Journal of Quantitative Spectroscopy & Radiative Transfer 139 (2014) 82–89

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

New device for monitoring the colors of the night

Henk Spoelstra

Lumineux Consult, Landgraafstraat 96, 6845 ED Arnhem, The Netherlands

ARTICLE INFO

Article history:
Received 15 July 2013
Received in revised form
24 December 2013
Accepted 1 January 2014
Available online 11 January 2014

Keywords:
Light pollution
Night sky spectrum
Filters
Monitoring

ABSTRACT

The introduction of LED lighting in the outdoor environment may increase the amount of blue light in the night sky color spectrum. This can cause more light pollution due to Rayleigh scattering of the shorter wavelengths. Blue light may also have an impact on circadian rhythm of humans due to the suppression of melatonin. At present no long-term data sets of the color spectrum of the night sky are available. In order to facilitate the monitoring of levels and variations in the night sky spectrum, a low cost multi-filter instrument has been developed. Design considerations are described as well as the choice of suitable filters, which are critical – especially in the green wavelength band from 500 to 600 nm. Filters from the optical industry were chosen for this band because available astronomical filters exclude some or all of the low and high-pressure sodium lines from lamps, which are important in light pollution research. Correction factors are calculated to correct for the detector response and filter transmissions. Results at a suburban monitoring station showed that the light levels between 500 and 600 nm are dominant during clear and cloudy skies. The relative contribution of blue light increases with a clear moonless night sky. The change in color spectrum of the night sky under moonlit skies is more complex and is still under study.

1. Introduction

1.1. Brief historical perspective

In recent years the research into the effects of light pollution on humans, nature and the esthetic quality of the night sky has evolved rapidly. The impact of light pollution on astronomical observations has been known for a very long time. Research into its quantitative impact started roughly in the mid nineteen seventies. In the past decade public awareness programs on national and international scale have been established and are continuing (e.g. Globe at Night and Earth Hour) [1,2].

During the last two decades, Defense Meteorological Satellite Program (DMSP) night time images of the Earth became available, which were modeled into light pollution maps by Cinzano in 1997 [3]. These increased the awareness of the impact of light pollution. More recently the high-resolution nighttime images made by astronauts from the International Space Station (ISS) and the images from the Visible Infrared Imaging Radiometer Suite (VIIRS satellite) have given researchers more refined data to study the impact of light pollution.

The recent commercial availability of low cost nighttime sky quality meters (SQM[1] and IYA lightmeter[2]) has boosted the worldwide research for long-term monitoring of light pollution. Nevertheless the scientific knowledge on the impact of nighttime lighting on humans and nature is still scarce and the book “Ecological Consequences of Artificial Night Lighting” was more or less the only published work [4].

In 2009 a standard work “Das Ende der Nacht” (The End of the Night) was released describing the problems of artificial lighting and its increase [5]. A second print and

[1] Sky Quality Meter from Unihedron http://unihedron.com.

[2] Lightmeter available through the Kuffner Observatory in Vienna. http://lightmeter.astronomy2009.at.

E-mail address: henk@lumineux-consult.com

0022-4073/$ - see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jqsrt.2014.01.001

updated book is scheduled for autumn 2013. In the past several years more scientific research programs into the impact of light pollution on humans and nature have started (e.g. LightPad,[3] Light on Nature[4] and Verlust der Nacht).[5] It is recognized that not only the amount of nighttime light has an impact but also the spectral distribution or color is an important parameter. Nocturnal animals, insects and humans react differently to the various colors in nighttime spectrum lighting due to the different spectral sensitivity of the eyes [6–8].

1.2. Present developments

There is a transition in lighting practices from conventional lighting (e.g. HPS – High Pressure Sodium, LPS – Low Pressure Sodium, fluorescent and so on) towards LED lighting. In general the main advantages of LED lighting are the higher energy efficiency, better color rendering, possibilities for dimming and better directional distribution of light. However the majority of LED lighting uses a phosphor to shift some of the original blue emitted light from the LED to the longer visible wavelengths from green to red. The remaining blue light will shift in the nighttime spectrum towards the blue wavelengths.

One well-known impact of the effect of blue light is the suppression of melatonin, which can cause sleeping problems and disruption of the circadian rhythm. Blue light is scattered more strongly than light at longer wavelengths due to Rayleigh scattering by air molecules and dust, hence the blue sky during daytime. At night it increases the amount of light pollution. Due to the possibilities of dimming and better directional light distribution of LED lighting, the increase in blue light on the night-time outdoor environment is unknown. Continuous monitoring of several spectral bands of the night sky will contribute to scientific knowledge of possible changes in brightness of those spectral bands.

1.3. Monitoring developments and design considerations

Monitoring can be done in broad and narrow spectral bands. Previously, narrow band spectrometers were used primarily in the professional astronomy and were very expensive. Moderate and low cost spectrometers are now becoming commercially available. Monitoring the nighttime spectra is becoming practical. Also, the use of standard digital cameras, which have filters for blue, green and red can be used by experienced operators.

The monitoring of the nighttime sky brightness with multiple Sky Quality Meters (SQM's) with several (broad) band filters has been initiated by Kyba [9]. In order to reduce costs, our new design makes use of only one SQM and an automated filter wheel.

Using multiple SQM's or using only one SQM with a filter wheel has both advantages and disadvantages. The main advantage of using multiple SQM's is that rapid changes in spectral bands (e.g. the colors of twilight can be monitored simultaneously), which cannot be done with a single SQM. The main advantage of using a single SQM with a filter wheel is the lower cost. The cost for a single SQM with filter wheel is about 2.5 times the price of a SQM (filters not taken into account). Using multiple SQM's has the disadvantage that drift between the separate SQM's can occur. On the other hand a filter wheel is a mechanical driven unit that can start malfunctioning due to wear.

2. Design and operation

2.1. Detector

The SQM-LE by Unihedron without the IR filter has been chosen as a relative low cost detector for the instrument. This SQM-LE has a Full Width Half Maximum (FWHM) viewing angle of 20° [10]. Its sensor is a TSL 237 detector manufactured by TAOS[6] with a spectral band from about 400 nm to 1100 nm (Fig. 1).

2.2. Filter choice

The main requirement for the choice of filters was to have spectral bands adjacent to each other without gaps and with minimum overlap, and that are commercially available. Specific band pass filters are expensive and are only practical in large quantities. At first glance, the relative low cost astronomical RGB filters from various manufacturers seemed to be appropriate, however further investigation revealed the band pass characteristics of these red and green filters are such that the sodium lines (originating from low and high pressure sodium lamps) are partially or totally excluded.

A comparison of the RGB filters from the various manufacturers was made by overlaying the spectral lines [11] from the high-pressure sodium (HPS) and fluorescent lamps with the transmission curves of the filters. This is shown for the filters of Baader[7] (Fig. 2), Astrodon[8] (Fig. 3), Orion[9] and Astronomik[10] (Fig. 4) and the astronomical Johnson-V filter (Fig. 5). The low-pressure sodium (LPS) spectrum has two main lines at 589 and 819 nm. The HPS spectrum shows four lines at 569, 584, 594 and 819 nm. The LPS line at 589 nm lies between the pressure broadened HPS lines at 584 and 594 nm. The LPS line at 819 nm coincides with the HPS line at 819 nm. These LPS lines are not shown in the figures for sake of readability. The fluorescent lamp has two strong emission lines at 544 and 611 nm and three weaker lines at 437, 488 and 586 nm.

[3] LightPAd project (Light and the Possible Absence of Darkness) at RIVM (Dutch National Institute for Public Health and the Environment).

[4] Light on Nature project at the Wageningen University in cooperation with NIOO – National Institute for Ecology in the Netherlands. www.lichtopnatuur.org.

[5] Verlust der Nacht at the Free University of Berlin www.verlustdernacht.de.

[6] Texas Advanced Optoelectronic Solutions (recently changed to AMS www.ams.com) http://www.ams.com/eng/Products/Light-Sensors/Light-to-Frequency-Sensors/TSL237.

[7] Baader Planetarium www.baader-planetarium.com.

[8] Astrodon www.astrodon.com.

[9] Orion Telescopes & Binoculars www.telescope.com.

[10] Astronomik www.astronomik.com.