Light pollution and sports lighting in dense urban areas: Early results in a case study of a stadium

G Ntoutsos¹, L T Doulos¹, S Zerefos¹, A Papalambrou² and T Balafoutis¹

¹ Hellenic Open University, School of Applied Arts and Sustainable Design, Parodos Aristotelous 18, Patras, Greece
² Greek chapter of the International Dark-Sky Association, Greece
³ E-mail: gddoutsos@yahoo.gr

Abstract. The use of municipal football fields by a large number of citizens and amateur athletes on a daily basis during evenings is a popular activity. Usually, the aiming of the pitch lighting, without taking into account the dense urban environment in the surroundings, causes light pollution. Obtrusive lighting in most cases is the rule and not the exception. This situation could be justified in football fields of the professional football leagues so as to address the needs of television broadcasts of the matches for two days per month per field. However, in amateur activities due to the lack of rules and the initial incorrect lighting design, the problem of light pollution is deteriorated. The scope of this research is to identify the main issue and the repercussions of obtrusive lighting in the urban fabric, propose a quick method to quantify light pollution in sport fields using IDA-Criteria for Community-Friendly Outdoor Sports Lighting guidelines and to further set some parameters for a method using more calculating surfaces.

1. Introduction

The evolution of science with the discovery of electricity and contemporary materials have led to today’s lighting applications so as to meet almost every need of ours, both indoors [1] and outdoors [2, 3], with the latter being constantly a great challenge [4, 5]. The need of outdoor lighting is undeniable, safety in urban [6, 7] and long-distance travelling [8], continuity of productive and commercial activity, entertainment and sports are just some of the key areas [9]. On the other hand, the lack of architectural elements of light limitation and the direct contact-interaction of the natural environment [10] with the diffused lighting are creating the phenomenon of light pollution [11, 12]. Light pollution – which we examine here as a result of lighting outdoor sports venues – is unfortunately not just for astronomers, but it has been recognized internationally as a significant pollution factor with serious consequences [13] for the environment [14] and human health [15]. In recent years, various actions have been proposed in order to reduce light pollution [16-18].

Sports lighting is considered as a special lighting application and must be carefully designed taking into account the nature of the sport, its speed and skill, the size and speed of the equipment. The main difficulty in lighting design concerns the position of the observers, who have conflicting needs. Nowadays, the main observer is television, where high levels of vertical lighting are needed on the players in order to produce a "perfect TV product" [19]. On the other hand, footballers, as observers also, should have visual comfort in order to be able to perform with low discomfort from artificial lighting [20]. Even if the lighting system of the stadiums is designed properly, over time, due to the decay and aging...
of the equipment and the changes of lighting requirements by the standards, an upgrade is needed. Furthermore, the use of the municipal athletic fields in dense urban areas by citizens and amateur athletes are a daily need for their well-being. However, the lighting installations cause light pollution in the surrounding urban area and obtrusive lighting is dominant in the nearby area. Although this situation may be justified in football fields of the 1st National Football League so as to address the needs of television broadcasts of the matches for maximum two times per month, in daily activities the lack of rules and the initial improper design of lighting intensifies the problem of light pollution. Now days light trespassing that causes light pollution in nearby areas is identified as a huge problem as the residents in these areas are making complains to municipality authorities more often than ever [21]. For this reason, a method is necessary to identify quickly the problems and correct them using specific lighting measurements and simulations as the athletic installations are being renovated with LED luminaires. The proposed quick method uses the IDA-Criteria for Community-Friendly Outdoor Sports Lighting v1.0 [22] from the International Dark-Sky Association [23] in order to quantify the light pollution in a case study and present in detail.

2. Methodology
The object of the present study is the methodology determining the light pollution caused by the lighting of outdoor sports facilities - during their use - in the surrounding urban area (roads, buildings, etc.). The proposed method is presented in Figure 1. In this case we refer to a football field which not only covers the needs of the local football team at the level of matches but also functions as a training center for track and field athletes and as a recreation area with mild sports activities for ordinary citizens. In a theoretical approach to the subject, we should look for the limits set by the lighting standards (EN 12193 - Light and lighting - Sports lighting) [20] for conducting activities in outdoor sports facilities, according to the type of sport (in this case, football) and the category of hosted games (international / national, regional, local, training, school / leisure games).

![Figure 1. Method used for examining the light pollution effect in a case study.](image)

To determine and measure the phenomenon of light pollution from the use of the stadium during the evening hours we will perform the following actions:

- **Measurements:** Using a luxmeter in horizontal and vertical position, we performed a series of measurements in the area around the stadium that included streets (horizontal position) and facades of buildings (vertical position). We selected points close to the stadium where the effect of lighting becomes apparent and measurements are taken for comparison purposes at the exact same points before and after the use of pitch lighting.

- **Calculations:** With the help of lighting simulation software and after entering the necessary elements (luminaires, measuring surfaces), we created an extra horizontal measuring surface for calculating the upward illuminance (Figure 2). In order to determine the extra horizontal measuring surface (with specific dimensions and height of calculations), we take into account the instructions of IDA [22]. Thus, we had the ability to obtain calculations for illuminance
and extract afterward the luminous flux directed upwards, in places where it would not be practically easy to make measurements using a luxmeter.

![Figure 2.](image)

**Figure 2.** Horizontal ceiling grid placed 1.5m above the top of the tallest pole, extending out to 45m beyond of each edge of the field.

After collecting the above data then through them we could prove the existence of light pollution either in the urban area around the stadium or directly upwards. The International Dark -Sky Association [21] has set various criteria for the evaluation of outdoor sports lighting such as compliance with all applicable codes and standards, application efficiency etc. For the quick method in order to identify the spill light two variables were selected:

- **Backlight:** Directionality and application efficiency will be addressed through measured illuminance. Total designed lumens not contained within the area encompassing the field perimeter and an area immediately adjacent to that area that has a 10m offset. No more than 15% of the total lumens may be outside of this region. Furthermore, spill Illuminance at Setback should be less than 2lx

- **Uplight:** All luminaires must be designed such as to not to emit direct light above the horizon, unless required for the activity (i.e. aerial sports) being played. In those cases, only 8% of the total (directly) applied lumens as modeled may be in this zone.

Having substantiated the existence of light pollution we can proceed to the examination of solutions to reduce the phenomenon. A) The use of modern more efficient luminaires with special features such as asymmetric polar diagrams and b) the addition of special components to the luminaires to limit the emission of light in undesirable areas, combined with the proper installation of poles will be included in actions for counter fighting light pollution. The results of this method will guide these actions.

### 3. Case study

The stadium where the above method was applied is the Municipal Stadium of a city of North Greece (Figure 3). It is a place that hosts the football field of the two local teams while it is also the second home stadium for two more local clubs. Around the football field there is a track area, basketball, volleyball and tennis courts, open stands with a capacity of 5,000 people, administration offices and other auxiliary storage spaces. The sports facilities are located in the South - West part of the city and in direct contact with the urban areas of the city, being a natural continuation of it. The lighting of the stadium is carried out by four groups of luminaires suspended on an equal number of metal masts and a series of luminaires in the area of the stands. The luminaires used in the existing installation are shown in Table 1.
Figure 3. The surrounding area of the football field (Source: Google Earth).

Table 1. Number of luminaires, corresponding power and luminous flux.

| Type of luminaires | Number of luminaires | Power per luminaire (W) | Total power (W) | Luminous flux per luminaire (lm) | Total luminous flux (lm) |
|--------------------|----------------------|-------------------------|----------------|-------------------------------|------------------------|
| A                  | 40                   | 1954.5                  | 78,180         | 158,756                       | 6,350,240              |
| B                  | 76                   | 1954.5                  | 148,542        | 160,447                       | 12,193,972             |
| C                  | 62                   | 1954.5                  | 121,179        | 158,039                       | 9,798,418              |
| D                  | 2                    | 1954.5                  | 3,909          | 159,635                       | 319,270                |
| Total              | 180                  | -                       | 3,518,100      | -                             | 28,661,900             |

4. Measurements

The measurements of illuminance were carried out on 22/04/2021 with a luxmeter in horizontal level (height 0.8m). Initially, markers were placed on the field to create a grid with measurements 9.55cm x 9.15cm in one quarter of the space. Since there was no more daylight and the lights of the stadium had been turned on for about 30 minutes, measurements were made first at the selected points in the stadium, in the pitch area and then around the installation on municipal streets and on the facades of neighboring buildings. After the end of the measurements and after the pitch lighting was turned off, the measurements were repeated at the exact same points except of course the pitch area. In Figure 4 there are photos from the above field activity with the stage lights on.

Figure 4. Area of the football field (left) and pitch lighting (right).
Figure 5. Spill light in the surrounding area.

When activating the pitch lighting of the stadium, the illuminance measurements in the surrounding urban area of the stadium (Figure 5), showed a significant increase in readings compared with the measurements made with the use of the municipal lighting only, in the same spots (Table 2).

Table 2. Results of the illuminance measurements along of the area around the stadium.

| Grid | Lighting levels when activating both the pitch lighting and the municipal lighting [lx] | Lighting levels when activating only the municipal lighting [lx] | Comments |
|------|--------------------------------------------------------------------------------------|---------------------------------------------------------------|----------|
| 1    | 63                                                                                   | 58                                                            | Measurements on the municipal road |
| 2    | 131                                                                                  | 68.6                                                          | Measurements on the municipal road |
| 3    | 127.6                                                                                | 71.8                                                          | Measurements on the municipal road |
| 4    | 4.7                                                                                  | 0.1                                                           | Measurements on the municipal road   |
| 5    | 10.2                                                                                  | 4.3                                                           | Measurements on the municipal road   |
| 6    | 57                                                                                   | 0.1                                                           | Measurements in front view of building. |
| 7    | 128.8                                                                                | 0.4                                                           | Measurements in front view of building. |
| 8    | 39                                                                                   | 1.3                                                           | Measurements in front view of building. |

According to the IDA guidelines for backlight lighting, the allowed limits of the luminous flux for light that exceeds the theoretical limit of 10 m cannot exceed 2lx. In our case, the measurements taken peripherally of the field refer to distances much longer than the above limit. Our results show an increase in light intensity from 4.6lx (Grid 4, Table 2) to 128.4lx (Grid 7, Table 2). According to the measurements, there is an increase of lighting in the urban area surrounding the stadium that is being planned, by light pollution products. The use of lighting systems in the pitch lighting, produces intense lighting in comparison to the lighting produced only by the municipal lighting in the same grid points. Especially against vertical surfaces in the playing field as in the front surfaces of buildings which seem to receive significant spill light.

5. Simulations
Applying also the IDA instructions for calculating the uplight, we created a measuring surface at a height of one and a half meters above the lighting poles of the stadium, which extends about 45 meters.
from the boundaries of the playing field (Figure 2). The final dimensions of this surface (264m X 180.5m) are 47,652 m². The average illuminance $E_m$ was equal to 168lx (Figure 6). In addition, the useful pitch lighting was calculated using the illuminance value of 1186lx that is incident inside the total area of the football field including an adjust area of 10m.

Equation 1 calculates the illuminance $E$, value as the quotient of luminous flux $\Phi$ that incidents in an area $A$. Using as an input the illuminance value that is calculated in an area, the luminous flux that incidents in that area can be calculated.

$$E = \frac{\Phi}{A} \Rightarrow \Phi = E \times A$$  \hspace{1cm} (1)

Where $E$ is the illuminance value (lx), $\Phi$ the incident luminous flux (lm) in an area (m²).

The total luminous flux of all luminaires of pitch lighting was 28,661,900lm without the effect of MF (Maintenance Factor: 0.95) while 27,228,805lm using the MF. That was necessary as all calculations were performed using the MF. Using Equation 1 for the total uplight, the useful pitch lighting and the reflected lighting was calculated (Table 3). Furthermore, the direct uplight and the spill lighting were calculated. The total uplight was calculated to be 29.4% while the direct uplight was 12.1%. Both percentages weren’t in compliance with upper limit of 8% from IDA.

**Table 3. Calculations of luminous flux, uplight and spill light**

| Source of luminous flux | Illuminance (lx) | Length | Width | Reflectance | Maintenance Factor | Luminous flux (lm) | Percentage | Luminous flux / Luminous flux of initial source |
|-------------------------|-----------------|--------|-------|-------------|--------------------|-------------------|------------|-----------------------------------------------|
| Luminaires (Initial source) | - | - | - | - | 0.95 | 27,228,805 | - | |
| Uplight (Total) | 168 | 264 | 180.5 | - | - | 8,005,536 | 29.4% | |
| Useful pitch lighting | 1,186 | 176.91 | 92.52 | - | - | 19,412,108 | 71.3% | |
| Reflected lighting | 1,186 | 176.91 | 92.52 | 0.17 | - | 3,300,058 | 12.1% | |
| Direct uplight$^a$ | - | - | - | - | - | - | 17.3% | |
| Spill lighting (except uplight)$^b$ | - | - | - | - | - | - | 11.4% | |

$^a$ Direct uplight: Uplight (Total) - Reflected lighting
$^b$ Spill lighting: Useful pitch lighting - Direct uplight

**Figure 6.** Calculation results for uplight using a horizontal ceiling grid placed 1.5m above the top of the tallest pole, extending out to 45m beyond of each edge of the field.
6. Conclusions

We selected a Municipal Sports Stadium with a football field and a) we applied the IDA instructions for the calculation and measurement process and b) checked the compliance with the guide on the pitch lighting facilities. Furthermore, we introduced the total Uplight, Useful pitch lighting, Reflected lighting, Direct uplight and Spill lighting as variables that can identify not only the light pollution but also to direct the action of counter fighting light pollution into specific directions. By comparing measurements before and after the activation of the pitch lighting, we identified extreme light pollution levels in the surrounding urban area. In more detail, we chose to look at two crucial sizes, backlight and uplight factors. For the backlight lighting accepting as a limit of 2lx at a distance of 10 meters from the boundaries of the field, we measured that in the field values increased up to 128.4 lx in front of a neighboring building which was about 75 meters from the field. In other words, we received values multiple of the allowed limit. For the uplight lighting which was not practically possible to be measured in the field, we used simulation software. In this case the calculation of the illuminance values, shown a percentage of unwanted luminous flux to the sky equal to 29.4% in relation to the total luminous flux produced by the pitch luminaires. This percentage also exceeds the 8% recommended by IDA for uplight lighting.

Moreover, we proceeded to introduce and calculate a) the Useful pitch lighting (71.3%), meaning that 28.7% of light is wasted, b) the direct uplight (17.3%) meaning that extra equipment is needed in order to cut off the upward direction of light and c) the Spill lighting (11.4%) meaning that 11.4% of the lighting is emitted to adjustment properties. The process of using software to simulate the sports lighting in order to calculate these values at the design stage will lead light designers to take measures to limit light pollution. In accordance with the above we can create in a future more detailed method for vertical surfaces in order to receive more information for the direction of spill light. The above methodology can give us a safe estimation of the existence or non-existence of a light pollution problem in the specific area which we can then confirm with field measurements. If necessary, we can then proceed to interventions by redesigning lighting in order to comply with the limits of IDA or from other national or international guides.

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