MODULAR LED LUMINAIRE WITH VARIABLE SPECTRAL POWER DISTRIBUTION OF LUMINOUS FLUX

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Abstract: To date, development of luminaires is focused primarily on energy performance levels and accepted colour qualities of light output. Recent researches aimed to healthy and smart lighting showed that standard properties of luminaires are insufficient in terms of all performance levels required for modern illuminating systems. Dynamic change of intensity and colour temperature of light source during day is necessary for right function of human circadian system. Therefore it was developed modular LED luminaire allowing dynamic change of the spectral power distribution of luminous flux with possibility of colour temperature changing in the range 2400 K - 10 000 K (Ra >90, $\Delta uv < 0.0005$) and also possibility to set any hue in the colour gamut given by fixture construction.

Keywords: LED luminaire; dynamic lighting; circadian rhythms; variable colour temperature

1. INTRODUCTION

It is not so long that electric lighting is accessible nearly anywhere, at any time of day. Rapid development of new power stations in the 20th century enable proliferation of artificial light into every residence, offices, schools, hospitals, restaurants and other buildings which people can occupy. Now in 21th century it can be noted new phrases in terms of light: "well - being", "light and health" or "circadian lighting". Recent researches brought new findings that light not only enables vision, but is also a critical signal to our biological systems, affecting circadian rhythms, pupillary response, alertness, and more. Humans are exposed to a substantial amount of electric lighting as well as natural light, all of which has some effect on our physiology regardless of the type of source. New researches related to light and health leads to the questions - how we should illuminate architectural spaces.

Artificial lighting passed diametrical change during its evolution. Fire from chips of wood and gas lamps was replaced by electrical ligth from tungsten bulbs, discharge lamps, fluorescent tubes and light emitted diods - LED, which is commonly used in these days. Different light sources have different spectral power distribution of luminous flux, therefore research of effects of dynamic lighting to the human beings in terms of visual and non-visual response is very important for correct projection of modern illuminating systems.

Future concepts of artificial lighting in offices, hospitals, educational institutes and residential objects should cover results of current and future researches, therefore luminaires used in lighting systems today should adapt them. Communication between interior and exterior of living area is also necessary. Cognitive lighting in combination with artificial intelligence may show as a right way for lightings of tomorrows.

2. LIGHT AND HUMANS

It is estimated that people spend 90% of their time indoors with limited exposure to natural light, while artificial illumination from general lighting, including mobile devices, computers and TVs, dominates. New technologies allow to improve efficiency and productivity **[1]**, but it is necessary to do many research yet for correct understanding of impact light to humans, because some works shows that light is necessary for vision as well as non-visual effects of light is needed for overall health and well-being. **[2, 3, 4,]**.

Light is a part of electro-magnetic radiation in range of wavelengths 380 - 780 nm. As light travels through the eyes, the cornea and lens refract it to converge on the retina, stimulating two different photoreceptor nerve cells, rod cells and cone cells, each independently tasked with the absorption of specific short (400 - 550 nm), middle (450 - 670 nm) and long (500 - 700 nm) wave light rays through activation of photo pigments rhodopsin a photopsin **[Fig. 1]**.

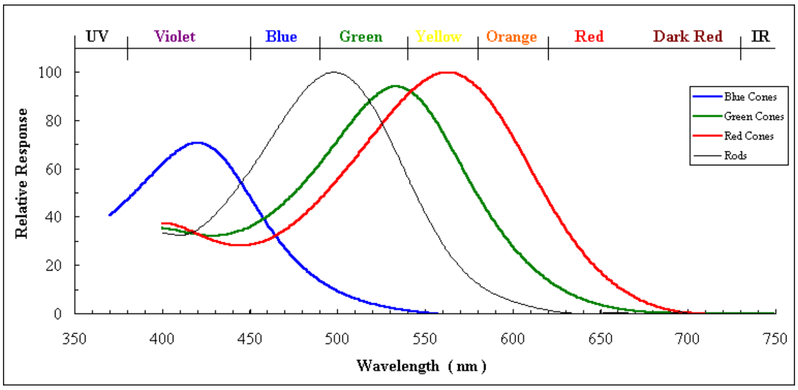


Figure 1: Spectral sensitivity of rods and cones **[5]**

In 2000, a study was published, identifying a new photo pigment, melanopsin, located within the retinal area of the eye. Unlike rod cells and cone cells located within outer retinal regions, this pigment was uniquely located within the ganglion cell layer. The research identified specific group of cells - ipRGCs (intrinsically photosensitive retinal ganglion cells), which contain melanopsin. These new type of photoreceptor did not participate in image formation, but it is responsible for circadian synchronization. Shortly after 2001, scientific evidence suggested that non-rod and non-cone photoreceptor systems existed that facilitated circadian rhythms. **[6, 7, 8, 9, 10]**.

2.1. BIOLOGICAL EFFECTS

Humans and other mammals operate within a 24-hour biological cycle, known as the circadian rhythm. This rhythm influences various aspects of our biochemistry, endocrinology, physiology, metabolism and behaviour to synchronize our internal processes as well as our external environment. At humans 24-hour cycle takes on the average 24.2 Hrs, but it can be in range 23,3 - 25,0 Hrs. 90% people have circadian cycle more than 24 Hrs. [**11, 12**].

These rhythms affect various aspects of biochemical processes, as well as endocrine system, physiological or metabolic processes and because cycles are not exactly 24 Hrs they have to be synchronized each day [**Fig. 2**]. In past was discovered that it is possible to synchronized circadian system by the light and after findings ipRGCs ganglion cells was found out, that these cell play main role in sending neurological signals to the hypothalamus, where is located central biological clock which synchronized circadian rhythms.

Each of the three photoreceptor cells show greater responsiveness to specific wave lengths. ipRGCs have the greatest sensitivity to short wavelength blue light from 464 - 484 nm. [**13, 14, 15, 16**].

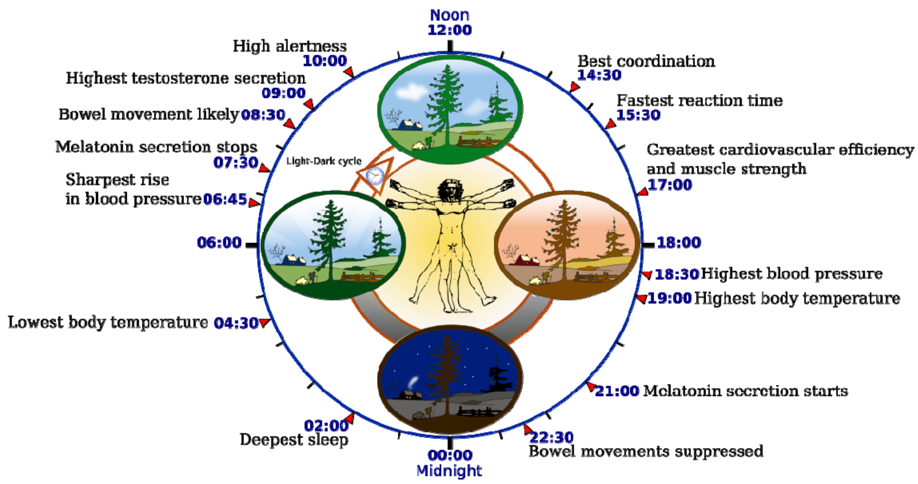


Figure 2: Some features of the human circadian (24-hour) biological clock [**17**].

2.2. OPTIMAL LIGHTING - VARIABLE SPECTRAL POWER DISTRIBUTION

According to standards illumination levels and homogeneity of illumination is basic requirement for the most task areas, but designers of illumination systems should also consider appropriate correlated colour temperature (CCT) when developing appropriate illumination throughout the space. While studies suggest 6000 K – 8000 K LEDs with a spectral composition leaning toward a blue spectral focus may have the best biological impact, this is likely undesirable to occupants. 5300 K or higher lights, closer to daylight white, may also be good for alerting affects, but proper selection must balance individual comfort and focus requirements. 3500 K – 5500 K were found through studies to be the most visually pleasing, however conclusions revealed there was not a single preferred spectrum **[18].**

Appropriate luminaires is needed for meeting requirements of modern lighting designs, therefore it was developed modular luminaire, which try to cover the most of lighting designers' needs.

CCT - Correlated colour temperature

It was described above that variable CCT is very useful for many lighting designs. Young people will prefer different CCT for learning or for working on PC, seniors may prefer different lighting scheme during day in terms of CCT and intensity as well. Modular luminaire was calibrated in range 2400 K - 10 000 K, because lower CCT is useful to use at evening time while higher CCT is more efficient for melatonin suppression during day.

CRI - colour rendering index

One of the main goal during development was CRI > 90 in whole range of CCT. Four different LEDs colours - Red, Green, Blue, White - with spectral half band width in range 20 - 100 nm was used to reach the aim.

Dimming

The luminaire is designed to hold CCT and CRI stable during dimming up to approx. 5% of max intensity. This part of development is not trivial, because natural behaviour of LEDs is colour shifting during dimming, therefore it is necessary algorithmically compensate colour shifts during LED driving.

Hue and Saturation

It is possible also to set any hue and saturation level in the colour gamut given by LEDs combination. This is useful for composition of lighting scene aimed to decoration or ambient lighting.

2.3. MECHANICAL DESIGN

Luminaire is modular by its shape. Luminaire has trefoil design so that it could be possible to combine more than one fixtures into various patterns. It is possible to use luminaire for direct or indirect illumination [**Fig. 3**].

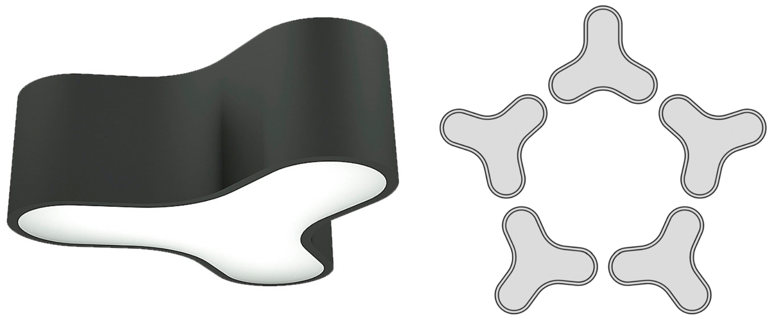
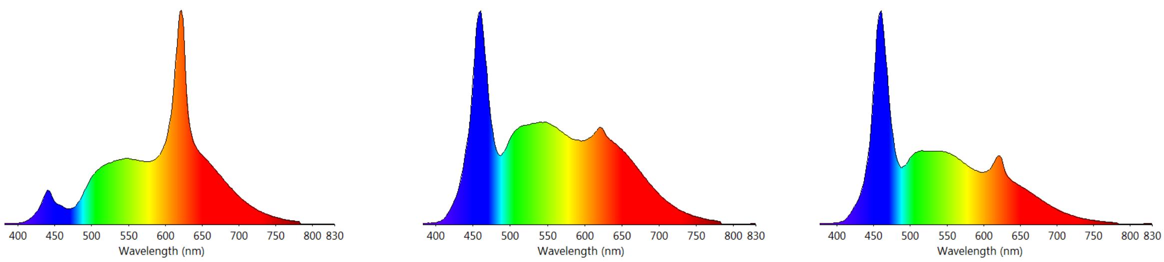


Figure 3: Trefoil design of luminaire, lighting pattern, mechanical dimensions

Aluminium metal plate was used as a flat heat sink for adequate passive cooling. Inner surface of luminare sides is not spectral dependent, because of quality colour mixing of four different LEDs colours. Special diffusive material of output optic is used for homogenous brightness across luminous area.

2.4. CONTROL

It was developed application for mobile phones for easy control of luminaire properties. Application has two modes: *manual* and *automatic*. In manual mode it can be set CCT, dimming, hue and saturation of light output. Automatic mode change CCT in defined range [**Fig. 4**]. Changing time correspond to sunrise and sunset time in given location.



2700 K, Ra 91 6500 K, Ra 96 9890 K, Ra 93

Figure 4: Example of spectral power distribution, which can be controlled automatically.

3. CONCLUSION

Future of lighting is at start of development in these days. It is still looking for the right communication protocol for smart lighting system, new LEDs are developed each six month with better efficacy and new materials for better cooling of LEDs systems is optimized as well as optic systems. Research of non-visual response of light is not finished yet, so we can look forward for new findings which can be lead lighting development to various directions.

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