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Chapter 3
Light pollution from small sports facilities

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The article assesses the degree of night sky pollution with artificial light emitted by existing sports facilities. The paper shows the standard requirements that have to be met by properly designed lighting systems for sports and analyzes the effect of the reflection coefficients of the luminous flux on light pollution. The existing sports complex in Bialystok was analyzed.

Index terms: outdoor lighting, light pollution, luminous flux, sports facilities

Introduction

The concept of light pollution appeared for the first time in 1985, when Dutch ecologist F. J. Verheijen described the negative impact of artificial light on nature as photopollution, while separating the issue into two groups: the pollution of biological-ecological and astronomical nature [1]. The term, describing pollution by artificial light of the night sky and significantly limiting or completely preventing the observations of constellations, astronomers then described as light pollution.

The problem of light pollution is mainly related to population density. Urbanized areas are equipped with a much larger number of lighting solutions, such as street lighting, roads, parking lots, advertising billboards, architecture illuminations and greenery areas, in relation to rural or urban-rural areas. Artificial light pollution of the night sky is also strongly influenced by sports facilities such as football fields, tennis courts and athletics stadiums. The lighting criteria related to games and match broadcasts are high, while the requirements set for sports facilities, due to the need to limit the emission of luminous flux in the upper half-space, are very often treated as loose tips and are not subject to any control or verification.

Normative requirements for sports facilities

Designing lighting systems, in the case of sports facilities, is not the easiest task because it requires taking into account both the comfort and safety of players, viewers, as well as adapting the installation to the requirements of television broadcasts. All available guidelines and standards take into account the type and rank of games that are carried out in a given sports complex, and also need to consider the type of television broadcasts performed within their area.

Currently, the most important documents defining the criteria to be met by properly designed lighting systems in sports facilities are:

- Report IES RP-6-15 Sports and Recreational Area Lighting [2],
- Polish Standard PN-EN 12193: 2008 Light and lighting – Lighting in sport [3],
- Sports federation documents relating to the sport discipline represented by the organization, e.g. Report FIFA Football Stadiums Technical Recommendations and Requirements [4]

In each of these documents, a division into lighting classes was made, depending on the type of gameplay, audience size or type of transmission, different normative requirements were presented for each class.

The IES Report RP-6-15 [2] categorizes four lighting classes:

- Class I – Facilities with audiences above 5000
- Class II – Facilities with audiences below 5000
- Class III – Facilities with audiences below 2000
- Class IV – Facilities with limited or no audience (recreational game only).

The required minimum average illuminance value for the lowest class IV is 200 lx, in the case of the highest class I, this value increases to 1000 lx (Table 3.1). For sports facilities of a training and recreational nature, average illuminance values on the horizontal plane constitute the basic reference parameter. In the case of facilities with television broadcasting, it is necessary to take into account an additional parameter, which is the illumination on the vertical plane.

TABLE 3.1. Recommended illuminance level for football fields [2]

Class	Horizontal illuminance [lx]	E_{max} / E_{min}
Class I	1000	1.7:1 or less
Class II	500	2.0:1 or less
Class III	300	2.5:1 or less
Class IV	200	3:1 or less

In addition to regulations regarding the selection of lighting, required levels of lighting, luminance and uniformity, the document also deals with the topic of light pollution. The specification stipulates the need to minimize the distribution of light outside the area of sports facilities, which may obstruct the observation of stars and disrupt the functioning of living organisms in the area.

Another document to consider when designing a lighting system in a sports facility is the Polish Standard PN-EN 12193: 2008 Light and lighting – Lighting in sport [3]. It defines the requirements for lighting intensity, uniformity, luminance and methods for measuring these quantities, indoors and outdoors, during the most popular European sports.

The requirements indicated in the standard [3] specify the maximum permissible value of disturbing light coming from external lighting installations divided into four environmental zones, from a completely dark zone E1, through zone E2 with low brightness, zone E3 with medium brightness, up to zone E4, characterized by high brightness.

For each zone, the standard [3] determines the percentage of luminaire luminous flux that is radiated above the horizon, i.e. the so-called ULR. It is defined as the percentage share of the luminous flux emitted by a lighting fixture or lighting system in the upper half-space, in relation to the installed flux [5]. The values of the maximum allowable interfering light from external lighting installations are summarized in Table 3.2.

TABLE 3.2. Maximum obtrusive light permitted for exterior lighting installations [3]

Environmental zone	**Light on properties**		**Luminaire intensity**		**Upward light**
	E_V [lx]		I [cd]		ULR [%]
	Pre-curfew *	Post-curfew	Pre-curfew	Post-curfew	
E1	2	0	2500	0	0
E2	5	1	7500	500	5
E3	10	2	10000	1000	15
E4	25	5	25000	2500	25

** If no curfew regulations are available, the higher values shall not be exceeded and the lower values should be taken as preferable limits*

One of the most restrictive guidelines related to the design of lighting installations in sports facilities is the one presented in the FIFA Football Stadiums Technical Recommendations and Requirements report [4]. The regulations are presented for five lighting classes (Class I – training and recreation without television broadcasts, Class II – leagues and clubs without television broadcasts, Class III – national games without television broadcasts), including two that require special lighting in connection with television broadcasts (Class IV – national games with television broadcast, Class V – international games with television broadcast).

Specifications for events transmitted in the media are presented in Table 3.3. Reference values, in the case of the FIFA report [4], are primarily the values of vertical and horizontal illuminance. For the fourth and fifth class, the average vertical illumination fluctuates between 1400 and 2400 lux, while the values of average horizontal illumination can reach values even above 3500 lux. All the values indicated in the document are so-called preserved values, which means that when designing the lighting system, the maintenance factor for a given sports facility should also be taken into account. As a result, the required average illuminance values can be up to one and a half times higher than the values given in Table 3.3.

The assumptions that were included in the report IES RP-6-15, Polish Standard PN-EN 12193: 2008 [3] and in the report of the FIFA federation are intended to guarantee the comfort and safety of practicing a given sports discipline, meet the dimensions of the facility and ensure the comfort of watching the game and its coverage. Designers and investors should also not forget about the existence of one more problem related to excessive emission of the luminous flux in the upper half-space, i.e. light pollution. Limiting the distribution of artificial light outside the area of a given sports facility is necessary to maintain the comfort of life of people living in the vicinity of stadiums and reduce the consumption of eclectic energy for the lighting of sports complexes.

TABLE 3.3. Lighting specifications for televized events [4]

		Vertical illuminance			**Horizontal illuminance**		
		E_V	U		E_V	U	
Class	Calculation towards	Lux	U1	U2	Lux	U1	U2
Class V	Fixed camera	2 400	0.5	0.7	3 500	0.6	0.8
	Field camera (at pitch level)	1 800	0.4	0.65			
Class IV	Fixed camera	2 000	0.5	0.65	2 500	0.6	0.8
	Field camera (at pitch level)	1 400	0.35	0.6			

** All indicated illuminance values are maintained values. A maintenance factor of 0.7 is recommended; therefore, initial values will be approximately 1.4 times as those indicated above*

Some documents and regulations highlight the negative impact of artificial light, emitted by existing objects and external lighting, on living organisms and introduce guidelines forcing control and reduction of the amount of artificial light emitted in the upper half-space (Table 3.4).

TABLE 3.4. Enviromental factor [4]

Angle of illumination	Distance from stadium perimeter	
Horizontal spill	50 m from stadium perimeter	25 lx
Horizontal spill	200 m further	10 lx
Maximum vertical	50 m from stadium perimeter	40 lx
Maximum vertical	200 m from stadium perimeter	20 lx

Luminous flux transmission

In the literature, the concept of "luminous flux" is defined as a photometric quantity derived from the energy flux (radial power), based on the assessment of radiation using a receiver with relative spectral sensitivity corresponding to the spectral sensitivity of the human eye adapted to photopic conditions (brightness) and described by formula (1) [6], [7]:

$$\Phi = K_m \int_{380}^{780} \Phi_{e,\lambda} V_\lambda \text{ [lm]}, \tag{3.1}$$

where:
$K_m = 683$ [lm/W] – photometric radiation equivalent,
$\Phi_{e,\lambda}$ – spectral distribution of radial power (energy stream),
V_λ – relative luminous efficiency of monochrome radiation.

The luminous flux falling on a given surface, depending on its type, may be reflected, transmitted or absorbed. Usually, two of the above phenomena occur simultaneously, i.e. reflection and absorption, due to the fact that there are neither perfectly reflecting nor perfectly absorbing bodies in nature [7], [8].

Transmission and absorption phenomena are not included in this article. In order to describe the degree of light pollution from existing sports facilities, the Lambertian reflection phenomenon of the object's surfaces was used. A relationship was used that determines the luminance value of a given surface (2), depending on its reflection coefficient and level of illuminance [10]:

$$L = \frac{\rho}{\pi} \cdot E \text{ [cd/m}^2\text{]}, \tag{3.2}$$

where:
ρ – reflection coefficient,
π = 3.14 – mathematical constant,
E – illuminance on the plane.

In order to determine the balance of luminous flux emanating outside the area of the analyzed sports complex and to analyze the excessive distribution of artificial light, it was assumed that a given sports facility constitutes a kind of lighting fixture (Figure 3.1).

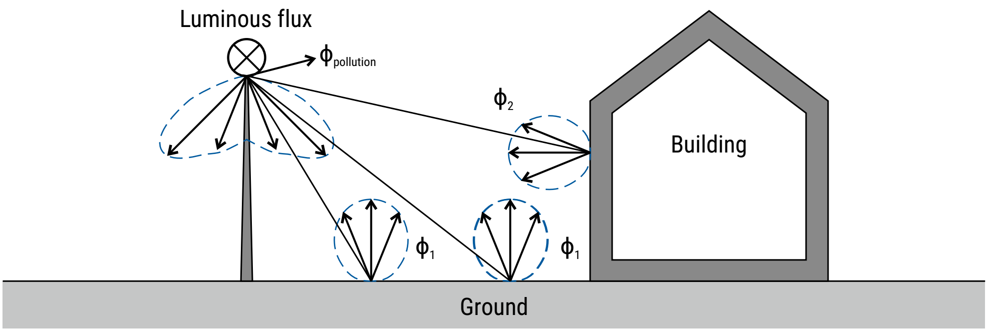


FIGURE 3.1. **Luminous flux balance**

It is worth noting that the luminous flux can be emitted in the upper half-space in two ways: directly or by reflection from various types of surfaces. The part of the light emitted directly towards the sky can be described by the so-called ULOR (Upward Light Output Ratio), formula (3.3) [11].

$$ULOR = \frac{\Phi_{up}}{\Phi_c} \cdot 100\%, \tag{3.3}$$

where:
Φ_{up} – luminous flux emitted in the upper half-space,
Φ_c – luminous flux of the light source in the luminaire.

The luminous flux balance can be described by formula (3.4).

$$\Phi = \Phi_1 + \Phi_2 + \Phi_{pollution} \text{ [lm]}, \tag{3.4}$$

where:
Φ_1 – luminous flux reflected from the ground,
Φ_2 – luminous flux reflected from existing objects,
$\Phi_{pollution}$ – luminous flux directed directly towards the upper half-space.

It should be noted that the light reflected from the ground and nearby objects is directed upwards, and then bounces off the cloud layer and returns to the ground. This not only causes excessive illumination of the night sky, but also an increase in illumination on the earth's surface. It is not possible to completely eliminate the luminous flux emitted in the upper half-space, but it is possible to use the luminous flux returning to the ground, among others, to improve the energy efficiency of road lighting, which will be presented later in the article.

Light pollution for selected sports complexes

The assessment of light pollution, based on the analysis of light beam distribution, was made on the example of existing sports complexes located in Bialystok (53° 07' N 23° 09' E). Two facilities were examined: the large-size Municipal Stadium and the Sports School, located in a small urban housing estate.

In the article "Estimating light pollution from sports facilities using DIALux simulation software" [12], the authors determined the amount of luminous flux emitted outside the studied sports facility – the Municipal Stadium in Bialystok, at different cloud heights, taking into account the actual light reflection coefficients. The obtained results showed that about 20% of the luminous flux comes out of the football field and increases the effect of sky pollution [12].

For the same facility, an analysis of light distribution in the upper half-space was also carried out, depending on the value of the stadium's surface reflection coefficients. During simulations, the values of light reflection coefficients on the stands surface (0.1 ÷ 0.9) and the main board of the object (0.1 ÷ 0.4), i.e. a football field, were modified [7]. The characteristics of the change in the value of lighting intensity together with the increase in the reflection coefficient of the stands and the differences between the lowest and the highest value for individual cases are presented in Figure 3.2.

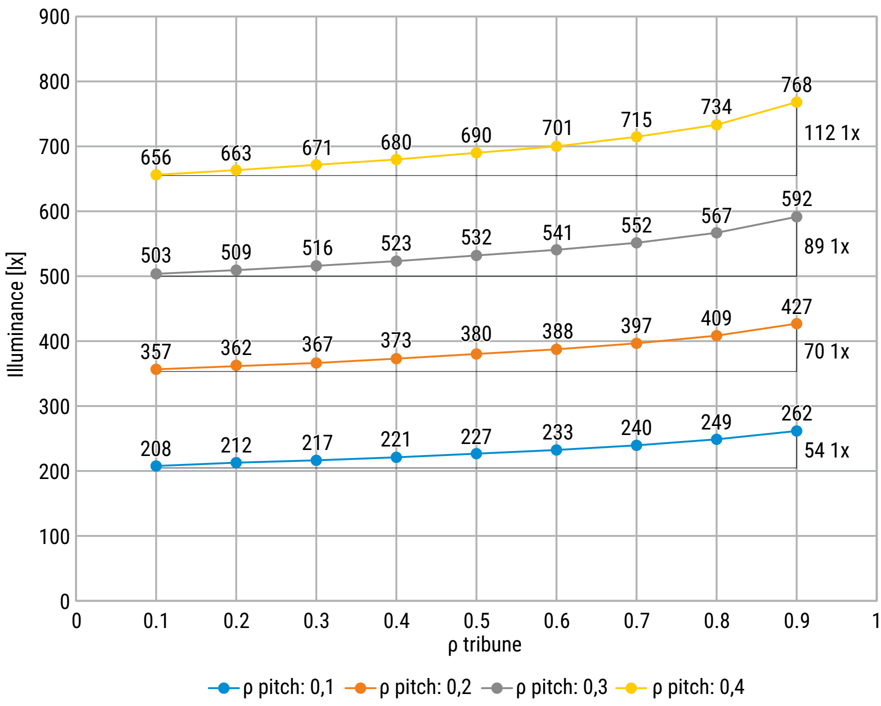


FIGURE 3.2. Graph of change in average illuminance as a function of tribune reflection coefficient [7]

The average illuminance values obtained by means of computer simulations oscillated between 208 and even 768 lux, which indicates a significant emission of the luminous flux from the stadium in the upper half-space.

Table 3.5 summarizes the calculated percentage values of the luminous flux escaping into the upper half-space. The amount of light that can be emitted by any football stadium, category IV (national games with television broadcasts) can reach [7]:

- from 3% for $\rho_{pitch} = 0.1$ and $\rho_{tribune} = 0.1$
- from 23% for $\rho_{pitch} = 0.4$ and $\rho_{tribune} = 0.9$.

TABLE 3.5. Average lighting distribution on adjusting streets surrounding the sports school in Bialystok

Gdańska Street	Lwowska Street	Lwowska Street	Pod Krzywą Street
Illuminance [lx]			
1.50 – 1.96	0.78 – 1.22	0.02 – 0.28	1.93 – 2.43
Luminance [cd/m²]			
0.18 – 0.23	0.09 – 0.14	0.002 – 0.03	0.23 – 0.28

This article analyzes the next sports complex at the Sports School in Bialystok (Figure 3.3). The school has a football field, two basketball fields and a tennis court. The fields are illuminated with 20 LED luminaires, each with a power of 450 W.

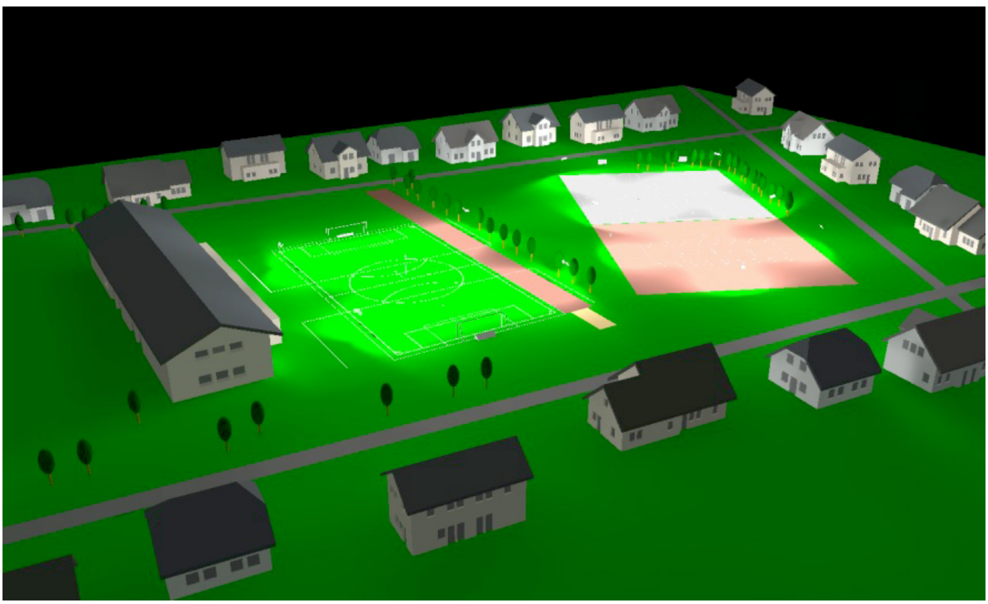


FIGURE 3.3. Sports School in Bialystok – view in the DIALux program

The school is surrounded by four streets (Figure 3.4), for which the possibility of reducing electricity consumption for the lighting of roads was analyzed, using the phenomenon of light pollution. Pod Krzywą Street is the best lit up, here the values oscillate between 1.93 and 2.43 lux, similarly in the case of Gdańska Street, from 1.5 to almost 2 lux. By comparing the results obtained with the required values, given in the lighting standard [3], it can be calculated to what extent it is possible to reduce energy consumption for the lighting of roads and streets located in the vicinity of a given sports facility (Figure 3.5).

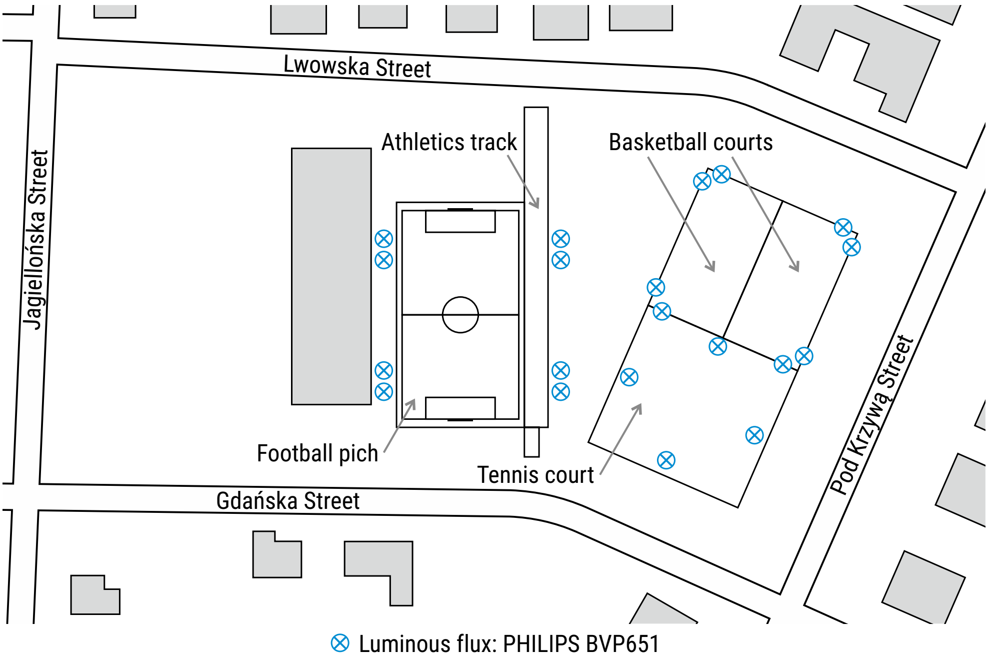
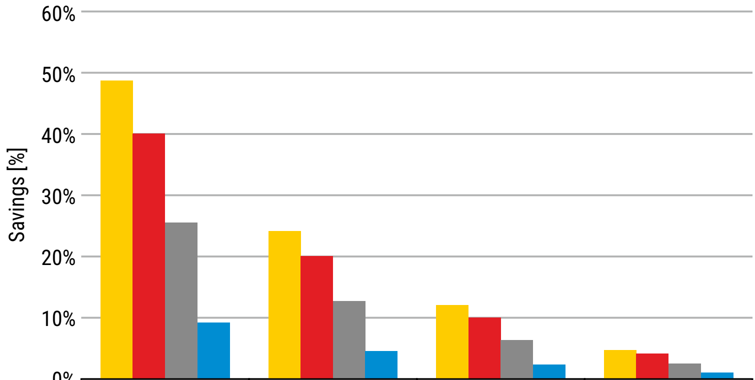


FIGURE 3.4. Sports School in Bialystok – top view

The average distribution of illuminance on adjacent streets is shown in Table 3.5.

In the case of the Sports School, it is possible to reduce energy consumption for the lighting of Pod Krzywą Street by about 24% while the lighting installation of the fields is switched on. For Gdańska Street, this is a saving of 20%, for Lwowska Street about 13% and less than 5% for Jagiellońska Street.



	5	10	20	50
Pod Krzywą Street	48.63%	24.31%	12.16%	4.86%
Gdańska Street	39.95%	19.97%	9.99%	3.99%
Lwowska Street	25.43%	12.71%	6.36%	2.54%
Jagiellońska Street	9.35%	4.67%	2.34%	0.93%

Required average illuminance [lx]

FIGURE 3.5. **Improving the energy efficiency of road lighting around the Sports School in Bialystok**

The following charts (Fig. 3.6 and 3.7) show the possibility of limiting the power of road lighting luminaires at night for the analyzed objects.

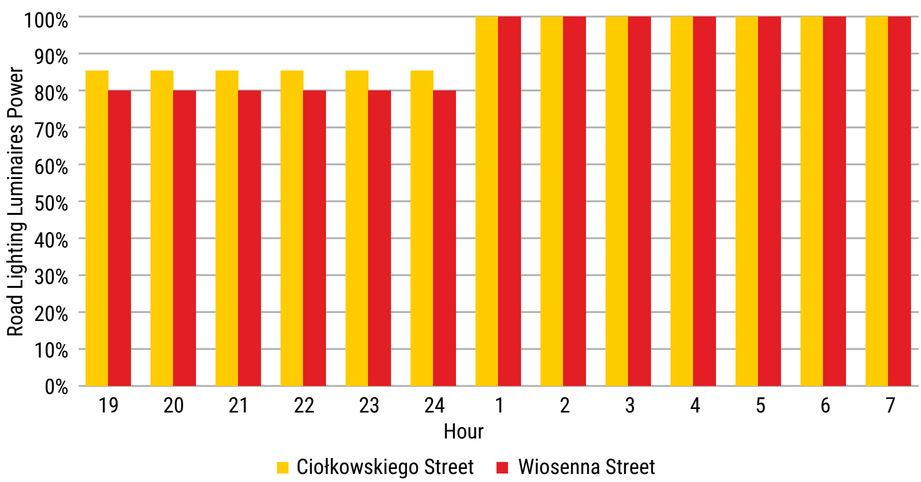


FIGURE 3.6. **Reduction of energy consumption for road lighting in the vicinity of the Municipal Stadium in Bialystok**

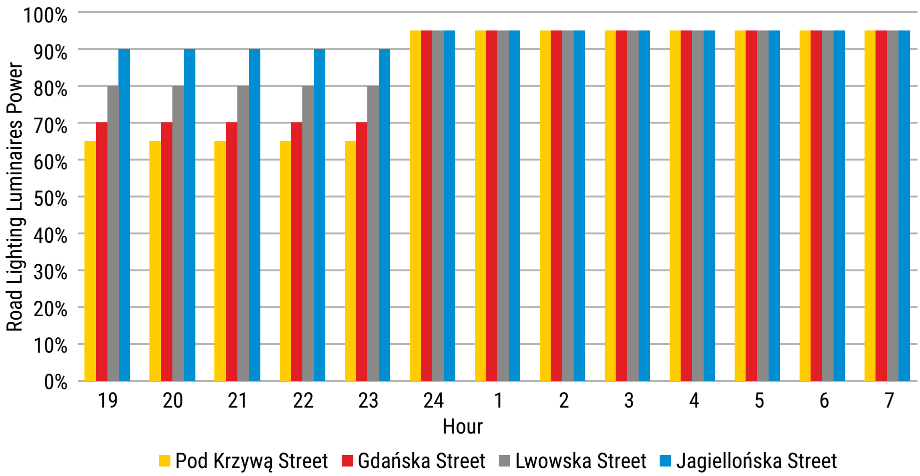


FIGURE 3.7. Reduction of energy consumption for road lighting in the vicinity of the Sports School in Bialystok

In the case of the Municipal Stadium, it is possible to limit the luminous flux of luminaires to 80 – 85% between 19:00 and 24:00.

For the Sports School, this means reducing energy consumption by up to 35% for Pod Krzywą Street between 19:00 and 23:00 and reducing the power of road lighting fittings throughout the night by 5%, due to the luminance of the sky itself.

Conclusion

Sports facilities, regardless of their size, significantly contribute to increasing the effect of pollution of the night sky with artificial light. The simulation analysis shows that it is possible to emit a light beam in the upper half-space even at a level of 50% from existing sports complexes. Such high values above all prove the ineffective lighting of sports facilities. It is possible to reduce light pollution by reducing the reflection coefficients of stadium structures, or in the case of closed facilities, by modifying their structure. However, none of these solutions will eliminate the problem of light pollution in full. Therefore, the authors of the article suggest the use of luminous flux emitted in the upper half-space, and then returning to the ground to improve the energy efficiency of road lighting. It is possible to partially reduce the energy consumption needed to illuminate the roads located in the vicinity of sports facilities when the lighting of the fields is on.

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