Research of the biological effectiveness of artificial lighting

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Abstract - The history of mankind numbers about 500 thousand years and overwhelming part of this period of time we have been governed by natural light. The Sun was the only source of light. Try to imagine the world in which people wouldn't know the ways of getting light. When the sun was setting, all the life stopped, and people hurried to their homes before dark. Now everything has changed. Sometimes people work and stay awake at night or often stay up late. It turns out that light allows us to see not only the world around us, but also it is the chief regulator of our biological rhythms. The interest to the biological effects of light increases every year. It all started with the discovery in 2002 of a new photoreceptor (neither rod, nor cone). Under a definite influence of light on these cells a person feels more cheerful and concentrated. This research work is dedicated to the data analysis of a new photoreceptor. Also the analysis has been done concerning the selection of light source, which will later be used in a lighting control system and with a help of which human biorhythms will be taken into account.

Index Terms - action spectra, biological rhythm, human, light, lighting, light sources, melatonin suppression

I. INTRODUCTION

Energy is the foundation everything. The ability to use it correctly and efficiently more and more often becomes a necessity for a modern man in light of recent financial crisis and the approaching energy crisis.

25% of generated electricity worldwide is spent on lighting. There are state energy consumption projects in this sphere in many countries. We must tackle this problem comprehensively: it can be both the usage of more energy-efficient light sources (e.g. LEDs), and introduction of control systems, and we also shouldn't forget about the comfort of people.

The aim of our project is to develop intelligent energy-efficient lighting, taking into account biological rhythms of a man. The choice of light sources was performed on several criteria. The main of them was the impact on the recently discovered photoreceptor (ipRGC - intrinsically photosensitive Retinal ganglion cell). Under a definite influence of light on these cells a person feels more cheerful and concentrated.

II. BIOLOGICAL EFFECTIVENESS OF ARTIFICIAL LIGHTING

It remained a mystery how a person understands that he has to wake up and start working actively, and when it's time to have a rest and go to sleep. in chronofotobiology light is the most important factor in control of our internal biological clock. The special section of a brain - the suprachiasmatic nucleus (SCN) is responsible for circadian rhythms. Ocular light transmits signals through specific retinal ganglion cells, the discovery of which in 2002 was revolutionary. A number of studies have been conducted, and it was noticed that in the morning the hormone cortisol is produced and in the evening melatonin is produced. Logical question arose, whether it is possible to fool our Nature, and suppress melatonin not under the influence of sunlight but under the influence of artificial light? For the first time the research of the suppression of night melatonin with experiments on rats was carried out in 1972.The researchers found that lighting one's eyes at night with E = 2500 lx, caused a strong decrease in melatonin compared with E = 500 lx. This fact initiated numerous studies on the effects of artificial radiation on biorhythms (circadian rhythms).

A. Action spectra

Robert Lucas and colleagues, including Russell Foster, were the first who proved once and for all that cells containing melanopsin fotopigment (cells ipRGC), have spectral characteristics that differ from the rods and cones [1]. In 2002 David Berson showed that rats have characteristic photosensitive cells, retinal - ganglion cell ipRGC, which always contain melanopsin. And so melanopsin (not the rods and cones - iodopsin and rhodopsin) was the most probable as the visual pigment of photoconversion and refers to cells ganglion ipRGC retina that set the circadian clock [2]. The existence of anatomical ganglion cells was found which are located in the inner retina (part of the retina closer to the vitreous body). At the same time the classical photoreceptors (rods and cones) are located on the outer part of the retina (closer to the pigment layer).

The majority of researchers consider that the peak spectral sensitivity of the receptor is between 460 and 484 nm. In 2003 Lockley showed that 460 nm (violet) wavelengths of light suppress melatonin twice as much as 555 nm (green) light, the maximal sensitivity of the colour sensing of visual system. However, in more recent work by Zaidi, Lockley and co-autours, it was mentioned that maximum sensitivity of cells ipRGC on the wave length was 481nm[3].

The analysis of the light sources was calculated by four spectral sensitivity of cells ipRGC "Fig.l".

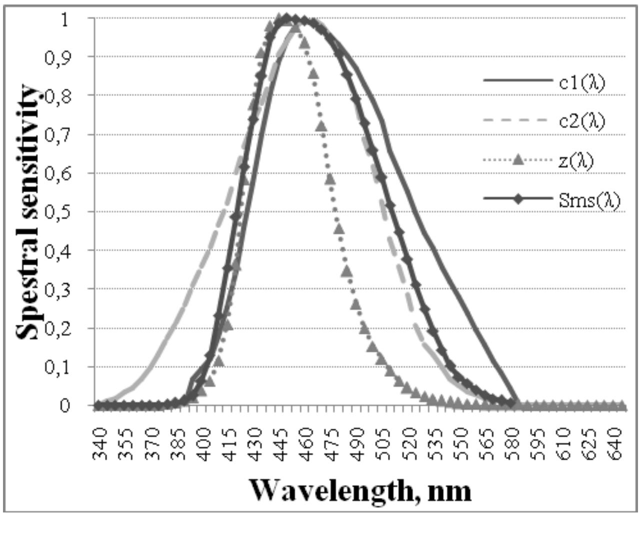


Fig. 1. Spectral sensitivity ipRGC (suppressing hormone "fatigue" -melatonin)

1)Curve c1(X). Steven W. Lockley He reviewed all spectral characteristics of the cells ipRGC in humans, and chooses the one which is most common in reliable sources. This spectral curve is taken from publications of Philips Lighting.

2)Curve z(X). D. Gaal suggested as a spectral function of the circadian performance with a maximum in the blue part of spectrum to use (as a first approximation) a standard feature International Commission on Illumination (ICE) (z (X)). This may somewhat simplify the study, but it may cause miscalculations.

3)Curve c2(X). George C. Brainard, John P. Hanifin, Jeffrey M. Greeson, Brenda Byrne, Gena Glickman, Edward Gerner, and Mark D. Rollag [4].

4) Curve Sms (X). Preliminary standard DIN V 5031-100 [5]

B. Calculations by the choice of light sources for interior lighting of premises

For the calculation reliable information was chosen from catalogs of companies "Osram", "Philips" and "Radium". 52 sources of radiation were analyzed. The following lamps were examined: incandescent lamps, metal halide lamps, sodium lamps (high and low pressure), fluorescent lamps (linear and compact), mercury vapor, ultraviolet, and light-emitting diodes.

Calculation formula of the coefficient of biological effectiveness:

$$X_{ms} = \int_{\lambda_1 = 380\,nm}^{\lambda_2 = 580\,nm} X_{\lambda}(\lambda) \cdot s_{ms}(\lambda)\, d\lambda$$

Where

X_{ms} is the effective radiant quantity for melatonin suppression;

$s_{ms}(\lambda)$ is the relative spectral sensitivity for melatonin suppression;

$X_{\lambda}(\lambda)$ is the spectral radiant quantity.

The comparison was performed on the following parameters: coefficient of biological effectiveness (1), luminous flux, the color rendering index, the power in the range of sensitivity of the cells responsible for human biorhythms, price, service life, the presence of mercury, size, power consumption, resistance to the inclusion on / off. The analysis has shown what kinds of light sources have good lighting, design and economic parameters, and also have the greatest effect on the suppression of hormone melatonin secretion:

LUMILUX 865 (fluorescent lamps (linear))

LUMILUX Skywhite 880 (fluorescent lamps (linear))

LED 4 crystals T_c = 7000 K.

Where

T_c - color temperature.

Comparison of the spectral characteristics of chosen light sources look at "Fig. 2".

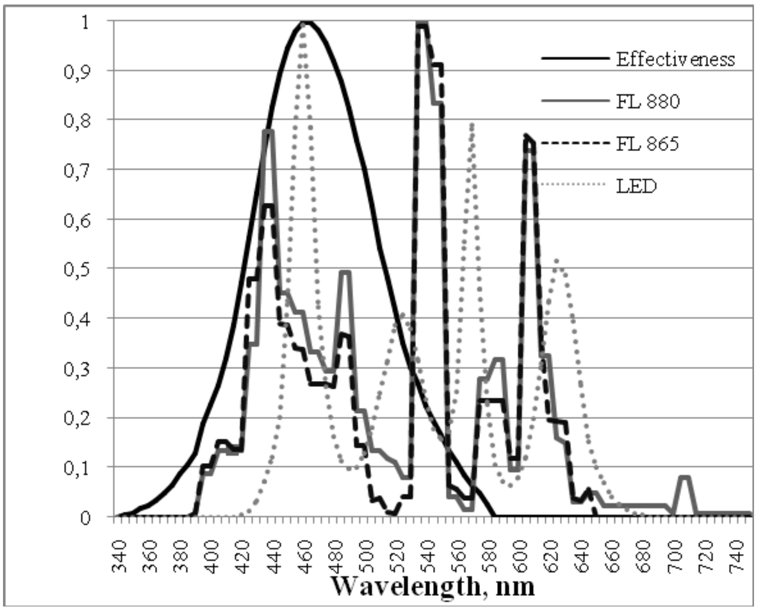


Fig. 2. The spectrum of LUMILUX Skywhite 880, LUMILUX 865, the LED 4 crystals T_c = 7000 K and the averaged spectral sensitivity of cells ipRGC.

Just that very sources, in our opinion, should be used in lighting devices in organizations where employees have to perform responsible work in dark time.

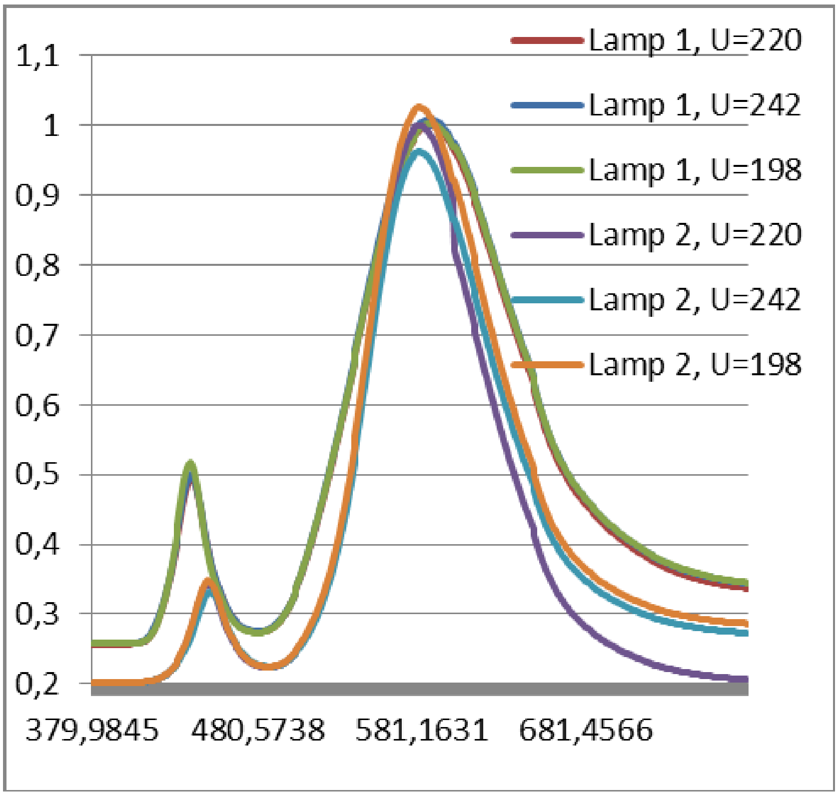
It is seen that there is practically no difference between the spectra of fluorescent lamps. LED has a big plus that is the convenience of flow regulation. But do not forget and disadvantages of LEDs. At the moment it is of great cost (in time, hopefully, this minus will disappear) and the large variation in color temperature (LED binning, this problem can be solved if to make the selection of LEDs tougher). Binning -this is automatic sorting of LEDs on such parameters as the luminous flux, wavelength (for color) or color temperature (for white LEDs), less-largest forward voltage drop. It should be borne in mind that the cost of bins is different - it is clear that the price of the bin with the maximum luminous flux is large, since the implementation of such an order will require sorting a larger lot of LEDs.

C. Experimentalpart.

Now energy saving projects began to introduce not only energy-saving

bulbs, but LED lamps with E27 cap. The analysis of several LED lamps was carried out at out department. Since many products in our country come from China, it was decided to investigate only these lamps. Lamps are exhibition samples.

The main quantity of lamps with low color temperature that is well suited for a cozy evening, but does not affect human biorhythms. Taking into account the poor quality of electricity in our country spectral measurements were carried out at nominal voltage and with deviations to 10%. The measurements were taken with a monochromator MDR-206. We measured the spectral density of the axial intensity: Range Scan: 380-780 nm Scanning step: 1 nm Receiver Type: Silicon photomultiplier The obtained data presented in Fig. 3. It is easy to notice that there is a change of spectrum in some bulbs, while others do not have any changes.



To create an intellectual illumination system with the ability to impact on human biorhythms such lamps are not suitable. However, this does not mean that the LEDs can not implement the required lighting system. There are two kinds of LEDs:

- phosphor
- multichip

If we want to use our equipment for internal illumination, it is necessary Ra > 80, where quite good reproducibility of the color temperature is needed, which can only be achieved by using multi-chip LEDs.

D. Problem of estimating the color of white LEDs. It is also worth thinking about assessing color LEDs There are many methods of evaluation, we focus on two ones: a method of color rendition index (CRI) and color scale method (CQS). The main differences from the usual CQS (CRI):

1. 15 test samples are used
2. calculation of color differences is carried out in the CIELAB;
3. The color difference is defined as the geometric mean among all 15 samples.

CRI method has several disadvantages that are particularly clearly manifested in the calculations associated with diabetes. Uniform-scale system U * V * W * is out of date and practically is never used. In the red region, this system gives higher values for the color differences, but in blue and yellow - understated. At the moment, to calculate the color differences CIE recommends a system of L * a * b *. In this space, luminance (lightness) sets the coordinates L *, which varies from 0 to 100, the chromatic component - two polar coordinates a * and b *. The first denotes the position of colors ranging from green to purple, the second - from blue to yellow.

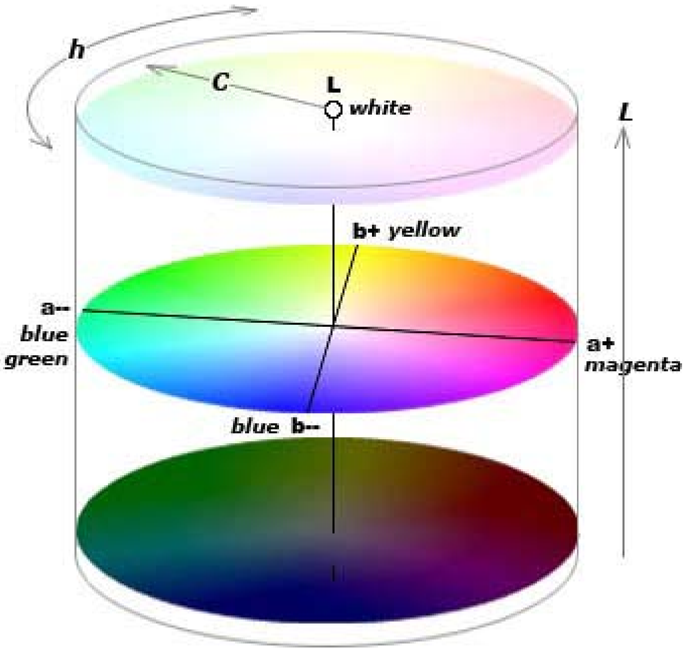


Fig. 4. Schematic representation of the space L * a * b *

None of the samples used to calculate the partial indices of color samples is saturated. LS (light soures) with a narrow spectral distribution (such as LED), this calculation gives too low values of Ra. If the calculated Ra is large, then it may well be that the vivid colors of LS sends a bad thing. This is due to the fact that the evaluation is used too few sample sand they all have too little saturation.

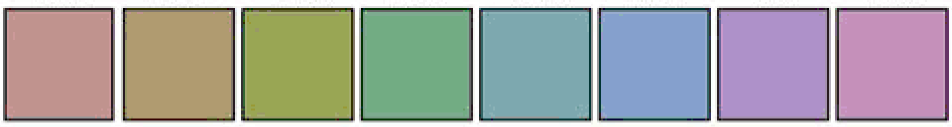


Fig. 5. Specimens used in the method of CRI.

In the method, scale and color evaluation is performed on fifteen samples (spectral reflectance, see Fig.6) which have very different values of lightness and saturation. Such a broad range of control flowers will receive more comprehensive results for the LS with different kinds of spectra, including those for diabetes.

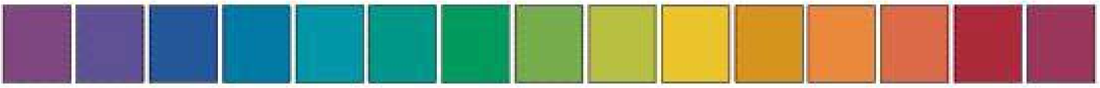


Fig. 6. Specimens used in the method of CQS. Since the method of the general color rendering index CRI is equal to the arithmetic mean of private, some LS even in very poor color rendering several samples have good values of Ra. This is particularly true for LS with a narrow spectrum. Color differences in the method of CQS is calculated as a geometric average, low color of one or two samples affects the value of the index scale and color score is a more objective one.

Thus, the new method takes into account many of the shortcomings and deficiencies of the old and may not be optimal for assessing color LEDs.

Carry out the calculation of color LEDs by two methods -the standard method forcal culating CIE color rendering index and a new method of scale and color and compare them.

Shows data for the LEDs Cree:

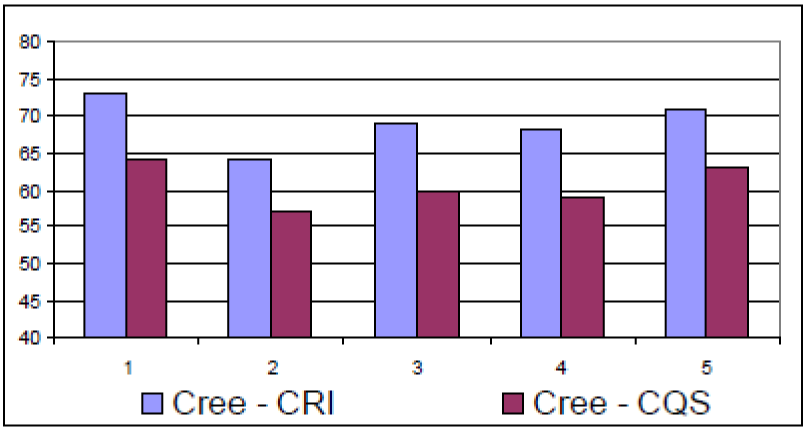


Fig. 7. General color index for different method

That the value of color is obtained by traditional methods overestimated, that is, it turns out that announced good color, but in fact part of the flowers will not be shared.

E. Requirements for sources

Thus produced demands for a light source, which will come to influence human biorhythms:

It shall be light emitting diodes (changing spectrum of LS affects their service life)

This multichip LEDs, and the more crystals the better the color quality we can make and the easier it will change the color temperature

This multichip LEDs without a common phosphor. Since we need to manage the current of each crystal individually, and get different spectra. If it will be phosphor LEDs, then the spectrum will be almost unchanged. When changing the current through the crystal spectrum will not change because a large share of emission phosphor. When operating current will not change the color temperature, but will vary the intensity of the phosphor.

The LEDs with optics allow you to mix light 3 or more crystals.

You must use the film to beat the lights, because in their absence, in sight of a man can is a bright LED (shine a source) that will increase the rate of decrease in efficiency during the day.

C. Analysis of of algorithms control systems

Two interfaces DALI and 0/1 ... 10 V are widely distributed on the market management systems.

0/1 -10 V is one of the earliest and simplest electronic lighting control signalling systems; simply put, the control signal is a DC voltage that varies between zero and ten volts. The controlled lighting should scale its output so that at 10 V, the controlled light should be at 100% of its potential output, and a t 0 V it should at 0% output (i.e. "Off"). Dimming devices may be designed to respond in various patterns to the intermediate voltages, giving output curves that are linear for: voltage output, actual light output, power output, or perceived light output.

Digital Addressable Lighting Interface (DALI) is a technical standard for network-based systems that control lighting in buildings. It was established as a successor for 0/110 V lighting control systems, and as an open standard alternative to Digital Signal Interface (DSI), on which it is based. The DALI standard, which is specified in the IEC 60929 standard for fluorescent lamp ballasts, encompasses the communications protocol and electrical interface for lighting control networks. Interface 0/1 ... 10 V is realized by a linear law, and DALI by a logarithmic. The human eye perceives light by the psycho-physiological Weber-Fechner law (the intensity of sensation is proportional to the logarithm of stimulus intensity). Thus the is most suitable interface DALI.

III. Further research

In the future we plan to check all the data and requirements in practice. There will be a laboratory, where studied the dependence of efficiency on the range and type of light sources. The study of this problem are costly to the lighting equipment. Therefore, the dates of commencement of work associated with obtaining the grant. Research will be conducted in our university computer Class size 5 * 6.5 * 3 pm Now there is a selection of subjects, which is caused by many factors:

1. the vision should be good, as the various deviations from the norm can give wrong results
2. persons within 1 month before and after the research must comply with the regime of the day (it's probably the most difficult requirement, since many operators are students at the threshold of exams to meet this requirement is not feasible.

3. a person shall not within 1 month before and after the study to change the time zone.
4. a person must be healthy

Studies should be conducted in the dark, but not at night when people have to sleep. The impact lasts 3-4 hours. In our latitude - Moscow, this can be done in the autumn-winter period (November-December-January)

That is, this time the sense of waiting for November, the purchase of equipment, we select the subjects.

IV. Conclusion

Today people develop more and more newer horizons, underwater depths, cosmos and the Earth's interior. There is no place for sunlight there. More often people stay in the premises. There is a growing need for a person to be energetic and concentrated on all day at work, where mostly there is lighting. But for the aid of people came their own body, which only gradually reveals its secrets.

I hope that the opening of new light-sensitive cells will not be forgotten, and will be used thoughtfully and effectively, is the main thing is to make human life better.

V. References

Periodicals:

[1] R. J. Lucas, R. H. Douglas, R. G. Foster. Characterization of an ocular photopigment capable of driving pupillary constriction in mice. Natural Neuroscience. 2001 Jun; 4(6): pp. 621-627.

[2] S. Hattar, H.W. Liao, M. Takao, D.M. Berson, K.W. Yau "Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity". Science. 2002 February 8, 295(5557): pp. 1065-1135.

[3] F.H. Zaidi, J.T. Hull, S.N. Peirson, K. Wulff, D. Aeschbach, J.J. Gooley, G.C. Brainard, K. Gregory-Evans, C.A. Rizzo Czeisler, R.G. Foster, M.J. Moseley, S.W. Lockley "Short-wavelength light sensitivity of circadian, pupillary, and visual awareness in humans lacking an outer retina", Current Biology 2007 Dec 18; 17(24):pp. 2122-2130.

[4] George C. Brainard, John P. Hanifin, Jeffrey M. Greeson, Brenda Byrne, Gena Glickman, Edward Gerner, and Mark D. Rollag "Action Spectrum for Melatonin Regulation in Humans: Evidence for a Novel Circadian Photoreceptor". The Journal of Neuroscience, August 15, 2001, 21(16): pp. 6405-6412.

Standards:

[5] TC 169 N 788 (Prestandard DIN V 5031-100), March 2003.