text below it is shown both approaches how it can be measured LED screens which are installed in an open environment. At the state of the project of the installation of LED board should be followed some standard requirements defined by standard EN 12464-2. Even more in some countries limit of photometric parameters are implemented into the law where limits are listed. The user of the LED screen should set these parameters onto screen to avoid obtrusive lighting from the light sources. In Slovakia limits in the Decree about Obtrusive Lighting from an Outdoor Light Sources are taken from mentioned standard. The limit values of luminances of the building facades are recommended according to EN 12464-2 and they are important for illuminations of objects as well.

Exterior lighting installations i.e. advertising screens, lighting systems of exterior lighting of industry, building areas, park areas etc. instead of public lighting are designed so as light from these lighting devices shall not produce obtrusive light on windows in the residential area. This is evaluated by the measurement of the illuminance falling on the window. The illuminance level is measured in the centre of the outside surface of the window. In the case when it cannot be prevented fall of light from sources installed in an open environment on windows of buildings in the residential area limits shall not exceed values of photometric quantities listed in the Table 1.

Table 1 – Limits values for exterior lighting according to EN 12464-2 standard

ENVIROMANTAL ZONE	Light on properties		Luminaire intensity		Upward light ratio	Luminance	
	E_v (lx)		I (cd)		R_{UL} (%)	L_b (cd.m ⁻²)	L_s (cd.m ⁻²)
	to 22:00	after 22:00	to 22:00	after 22:00		Building facade	Signs
E1	2	1	2500	0	0	0	50
E2	5	1	7500	0,5	5	5	400
E3	10	2	10000	1,0	15	10	800
E4	25	5	25000	2,5	25	25	1000

where

- E1 intrinsically dark areas, such as national parks or protected sites;
- E2 low district brightness areas, such as industrial or residential rural areas;
- E3 medium district brightness areas, such as industrial or residential suburbs;
- E4 high district brightness areas, such as town centres and commercial areas;
- E_v vertical illumination of outside surface of window
- I the luminous intensity of each source in the potentially obtrusive direction
- L_b the maximum average luminance of the facade of building
- L_s the maximum average luminance of signs

Also other requirements are written in the Slovak national Decree of Ministry of Health No. 539/2007 as L_{max} the maximum level of luminance building facades and dynamic advertisements. These are related to change of intensity and change of the colour of light in the room of the residential building affected by obtrusive light. They are subjectively evaluated. This subjective assessment of this effect is sometimes very difficult especially when LED board is installed in the centre of the city because of effect of other lighting

sources. Changes in the intensity of light and changes of the colour of light from exterior light sources must not be observable in the residential room. Changes of luminances found by direct view on exterior light sources are not evaluated if not cause an observable change of residential room. In time of evaluation the light sources in the room are turned off. In other countries are already created other approaches for requirements about obtrusive lighting related to spatial distribution of luminous flux from luminaires and others. In the near future should be provided some international unified guideline or recommendation how to treat obtrusive lighting of outdoor lighting installations with dynamic changes on the luminous part of signs, adverts etc.

2 Outdoor LED screens

The different types of LED modules consist LED screen boards on the market can be found. They have installed different types of LEDs to reproduce whole scale of colours. Mostly the solution display colour is used RGB technology in the module where by means of three coloured LEDs red, green and blue chips is mixed to display arbitrary colour. Sometimes it is improved RGBW to render better white colour. Forthcoming technology is using SMD modules. The producers of LED screen boards have started recently use this technology for LED screen panels where higher resolution can be achieved in combination with better colour rendering. In the pictures below are depicted examples of LED modules which were investigated in an outdoor installation of the screen boards for advertising.

Figure 1 – LED module with RGB technology

Figure 2 – LED module with SMD modules

These modules are mounted to create LED screen board as it is shown in the picture Figure 2. As it was mentioned above they should be operated in reasonable limits after sunset prescribed by standard or by the Decree if it is implemented into the law system of the country.

Figure 3 – Controller examples for setting of the luminance level (“brightness” of the screen)

Setting is performed by adjusting of luminance level of the screen by the controller of “brightness”. Simultaneously is measured luminance level by luminance meter. The example of the controllers is shown in the picture Figure 3 where scale is commonly represented by numbers from interval e.g. 0 to 100, 0 to 255 or 0 to 16. For each number belongs certain luminance level what is investigated by the photometric measurement.

The photometric measurement can be performed in two ways. First possibility is to measure photometric parameters when LED screen is installed already in an outdoor environment i.e. on-site measurement or it can be performed under laboratory conditions. On-site measurement is much easier than laboratory measurement because it reflects real conditions of installation of the screen. By means of this field trial are ensured angular positions of the observer under investigations. On the other hand it can be used just for one type of the installation of the screen.

Figure 4 – Example of the field trial (view from window of opposite building)

Example of photometric measurement for outdoor installation of the LED screen from the window of building is shown in the picture Figure 4.

The laboratory measurements of the photometric parameters of LED modules provide more advantages than on-site measurement. In the picture Figure 5 is shown linear dependence of the luminance level on the controller step where dependence of luminance level from controller value is shown. This behaviour was found also for other types of controllers and screen modules both of types mentioned in previous section. Also angular dependence of the screen is performed to show what angle is critical for observer. This measurement can be performed by goniophotometers in the appropriate coordinate system. Furthermore it is very important to set this dependence for the theoretical calculation of obtrusive light illuminance from the screen to be installed in an outdoor environment.

Figure 5 – Dependence of luminance level on the control unit value

From the laboratory measurement can be assessed luminance level for the worst case as can LED screen be operated. Afterwards photometric quantities both luminance level and illuminance level of obtrusive light from the screen can be easily assessed for applications where LED modules of same type will be installed on various place. The calculation can be performed by means of relations between photometric quantities among them.

In the table is presented example from angular measurement of the LED module under laboratory conditions. Firstly is measured and evaluated relative dependence of the luminance for each direction of the screen.

Table 2 – Relative values normalised to the luminance in perpendicular view of the screen

Angle α °	Horizontally / (L_{α}/L_0) %	Vertically / (L_{α}/L_0) %
0	100.0	100.0
10	99.5	82.5
20	97.9	62.7
30	94.4	21.1
40	91.0	4.7
50	84.5	1.8
60	71.5	0.9
70	43.9	0.5
80	8.7	0.3
90	0.0	0.0

Then it is measured luminance level dependent on controller unit value in one direction what is usually the worst case which can occur in installation of the screen.

Table 3 – Luminance level in perpendicular view of the screen

Step	L / cd.m ⁻²	Step	L / cd.m ⁻²
16	5055	8	2550
15	4740	7	2230
14	4430	6	1920
13	4120	5	1605
12	3810	4	1286
11	3490	3	966
10	3180	2	646
9	2860	1	325

The yellow row in the table shows the minimum what can be set on the controller unit to avoid glare of observers of the screen operated in the night time. From this it can be calculated the worst case for illuminance of the obtrusive light of the building situated in the opposite side of the LED screen. The dimension of the screen to be installed must be known to assess this illuminance level according to the relations

$$L = \frac{I_{\alpha}}{A \cdot \cos \alpha} \quad (1)$$

$$E = \frac{I_{\alpha}}{d^2} \cdot \cos \alpha$$

where

- L is the luminance emerging from screen area in cd.m⁻²;
- E is the illuminance falling on the window on the building in lx;
- d is the distance of the screen;
- A is the LED screen area;
- α is the angle between of the line of view and the normal of the screen area

For this example it can be calculated luminance level for screen with dimension (3 x 2)m what is 646 cd.m⁻² (permitted value by standard EN 12464-2 for E4 environmental zone) and illuminance at the distance approximately 100 m cause obtrusive illuminance in the middle of the window 0,38 lx as the worst case.

3 Flood lighting of historical building facades

Second case of potential source of obtrusive lighting is flood lighting of historical buildings facades in the centres of cities, churches or other buildings which are illuminated by luminaires used for this purposes (Figure 6). The example of measurement and evaluation of

obtrusive lighting of flood lighting controlled by lighting control system of building facade in Bratislava city (Slovakia) is described below.

Figure 6 – Flood lighting of historical building G4 on Gorkeho street in Bratislava

The obtrusive light measurement was performed by a direct method of measuring the illuminance on the front plane of window by luxmeter for measuring the vertical illuminance corrected for the spectral sensitivity of the human eye $V(\lambda)$ and measurement of the luminance by means of the luminance image meter in combination with spot luminance meter corrected for the spectral sensitivity of the human eye $V(\lambda)$ for three situations of facade illumination and architectural elements after reconstruction of the office building G4 on Gorkeho Street in the direction of possible obtrusive lighting in the bedroom of apartment. Flood lighting consists of 20pcs of LED lights S.6420w 14 SHAPE SIMES, 9pcs LED lights S.1501w 14 MINIKEEN and 3pcs LED lights S.1513w SIMES evenly distributed on the bottom edge of the building windows with a luminous part directed to the upper direction, the tower flood lighting and lighting of the facade of a balcony with white color under a corn tower consisting of 4pcs LED tube lights S.5905N by SIMES. Part of the exterior lighting of the G4 office building is also 2 pieces of LED reflector lamps with motion sensor located above the entrance door of the building.

Figure 7 – Flood lighting of balcony and corn tower of the building on Gorkeho street

Before and after the measurement, the illuminance and luminance level were made when the flood lighting system of the building was turned off. Subsequently, these values were subtracted from the measured values when measuring the illumination intensity of the turned on ad device. The office building facade was about 14.0 m away from the middle of room window to assume the worst case. The measurement results are the arithmetic mean of ten independent vertical illumination measurements at nine measurement points on the vertical plane at the window vertical plane, taking into account the expanded measurement

uncertainty 10% ($k = 2$) for the worst case of the obtrusive lighting. The vertical illuminance when luminaires of flood lighting were off in the center of the window was measured

$$E_{v0} = 1,37 \text{ lx} \quad (2)$$

Table 4 – Measured values of vertical illuminance level on plane of front window of building

Lighting system	E_v (lx)	$(E_v - E_{v0})$ (lx)
Flood lighting of building G4	8.31	7,63

The luminance measurement on the facade of the G4 building was evaluated from areas of building facade divided into four parts and for the architectural element of the balcony and tower turret, was made by spot luminance with field of view 1° and by means of image luminance meter. The measurement results are the average of ten independent luminance measurements and the average of the four delimited areas of the G4 building facade with respect to the expanded uncertainty 9% ($k = 2$) of luminance level.

Table 5 – Measured values of average luminance area parts of building facade $L_{s,i}$ (cd.m^{-2})

Lighting system – flood lighting G4	
Area of facade $i = 1 \dots 4$	Luminance on facade $L_{s,i}$ (cd.m^{-2})
Facade area 1	3,17
Facade area 2	2,72
Facade area 3	2,39
Facade area 4	1,92
Average luminance L_b (cd.m^{-2})	2,55
L_{max} (cd.m^{-2})	< 150

Table 6 – Measured values of average luminance L_s (cd.m^{-2}) of corner tower

Lighting system – flood lighting G4	
Area of architectural element	Luminance L_s (cd.m^{-2})
Area of corner tower	5,17
Average luminance L_b (cd.m^{-2})	5,17
L_{max} (cd.m^{-2})	< 150

Table 7 – Measured values of average luminance L_s (cd.m^{-2}) of balcony

Lighting system – flood lighting G4	
Area of architectural element	Luminance L_s (cd.m^{-2})
Area of balcony facade	37,8
Average luminance L_b (cd.m^{-2})	37,8
L_{max} (cd.m^{-2})	< 150

The maximum luminance intensity of the light sources in the direction of possible obtrusive lighting was determined for the worst case by measuring the luminance of the building facade G4, the luminance of the corner tower and the luminance of the balcony facade, where the area corresponding to the area observed from the window view of room as the worst case and it was determined from the luminance scene acquired by image luminance meter.

Table 8 – Calculated values of maximal luminous intensity in direction of possible obtrusive lighting I (cd) under view angle 20°

Lighting system	Maximal luminous intensity of area I (cd)
Building facade G4	442,4

Table 9 – Calculated values of maximal luminous intensity in direction of possible obtrusive lighting I (cd) under view angle 30°

Lighting system	Maximal luminous intensity of area I (cd)
Corner tower	148,3

Table 9 – Calculated values of maximal luminous intensity in direction of possible obtrusive lighting I (cd) under view angle 23°

Lighting system	Maximal luminous intensity of area I (cd)
Balcony	1235,4

Figure 8 – Luminance analysis of building facade G4

Figure 9 – Luminance analysis of corner tower

Figure 10 – Luminance analysis of balcony

4 Conclusion

In the paper were presented possibilities of outdoor LED screen installations and flood lighting obtrusive lighting measurement of historical building in Bratislava city, Slovakia. Furthermore it was described two possibilities how to assess limits in which can be screen to be operated. The laboratory measurement is possible way how to simplify measurements in outdoor environment to avoid glare of observers and habitants of the residential area as it is at on-site measurement. In the future work should be validated assumptions from theoretical calculations based on the laboratory measurement. It can be realised by means of comparison measurement of various LED screen boards with various modules. From results of measured photometric parameters of flood lighting of historical buildings it can be concluded that luminance level of balcony and illuminance level exceeds post-curfew limits stated in the standard EN 12464-2. Therefore each lighting system should have appropriate project preparation including calculation of relevant photometric parameters before installation to avoid obtrusive lighting levels. In the future should be provided regulations for dynamic lighting systems.

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