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Daylight Contribution to an Artificially Lit Football Field

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Summary

Sports fields all over the world have to fulfil certain requirements defined for light conditions. Especially for the football industry these rules are very strict. Daylight has never been studied for meeting those requirements, although it has the possibility to reduce energy costs and increase visual comfort. This study investigated potential daylight contribution to a currently artificially lit sports field. As a real world example, the Philips Stadium, home of football club PSV, in Eindhoven, the Netherlands, is chosen to model, validated with on-field measurements. A model in DIALux was used to simulate a football season and focus on what the Union of European Football Associations (UEFA) has required, such as illuminance levels, uniformity and glare. Results indicate that daylight always fulfils a few of the requirements, although there are only a few situations in which all are fulfilled.

1 Introduction

During the day the sun is the most dominant source of lighting. Even though light levels provided by daylight are much higher than electric light levels in sports stadiums, the artificial light source is always switched on. The stadium itself forms a barrier for the sun by casting shadows on the field. Depending on the stadium's orientation, time of day and year, and weather conditions, daylight is often unevenly distributed over the playing field. During the evening the amount of daylight is frequently significantly reduced or even absent. Artificial lighting can be the solution to guarantee the required uniformity and illuminance levels.

The importance of a good light distribution is demonstrated based on the situation in the Santiago Bernabeu stadium of Real Madrid (Spain) in 2005. Parts of the field did not get enough light due to the shadow casted by the stadium's geometry. The grass in the shadow areas withered very quickly.

The light distribution is also important during the football game. Therefore it is not surprising that the Union of European Football Associations (UEFA) specified the light requirements for football stadiums during matches. In order to host the most important matches, stadiums must meet category 1 ranking of the UEFA lighting requirements (Gomez, Seron, Aporta, & Gutierrez, 2005). This ranking consists of requirements for i.e. illuminance, uniformity, and glare (see Table 1). Since the majority of the public watches the games via television, additional requirements are designed to make the match visible onscreen (UEFA, 2014). Uniformity plays a big role and is calculated in two ways. U_1 is calculated with $E_{minimum}/E_{maximum}$, and U_2 is $E_{minimum}/E_{average}$. Agreement to these uniformity values prevents the existence of extreme high or low values.

Glare, the difficulty seeing in the presence of bright light, can be calculated according to different standards, designed for different situations. In 1994, the CIE developed a glare evaluation method for outdoor sports lighting and area lighting applications (CIE document 112-1994). The Glare Rating calculation grid provides an indication of glare experienced by the observer for each point in the grid based on the veiling illuminance produced by the luminaires and the environment (ground plane only) on an observer's eye. Glare Rating (GR) is used by the UEFA.

Table 1. Requirements set by the UEFA on Lighting for a Category 1 Stadium (UEFA, 2014)

	Minimum Requirement
$E_{h\ avg}$ (average horizontal illuminance)	2000 lux
Uniformity U_{1h} / U_{1h}	0.50 / 0.70
$E_{v4\text{-}96avg}$ (4 point average vertical illuminance (all four viewing directions))	2000 lux
Uniformity U_{1v} (4-point average) / U_{2v} (4-point average)	0.35 / 0.50
$E_{v\ ave\ 270°}$ (average vertical illuminance on main camera plane (270°)	2000 lux
Uniformity $U_{1v\text{-}270°}$ / $U_{2v\text{-}270°}$	0.50 / 0.70
Glare Rating (GR)	< 50

Football stadiums around the world put a lot of time and effort into the design of the lighting including suitable luminaires and correct positioning. The contribution of daylight was never researched for its contribution to the lighting of a sports facility.

Since the energy demand grows, saving energy and reducing emissions is one of the main challenges the world is facing today (Zahedi, 2010). Therefore it is important to take every opportunity to reduce energy consumption, and thus also every opportunity to reduce lighting energy demand. This makes it very important to see if and how daylight can be used to subsitute or support artifial lighting for a football field.

2 Method

In collaboration with football club PSV in Eindhoven, the Netherlands, measurements in their football stadium situation were performed. Recently, the light situation in the Philips Stadium attracted publicity because the lighting company Royal Philips installed new LED luminaires. This makes it the first football stadium in the Netherlands and the third in the world that has this state of the art lighting system installed.

The study consisted of two parts:

1) real-time measurements, and

2) a simulation study.

To come to an extensive and structured mapping of the light situation, real-time measurements (both illuminance and luminance) have been carried out to validate the results of simulations (Szűcs, Perraudeau, & Allard, 2006). There are 10 moments in the Dutch Eredivisie ('Honour Division') Season simulated that cover clear and overcast sky conditions and different sun positions. Illuminance values on the horizontal plane were used as input for the model. Glare indices were calculated based on luminance measurements, from the line of sight of the users, which are in this case the football players. This will show the quality of the lighting in the stadium, which then will be compared to the visual comfort that daylight yields. The Daylight Glare Index (DGI) is used for daylight glare measurements, and the Unified Glare Rating (UGR) for artificial lighting measurements.

2.1 Visual comfort assessment

The first experiment was done to detect glare: an important test to evaluate visual comfort by daylight and in night situations. This was done using a photo camera with a wide angle lens as measurement equipment and using the software tool 'Evalglare' (Wienold and Christofferson, 2005; Suk and Schiller 2012) for the image processing. The camera used was a Canon EOS D60 provided with a Sigma 4.5mm F2.8 EX DC fish-eye lens with a diagonal viewing angle of 180°, all connected to a laptop. This laptop ran the DSLR Remote Pro software and the light simulation software Radiance, including Evalglare. With High Dynamic Range (HDR) images, directly imported into Radiance, luminance values per pixel were combined into false colour images. Also, glare values were calculated with the standards DGI, and UGR.

The real-time measurements were done at seven positions on the football field (A, B, C, etc., see Figure 1a) facing two directions towards both goals. These seven positions were chosen since the football players come there frequently, as seen in red in Figure 1b.

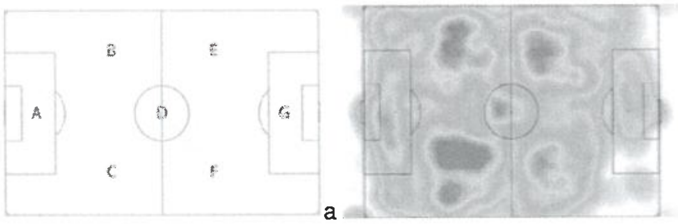

Figure 1. (a) Measurement positions on the field for the Visual Comfort Assessment ; (b) Heat Map of the PSV Player Positions during the first match PSV vs. Manchester United with the new LED luminaires on the 15th of September 2015 (OrtecSports, 2015)

2.2 Light level assessment

Illuminance was measured with the help of three illuminance meters (Minolta 1 * T-10A and 2 * T-10MA receptor heads). These meters have silicon photocells and a measuring range of 0.01 to 299,990 lx. Theoretically, the devices have a linearity of ± 2% ±1 digit of displayed value and the T-10A was calibrated automatically. Two T-10MA's were mounted on a tripod at a height of 1.0 m, with the first cell placed on top of the tripod to measure horizontal illuminance, and the second one on the side of the tripod to measure the vertical illuminance. During the measurement the tripod was rotated in four directions, facing the four different tribunes (north, east, south, and west).

To relate these results to the lighting conditions outside the stadium, horizontal illuminance values from a weather station on the roof of a two-storey building on the TU/e campus were retrieved. This was used to analyse how well the DIALux model performed. The daylight measurements are done on the 18th of November 2015 between 1:51 PM and 2:41 PM, and the night measurements on the 7th of December 2015 between 7:19 PM and 7:57 PM.

2.3 Computer simulation model

The computer simulation model was made with DIALux 4.12, which has built-in sports elements. Information about the LED luminaires and their positions was retrieved from Philips. In total, 296 luminaires hang from the canopies of the stadium, mounted in a line configuration. Every luminaire has a slightly different angle and aiming point compared to its adjacent luminaire, as can be seen in Figure 2. Figure 3 shows an aerial view of the Philips Stadium and the simulation model in DIALux. Simulations are done for the 1st of the month at 12 AM for one half (August until December) of the Dutch Eredivisie season (August until June).

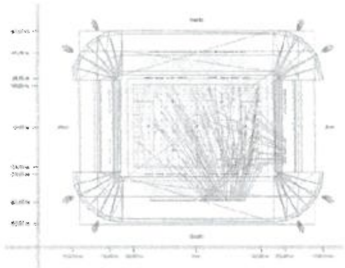

Figure 2. Overview of the luminaires in the Philips stadium and their main direction as used in DIALux

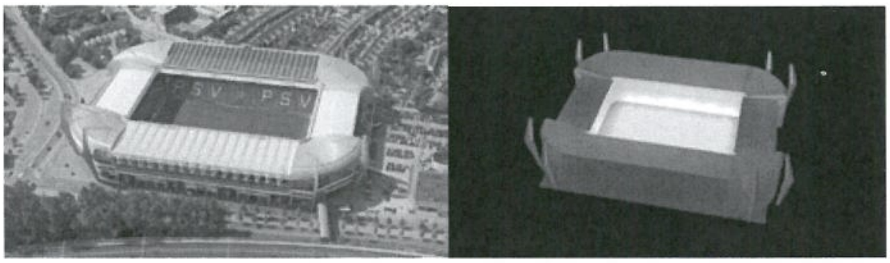

Figure 3. Aerial photo (left) and DIALux model (right) of the Philips Stadium in Eindhoven, the Netherlands

3 Results

Table 2 shows that the difference between the measured and simulated values is within an average comparison factor of 1.12, which means that the simulated values are on average 12% higher than the measured values.

Table 2. Comparison on measured values to simulation results on artificial lighting

Position	Measured horizontal illuminance in lx	Simulated horizontal illuminance in lx	Comparison Factor [simulated/measured]
A	2420	2380	0.98
B	2150	2740	1.27
C	2320	2740	1.18
D	3200	3010	0.94
E	2180	2750	1.26

F	2280	2740	1.20
G	2330	2380	1.02
Average			1.12

Below, in Table 3 and Table 4, the results from the Light level assessment are shown. All figures that do not meet the requirements set by UEFA are presented in *italic* **bold**. Table 5 shows the glare results from measurements and simulations.

Table 3. Horizontal illuminance and uniformity values from simulations

Horizontal illuminance in lx		E_{max} in lx	E_{min} in lx	E_{avg} in lx	U_1	U_2
Artificial lighting		4 210	2 160	2 940	0.51	0.73
Month	Sky condition					
August	Clear Sky	70 570	4 970	52 720	***0.07***	***0.09***
	Overcast Sky	13 480	8 130	11 540	0.60	0.70
September	Clear Sky	58 200	4 280	34 940	***0.07***	***0.12***
	Overcast Sky	11 720	7 070	10 030	0.60	0.70
October	Clear Sky	41 220	3 550	17 760	***0.09***	***0.20***
	Overcast Sky	9 280	5 600	7 940	0.60	0.70
November	Clear Sky	8 870	2 910	5 990	***0.33***	***0.49***
	Overcast Sky	7 050	4 250	6 040	0.60	0.70
December	Clear Sky	5 450	2 080	3 960	***0.38***	***0.52***
	Overcast Sky	4 900	2 960	4 200	0.60	0.70

Table 4. Vertical illuminance and uniformity values towards the camera from simulations

Vertical illuminance in lx (towards camera, °270)		E_{max} in lx	E_{min} in lx	E_{avg} in lx	U_1	U_2
Artificial Lighting		4 340	1 550	2 750	***0.36***	***0.56***
Month	Sky condition					
August	Clear Sky	18 190	4 380	13 270	***0.24***	***0.33***
	Overcast Sky	6 360	1 810	4 700	***0.29***	***0.39***
September	Clear Sky	17 010	3, 80	10 980	***0.23***	***0.36***
	Overcast Sky	5 530	1 580	4 090	***0.29***	***0.39***
October	Clear Sky	14 670	3 650	8 120	***0.25***	***0.45***
	Overcast Sky	4 380	1 250	3 240	***0.29***	***0.39***
November	Clear Sky	8 670	3 220	5 340	***0.37***	***0.60***
	Overcast Sky	3 330	950	2 460	***0.29***	***0.39***
December	Clear Sky	3 500	2 010	2 800	0.57	0.72
	Overcast Sky	2 310	660	***1 710***	***0.29***	***0.39***

Table 5. Glare indexes from measurements and simulations

	Point on field						
Glare index	A	B	C	D	E	F	G
Simulated Artificial Lighting [GR]	44	46	47	40	47	46	44
Measured Artificial Lighting Facing West [UGR]	11.6	9.3	9.3	12.2	10.8	12.7	11.8
Measured Artificial Lighting Facing East [UGR]	11.2	10.6	11.9	12.3	9.6	9.1	11.0
Measured Daylight Facing West [DGP]	0.26	0.38	0.33	***0.46***	***0.53***	***0.40***	***0.46***
Measured Daylight Facing East [DGP]	***0.43***	***0.46***	0.33	***0.53***	***0.49***	0.37	0.27

4 Discussion

Especially for the vertical illuminance values, most of the results do not meet the requirements for stadium lighting, except for one simulated situation: the clear sky in December. This situation has a bright sky with a shadow casted on the whole field, which improves illuminance uniformity. It is predicted that this will also apply to an overcast sky in mid-summer since this yields a high uniformity and a semi bright sky, which might be enough to meet the requirements. This is left out of the simulations since the first match of the Dutch Eredivisie season is played in August.

The simulation results show relatively high glare indexes even though they do not exceed the requirement of 50. This is comparable for both the day and the night situations in the stadium. Situations with daylight show the highest probability for glare, but it must be noticed that the results are collected on the 18th of November at noon when the sun had a low position, but just high enough to reach players on the field. Therefore it is predicted that any other moment in the Eredivisie season, will result in lower glare probability.

5 Conclusions

It is concluded that daylight can be used to meet the football lighting requirements in December with a clear sky, which occurs 27% of the time in the Netherlands (KNMI, 2016). Since half of the year is simulated, also clear skies in January will be meeting the requirements. This comes down to 6% of the Eredivisie season.

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