Artificial light sources as a light pollutant of human melatonin suppression

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Abstract—Blue light emitted by LEDs might influence the natural biological rhythm of a human being, which can be considered as environment pollution. In this paper the effect of the latest commercially available LEDs on melatonin suppression index (MSI) was analyzed. The research was based on spectral power distribution of a given LED (SPD) and melatonin suppression function in reference to melatonin suppression under daylight (illuminant D65). The results of calculations show a strong correlation between CCT and MSI; however, MSI factor might vary for different LEDs with the same CCT.

In recent years we could observe rapid development of LED technology. As a result, conventional light sources have been replaced in most lighting applications today. The lifetime and efficiency of LEDs were the main driver for this change. Contemporary LEDs can offer efficiency above 200 lm/W and lifetime exceeding 50 000 hours. Nevertheless, further efficiency improvement is difficult to achieve, as we are getting closer and closer to theoretical limits [1]. On the other hand, the lifetime is satisfactory for most applications of general lighting. For these reasons, LED manufacturers are searching for other ideas to improve their products. Improvements in light quality is currently the most promising way of further LEDs development. In particular, the wellbeing is a key aspect of every modern lighting installation [2-3]. It was proven [4-5] that blue light creates not only visual sensation, but can also influence the biological rhythm of the body, the so-called circadian cycle. The mechanism was created by thousands of years of evolution and has a strong influence on our comfort, concentration and alertness. On the other hand, disorders of this cycle might lead to a serious disease. Blue light might also cause immediate eye damage, but this mechanism is independent from the topic discussed in this paper [6]. For these reasons, a high amount of blue light is considered as environment pollution. White LEDs are called: blue rich light sources, i.e. contain a significant amount of radiated power in the range 400÷500 nm. Light in this range is responsible for stimulating intrinsically photosensitive retinal ganglion cells (so called ip-RGC [7]). This information is utilized by the brain for melatonin secretion. Finally, melatonin concentration in blood determines the phases of human activity and sleep.

There are few ways to quote and measure the potential influence of a given light source on human body in respect to blue light exposition [8-11]. Melatonin suppression index (MSI) was one of the first commonly used factor for describing the phenomena. It relates to the spectral power distribution of a given light source, as the experimentally measured melatonin suppression function M(λ) and daylight radiation as illuminant D65; see Eq.(1) and Fig. 1. In other words, it describes relative melatonin secretion.

$$MSI = \frac{\int_{380}^{730} S_{lamp}(\lambda)\cdot M(\lambda)}{\int_{380}^{730} M(\lambda)\cdot D65(\lambda)} \tag{1}$$

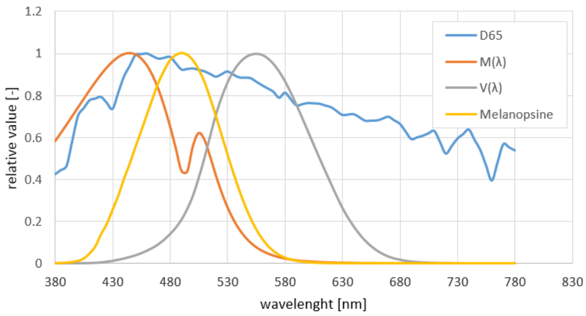

Fig. 1. Spectral power distribution of illuminant D65, melatonin suppression function and human eye sensitivity.

As much as MSI is a well accepted index, CIE in the latest publications recommends using the most primary response of human body to blue light stimulation [12]. The melanopic sensitivity curve represents the response of a photo pigment which is contained in ipRGC (see Fig. 1 and formula 2). Calculated values should be expressed in radiometric units with a relevant comment about the weighting function (in this case: melanopic fux or melanopic irradiance).

$$E_{e,\alpha} = \int_{380}^{780} E_{e,\lambda}(\lambda)\cdot S(\lambda) dV(\lambda) \tag{2}$$

The typical spectral power distributions SPDs for representative LEDs of given correlated color temperature

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CCT were presented on Fig. 2, and their colorimetric parameters are described in Table 1 and Table 2.

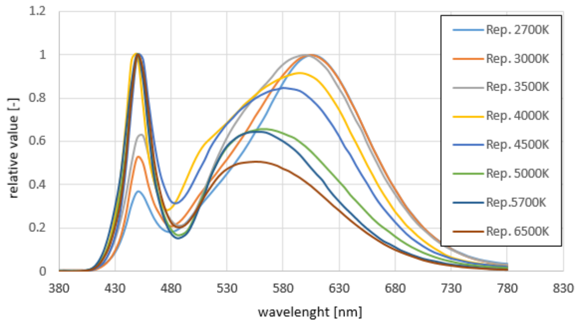

Fig. 2. The SPDs of standard white representative LEDs.

Table 1. The colorimetric parameters of typical LEDs presented in the market

SPD	Typical LEDs			
CCT	2700K	3000K	3500K	4000K
x	0.4546	0.4353	0.4171	0.3754
y	0.4085	0.4018	0.3961	0.3728
u’	0.2600	0.2504	0.2411	0.2234
v’	0.5257	0.5203	0.5152	0.4991
CRI	81	83	80	84

Table 2. The colorimetric parameters of typical LEDs presented in the market

SPD	Typical LEDs			
CCT	4500K	5000K	5700K	6500K
x	0.3634	0.3424	0.3271	0.3113
y	0.3703	0.3514	0.3457	0.3237
u’	0.2164	0.2097	0.2014	0.1988
v’	0.4962	0.4842	0.4791	0.4653
CRI	82	76	72	80

However, LED technology and phosphor compositions bring a wide range of possibilities to create any required spectral power distribution of white light. For that reason, there is a theoretically unlimited number of ways to create white light. For example, warm white light might be created with the use of different blue emitters and phosphor compositions (see Fig. 3 and Table 3).

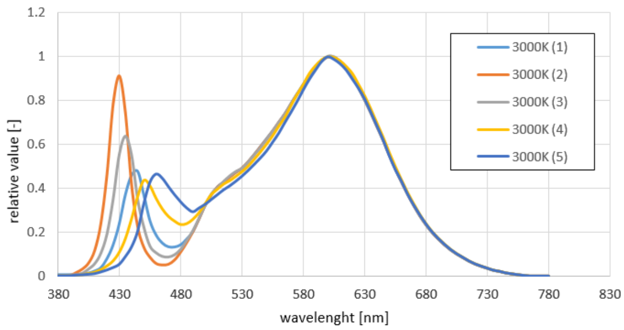

Fig. 3. Different SPDs of warm white LEDs (3000K).

Table 3. The colorimetric parameters of LEDs with CCT=3000 K and different SPDs

CCT	LED with CCT=3000K				
Sample	1	2	3	4	5
x	0.4371	0.4317	0.4347	0.4354	0.4349
y	0.4047	0.3934	0.3996	0.4012	0.4002
u’	0.2504	0.2518	0.2511	0.2508	0.2509
v’	0.5217	0.5163	0.5193	0.5200	0.2509
CRI	80	78	79	81	82

There are also commercially available LEDs which mimic sun radiation in the visible range (see Table 4 and Fig. 4). Their SPD is very different from typical LEDs, which improves colour perception and according to marketing materials, the amount of blue light is closer to natural light. However, it was all achieved by the cost of efficiency, which is significantly lower than in the case of standard LEDs.

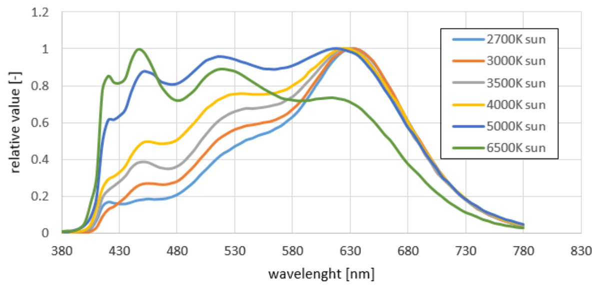

Fig. 4. The SPDs of LEDs which mimic sun light radiation in visible range.

Table 4. The colorimetric parameters of "sun type" LEDs

SPD	"sun type" LEDs					
Sample	2700K	3000K	3500K	4000K	5000K	6500K
x	0.4587	0.4372	0.4121	0.3911	0.3475	0.3146
y	0.4089	0.4060	0.3946	0.3868	0.3545	0.3287
u’	0.2625	0.2499	0.2385	0.2280	0.2119	0.1993
v’	0.5265	0.5222	0.5139	0.5075	0.4864	0.4684
CRI	97	97	97	98	97	96

Nowadays, the conception of human centric lighting becomes more and more popular. The idea is based on "tailored light", which is adequate for a specific time of day. The goal of this is to make artificial light the most like the sunlight and keep the natural biological rhythm of the day. On the other hand, such dynamic light might be supportive in boosting alertness and concentration when needed or help to relax and fall asleep in order to support fast recovery. Thus, stimulation by light is an integral point of this idea. For that reason, special LEDs with an increased radiation of around 480 nm were developed (see Fig. 5 and Table 5). In this case, additional light radiated around the maximum of melanopsine sensitivity will influence melatonin secretion. Such light will improve alertness and might be perceived as energizing. Nevertheless, it is important to mention that irresponsible use of such light might bring a negative effect on human body.

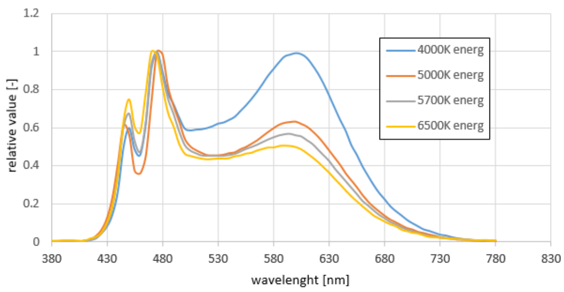

Fig. 5. The SPDs of LEDs with additional blue light radiation in the range of maximum melatopsine sensitivity (energizing).

Table 5. The colorimetric parameters of "energizing type" LEDs

SPD	"Energizing type"			
CCT	4000K	5000K	5700K	6500K
x	0.3821	0.3430	0.3267	0.3112
y	0.3816	0.3532	0.3402	0.3253
u’	0.2243	0.2094	0.2033	0.1981
v’	0.5039	0.4851	0.4762	0.4661
CRI	84	84	84	84

To compare the circadian stimulus of different LEDs, their luminous flux was normalized to the same level and then the MSI factor was calculated and analyzed. There is a clear relation between the correlated color temperature of a given LED (CCT) and its MSI parameter. The colder light is, the higher MSI is expected (see Fig. 6). In the case of LEDs with an additional blue light content (energizing), MSI might be increased by (2÷8)% on top of standard LEDs. On the other hand, LEDs with SPD like sun light might bring significantly higher MSI (even 14% above standard LED with high CCTs). This trend is also relevant for lower CCTs (warm light). The lowest MSI is expected from standard LEDs, so this kind of light might the most useful for relaxation and it is less sleep disturbing.

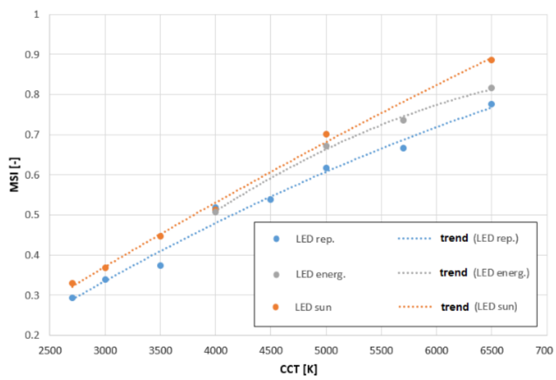

Fig. 6. MSI for different white LED technology across CCT.

The analysis of LEDs with the same CCT, but a different SPD shows big differences in the MSI parameter (see Fig. 7). There is a 23% gap between sample 1 and 2, which leads to a clear conclusion that the CCT of a light source, even in the same technology, cannot be associated with melatonin secretion or influence on biological rhythm.

Blue light should not be considered as a tread only. In fact, it occurs in nature in high amounts. Nevertheless, badly timed over-exposure to this stimulus is not recommended. The only way to control blue light pollution from artificial light sources is to limit it at application level. Thus, special attention should be taken while choosing optimal light sources for a given luminaire.

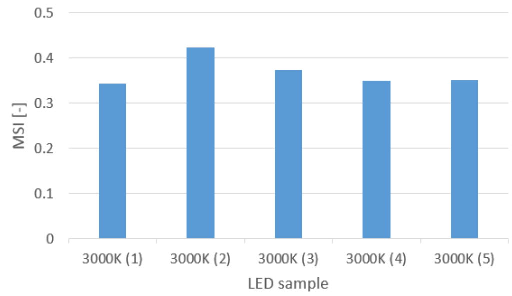

Fig. 7. The MSI values for LEDs having the same CCT=3000K but different SPD.

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