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Measurement of daylight illuminance levels in transient periods for public lighting control

***Abstract**. Current activities in the field of public lighting research and standardization are focused on establishment of energy efficiency numerical indicator based on installed power, target photometric parameters and operation time. Up to now, indicative annual operation times for public lighting systems are used for calculations. Public lighting control itself is based on photosensing and/or various clock switching, both without any relevance to real needs. There is lack of correlation to lighting levels given in standards for particular lighting classes. Basement for such correlation must be derived from available daylight and its diminution during transient periods of sunrise and sunset. This article is aimed at measurement of daylight levels throughout these periods of day which are not studied yet for other daylight utilization applications.*

***Streszczenie.** Obecne działania w zakresie badań oświetlenia obiektów publicznych koncentrują się na określeniu numerycznego wskaźnika efektywności energetycznej opartego na mocy instalowanej, zaleceń parametrów fotometrycznych i czasu działania oświetlenia. Do tej pory w obliczeniach oświetlenia publicznego wykorzystuje się roczny odniesieniowy czas działania. Układy sterowania oświetleniem publicznym wykorzystują czujniki światła i zegary czasowe, bez odniesienia do rzeczywistych potrzeb. Brak jest zwłaszcza odniesienia do poziomów oświetlenia podawanych w normach dla klas oświetleniowych. Podstawę takich określeń powinno stanowić dostępne światło dzienne i jego ograniczenie w okresach przejściowych, wschodu i zachodu Słońca. W artykule skoncentrowano się na pomiarach dziennego natężenia oświetlenia w okresach dnia, które nie były badane w innych zastosowaniach oświetleniowych. (**Pomiary poziomów dziennego natężenia oświetlenia w okresach przejściowych do kontroli oświetlenia obiektów publicznych**)*

Keywords: daylight, public lighting, street lighting, operation time of lighting, energy efficiency of lighting
Słowa kluczowe: światło dzienne, oświetlenie publiczne, oświetlenie drogowe, czas działania oświetlenia, efektywność energetyczna oświetlenia

Introduction

Public lighting is known for interesting energy saving potential throughout the Europe [1]. Reasons can be found in relation between technological development in lighting and construction of roads and their infrastructure in the framework of urban development. As lifetime of lighting systems is high, older systems are still operated and, therefore, side by side mercury, sodium and modern metal halide or LED based luminaires can be found. Since the new millennium strong emphasize is put to energy efficiency of lighting systems what intensified re-construction of obsolete systems in order to reduce their energy demand, though, often not performed rationally and according to technical standards, resulting to decrease of lighting levels below desired values. European Union supports the encouragement to install and use energy efficient technologies in lighting and provides legal tools for the process. Tried and experienced energy labelling of equipment and energy certification of buildings [2], including built-in lighting as a self-standing sub-system, is now continuing to involve other lighting applications. For public lighting, energy efficiency numerical indicator is being defined and prepared for introduction.

Lighting levels for road sections of given visual condition and traffic situation, combined to lighting classes, are pre-scribed by technical standards. Required lighting levels can be provided by less or more efficient lighting systems [3]. Lighting system performance is, however, a static parameter that can relate the installed power to the area to be lit and to the required luminous parameter. But installed power is just one of the two aspects that influence the electricity bill for municipalities and thus energy demand reduction and CO_2 reduction for the EU. The other aspect is operation time in simple systems or operation profile in more sophisticated systems. Even for simple systems, no common standard time for energy calculations is yet agreed in Europe. For adaptive lighting systems and systems with lighting dimming there is no common basis at all.

Practically it means that there is no generally accepted method for comparison of the energy efficiency of different lighting systems. Lack of standard is disadvantageous to decision makers (municipalities, assessors/evaluators of lighting designs for European funds). The past has shown that this situation led to set up unfair or weird criteria for selections of lighting projects. On the other hand, for manufacturers it is a paradise allowing them to declare „miraculous“ benefits of their lighting regulators [4].

Aim of this article is to contribute to the operational aspects of public lighting systems. Long term research activities at the Slovak University of Technology in this field cropped first fruits of the R&D efforts and started up new approaches based on natural lighting level measurements.

Background

Operation of public lighting system is bounded by time of sunset and time of sunrise. Many assumptions are based purely on this range, giving thus i.e. full-range operation time. However, it is impractical to switch on the lighting right after sunset when there is still enough light to enable sufficient visual performance. Requirements to switch-on and switch-off times are currently prescribed by neither international technical standard, including the group of European standards EN 13201:2004 [5] which is actually under revision and will be completed by fifth part devoted to energy aspects. Thus, time to switch-on and switch-off the lighting can be derived from lighting levels for individual lighting classes of roads according to TR13201-1 and EN13201-2 (see Table 1) assuming the fact that these levels need to be satisfied by artificial lighting when daylight is not sufficient, i.e. below the stated levels.

Of course, this approach is too simplified and do not account for three specific problems:

- artificial light is spectrally different from daylight and because visual conditions are in mesopic range, specified lighting levels are not validly applicable to daylight
- dynamic variation of the adaptation luminance during transient period of sunrise and sunset
- start-up time of lighting systems is comparable to illuminance gradient of daylight within the range of interest.

Table 1 Lighting levels in terms of maintained horizontal illuminance assigned to comparative lighting classes according to TR13201-1 and EN13201-2

E (lx)	Comparable Lighting Classes*		
50	CE0		
30	CE1		ME1
20	CE2		ME2
15	CE3	S1	ME3
10	CE4	S2	ME4
7,5	CE5	S3	ME5
5		S4	ME6
3		S5	
2		S6	
not defined		S7	

* For ME lighting classes the design criterion is luminance in cd.m^{-2}

Slovak national standard STN 36 0400:1984 [6], withdrawn in 2005 after the group EN 13201 came in force, stated the time difference for switching to 1/2 hour before sunrise and after sunset for winter season (September 23 to March 21) and 3/4 hour for summer season respectively. Until there are devoted studies performed, above mentioned time delays can be temporarily accepted. The mentioned time spans can be referred as tailored operation time. Due to seasonal variation of sun's path, calculations and measurements should be performed on daily basis or in simplified cases on monthly basis.

As alternative method, STN 36 0400 provided determination of the switching times according to lighting levels as follows:

- switch-on lighting when daylight falls below 80 lx in unobstructed exteriors of dense urban areas or complicated traffic situations and 40 lx otherwise
- switch-off lighting when daylight raises above 40 lx in unobstructed exteriors of dense urban areas or complicated traffic situations and 20 lx otherwise

Both methods have been widely used before – time method by means of manually settable time switchers and illuminance method by means of photocells. Time switchers have been nowadays replaced by programmable (or preprogrammed) actuators like relays or controllers and these maintenance free devices are preferred against photocells which are influenced by the surroundings and dust/dirt deposits on the sensor.

Most of lighting systems are switched centrally in a distribution box. In fact, there is then no correlation between lighting classes and lighting network topology. In such cases the light switching should take into account always the highest lighting class.

Suitable switching profiles, light dimming and other techniques may contribute to optimize energy utilization for public lighting [7]. Due to seasonal changes of daylight availability, at least one-year basis should be used for setting up the parameter. If no dimming is applied, standard annual operation times can be derived for different geographical locations. However, particular local conditions or requirements may be applied as well. If dimming systems are to be installed, lighting levels should correspond to lighting classes linked to the relevant area as per EN 13201-2 [5] or CIE 115 [8], differentiated for normal (full-level) and dimmed operational regimes. Lighting designer has to consider all assumptions and calculations perform with the most probable switching/control diagram (example on Fig. 1). The diagram must be attached to calculations as part of the lighting project.

Daylight is continuously measured in several CIE IDMP stations [9], including vertical illuminances [10]. However, illuminance from daylight is not yet systematically studied for the purpose of switching of public lighting systems. For daylighting purposes measurements are performed from ca. 50 lx above what is the upper limit in public lighting. Irradiance in solar energy engineering is studied from the solar altitude 5° above [11]. Detailed enough data on decrease of illuminance right after the sunset and increase of illuminance right before sunrise, as transient periods between day and night, are not available. Then night sky is subjected to measurements for the purpose of obtrusive light assessment [12].

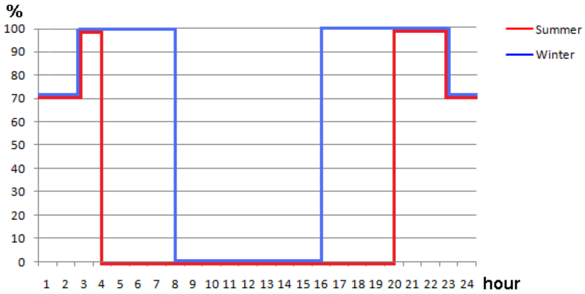


Fig. 1 Typical daily switching profile for 50° latitude with light dimming

Methodology

Measurements of the Slovak University of Technology are performed in three locations: Bratislava (normal to increased pollution), Bernolákovo (close to Bratislava, normal pollution) and Matúškovo (60 km from Bratislava, clean environment – Fig. 2). Measurements are performed since 1st of May 2012. Because measurements cannot be for technical reasons fully automated, measurements are performed approximately every 3 – 4 days with preference of good weather. Both sunset and sunrise periods are subjected to measurements. For each measurement, actual local conditions are recorded, like ambient temperature, weather, cloudiness, moon phase etc. Horizon is unobstructed (< 5° shading).

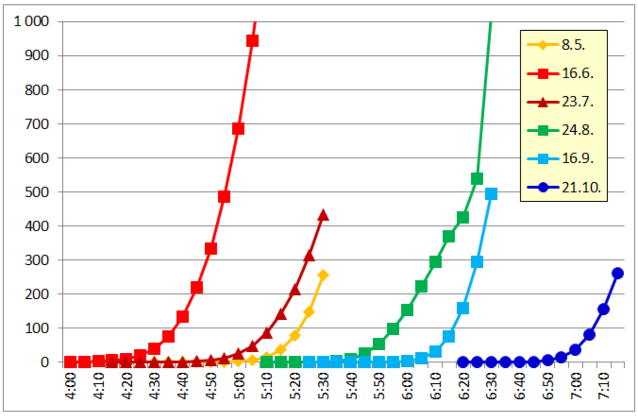
Fig. 2 Measurement site in Matúškovo (48,163° N, 17,726° E) with photometric head placed to a tower rooftop

Fig. 3 Measuring equipment

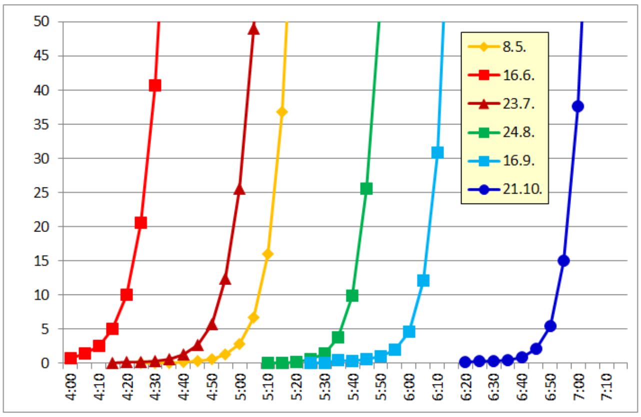
Measuring equipment (Fig. 3) consist of precise illuminance meter Krochman Radiolux 111 with a remote photometric sensor and a notebook for reading and recording the measured data. Internal clock of the notebook is kept synchronized with reference time through a web link. For precise measurements the sampling frequency is set to 5 seconds, for ordinary measurements the notebook samples each 30 seconds. Data on illuminance with time stamp are streamed to an excel sheet which is easy to process for consequent analyses.

Results

Increase of illuminance around sunrise is depicted on Fig. 4 and decrease of illuminance around sunset is depicted on Fig. 5 with close-up cut-off of the range 0 – 50 lx (50 lx is the benchmark for highest lighting class). Times of light level nodes according to EN 13201-2 are given in Table 2 for sunrise and Table 5 for sunset. Tables 3 and 6 (for sunrise and sunset respectively) indicate time span between sunrise or sunset and the moment when certain illuminance level is reached. Illuminance gradient is in Table 4 for sunrise times only.



a) Illuminance range 1 000 lx



b) Illuminance range 50 lx

Fig. 4 Horizontal Iluminance E (lx) vs time around sunrise

Table 2 Times of sunrise and times of specified light levels at sunrise for months from May to October

Light Level (lx)	Time of light level (hh:mm)					
	8.5.	16.6.	23.7.	24.8.	16.9.	21.10.
2	4:58	4:08	4:43	5:31	5:55	6:44
3	5:00	4:11	4:45	5:33	5:58	6:46
5	5:03	4:15	4:49	5:36	6:00	6:49
7,5	5:06	4:18	4:51	5:38	6:02	6:51
10	5:07	4:20	4:53	5:40	6:04	6:52
15	5:10	4:23	4:56	5:41	6:06	6:54
20	5:11	4:25	4:58	5:43	6:08	6:56
30	5:14	4:27	5:01	5:45	6:10	6:58
50	5:17	4:31	5:05	5:49	6:12	7:01
Sunrise	5:24	4:48	5:14	5:59	6:32	7:27
$E_{sunrise}$ (lx)	131	283	129	142	593	649

Table 3 Times before sunrise when specified light levels are detected

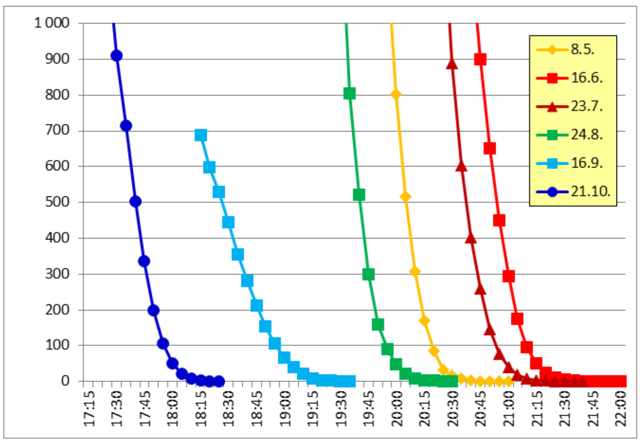
Light Level (lx)	Time before sunrise (hh:mm)					
	8.5.	16.6.	23.7.	24.8.	16.9.	21.10.
2	0:39	0:40	0:31	0:28	0:37	0:43
3	0:37	0:37	0:28	0:26	0:34	0:41
5	0:34	0:33	0:25	0:23	0:32	0:38
7,5	0:31	0:30	0:22	0:21	0:30	0:36
10	0:30	0:28	0:20	0:19	0:28	0:35
15	0:27	0:25	0:17	0:18	0:26	0:33
20	0:26	0:23	0:15	0:16	0:24	0:31
30	0:23	0:20	0:13	0:14	0:22	0:29
50	0:20	0:16	0:09	0:10	0:20	0:26

Table 4 Gradient of illuminance at different light levels during sunrise and for different months

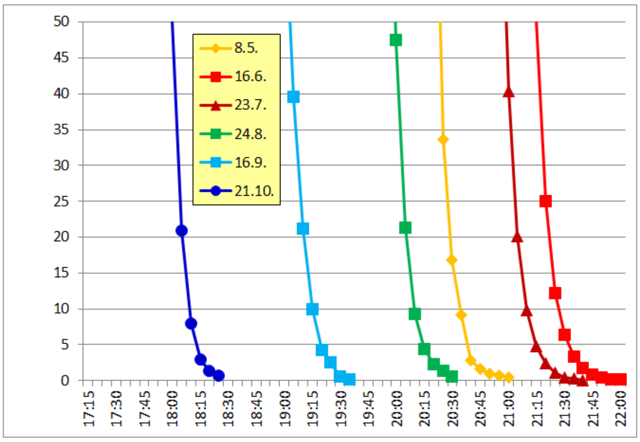
Light Level (lx)	Illuminance gradient ($lx.min^{-1}$)					
	8.5.	16.6.	23.7.	24.8.	16.9.	21.10.
2	0,30	0,30	0,22	0,40	0,40	0,30
3	0,65	0,65	0,65	0,64	1,00	0,60
5	0,80	0,63	0,81	1,00	1,10	1,00
7,5		1,00	0,96	1,60	1,60	1,60
10		1,36	1,27	2,20	2,00	2,30
15		1,93	2,21	3,20	3,70	3,10
20		2,72	2,63	3,80	4,60	4,10
30		3,71	3,70	5,00	6,50	6,00
50		6,23	5,45	6,80	9,30	8,50

Table 5 Times of sunset and times of specified light levels at sunset for months from May to October

Light Level (lx)	Time of light level (hh:mm)					
	8.5.	16.6.	23.7.	24.8.	16.9.	21.10.
2	20:44	21:39	21:21	20:21	19:22	18:17
3	20:40	21:35	21:17	20:18	19:21	18:14
5	20:36	21:31	21:14	20:14	19:18	18:12
7,5	20:34	21:28	21:11	20:11	19:16	18:10
10	20:32	21:26	21:09	20:09	19:14	18:08
15	20:30	21:23	21:06	20:07	19:12	18:06
20	20:28	21:21	21:04	20:05	19:10	18:05
30	20:26	21:18	21:01	20:03	19:07	18:02
50	20:23	21:15	20:58	19:59	19:02	18:00
Sunset	20:13	20:56	20:43	19:50	19:01	17:46
E_{sunset} (lx)	740	283	129	164	61	307



a) Illuminance range 1 000 lx



b) Illuminance range 50 lx

Fig. 5 Horizontal illuminance E (lx) vs time around sunset

Table 6 Times after sunset when specified light levels are detected

Light Level (lx)	Time after sunset (hh:mm)					
	8.5.	16.6.	23.7.	24.8.	16.9.	21.10.
2	0:44	0:43	0:38	0:31	0:21	0:31
3	0:40	0:39	0:34	0:28	0:20	0:28
5	0:36	0:35	0:31	0:24	0:17	0:26
7,5	0:34	0:32	0:28	0:21	0:15	0:24
10	0:32	0:30	0:26	0:19	0:13	0:22
15	0:30	0:27	0:23	0:17	0:11	0:20
20	0:28	0:25	0:21	0:15	0:09	0:19
30	0:26	0:22	0:18	0:13	0:06	0:16
50	0:23	0:19	0:15	0:09	0:01	0:14

Discussion to the results

From Tables 2 & 5 follows that in the moment of sunrise/sunset the level of illuminance is still high enough. Around summer solstice the illuminance peaks in comparison to other days. Lowest levels in winter season are to be obtained by the end of 2012.

3/4 hour standard time span for summer, used in older national standard STN 36 0400, is in good accordance with values measured close to solstice and related to the lowest lighting class S6 with 2 lx, used for pedestrians. For common motorized traffic the lighting classes ME5 to ME3 are prevailing, for which corresponding illuminance levels 7,5 to 15 lx are reached during 25 to 30 minutes from sunrise/sunset. For yet higher lighting classes the specified illuminance levels are reached as soon as 10 to 20 minutes from sunrise/sunset. It is important to point out that lighting system needs at least 5 minutes to reach almost-full luminous flux of lamps, thus this time has to be added to the values mentioned above. Start-up time of lighting system is important also in connection with illuminance gradient given in Table 4. During 5 minutes the illuminance level can rapidly change. This change is fastest in time close to sunrise/sunset and slow close to steady-state levels of tenths of lux. It means that the start-up time is significant for higher lighting classes. From the results it also follows that the fast illuminance gradient in the range up to 50 lx allows to define a common basis for lighting control of networks with mixed topology.

Conclusions and outlook

For determination of operating time of public lighting systems, methods known from daylighting and solar energy engineering can be used. However, there is lack of data on behaviour of illuminance around the moment of sunrise/sunset and first of all after sunset and before sunrise, as these times are meaningless both for daylighting and utilization of solar radiation. Long-term measurements of the Slovak University of Technology are intended to obtain sufficient data sets to provide necessary analyses. Up to now, 6 month period is measured and measurements are being continued.

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Európska únia

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