Light & Engineering
Vol. 27, No. 5, pp. 9–14, 2019
https://doi.org/10.33383/2018-073

SENIOR LIVING – LIGHTING, CIRCADIAN RHYTHM AND DEMENTIA II[1]

Gašper Čož

Lumenia d.o.o.
Breg pri Litiji 50, 1270 Litija
E-mail: gasper.coz@lumenia.com

ABSTRACT

Light has always been an important part of human nature and development process. The on-going studies of light having an impact on human bodies are discovering astonishing facts. These facts show that the light has an effect on human bodies and can help reduce diseases and improve health. It is proven that the skylight can help substantially in this process, and our client decided to achieve a similar effect with the use of an artificial light. The development of such light involved a lot of a background investigation on what prospect of the light has the biggest effect on the human body. A nursing facility for elderly people was the first project where we installed such lights and the results are showing evidence of the light impact on human hormones.

Keywords: circadian rhythm, luminaire development, spectrum analysis, project measurements

I. EFFECTS OF LIGHT

Until recently, the biological implications of light and the light spectrum have not been a matter of interest for the producers of lighting fixtures. This has changed with a recent research which showed a very strong connection between the quality of light and health [1,5,7]. Effect on health can be traced throughout the history, and it wasn't until less than twenty years ago, though strong evidences of daylight's profound effect, that a brief understanding of this process arose [6].

Just until a few years ago the main interest of the lighting industry was "only" how to make the most energy efficient lighting in order to satisfy the visual needs or what is nowadays known as "Image Forming" process (later IF). Gradually, however, the attention also focused on "Non-Image Forming" processes (later NIF), since it became clear that they also are affected by light. By a deeper understanding of how the human vision works, the knowledge on both matters has increased. It became apparent that what was satisfactory for IF was not satisfactory for NIF, and the need to develop a lighting that satisfies both processes has become increasingly important [5].

However, there are only a few projects in practise that require solutions and spectrums for those two biological, but different processes – the visual IF and the circadian rhythm NIF, and there is yet no generally accepted standard to lean against.

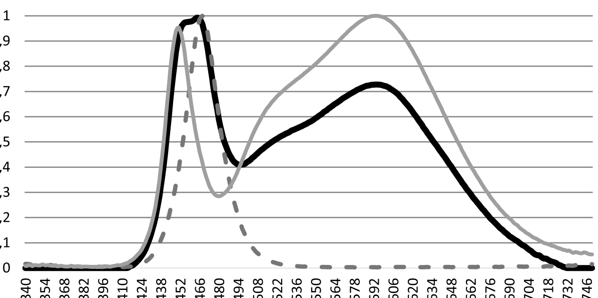

Fig. 1. Relative Spectral Irradiance

[1] Editing and styling by Elena P. Emelyanova, senior lecture of Institute of Linguistics and International Communication at I.M. Sechenov First Moscow State Medical University

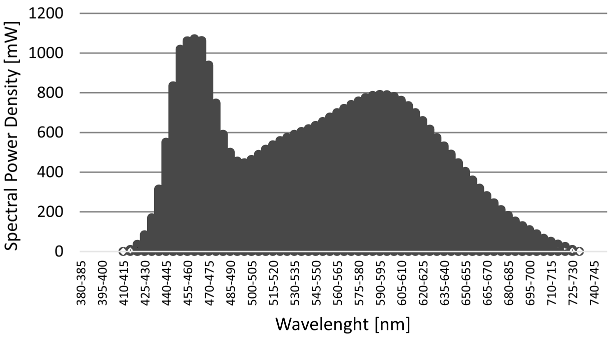

Fig. 2. Spectral Power Density

When you are suddenly faced with client's requirements for both, you have to start investigating. You begin by developing first the spectrum of the light source and then the optical features of the fixtures for both IF and NIF so that the optimal effect should be obtained [10].

2. LUMINAIRE SUPORTING NIF

2.1. LED Spectrum

Let's have a look at the light spectrum first. The subject matter on what is required for the visual need, IF, is well researched and the light sources are developed mainly to satisfy this need in an optimal way. There is, however, significantly less data for the NIF, although a lot research has been done to form a solid base to work on. The most important and the very basic result of this research is that the light spectrum should contain enough energy within the action spectrum for melanopsin which has a peak between 455 nm and 490 nm. Since this spectral band is not of great importance for vision or the colour rendering index, LED and chips manufacturers do not have a broad choice of chips emitting this part of the spectrum. This means that one

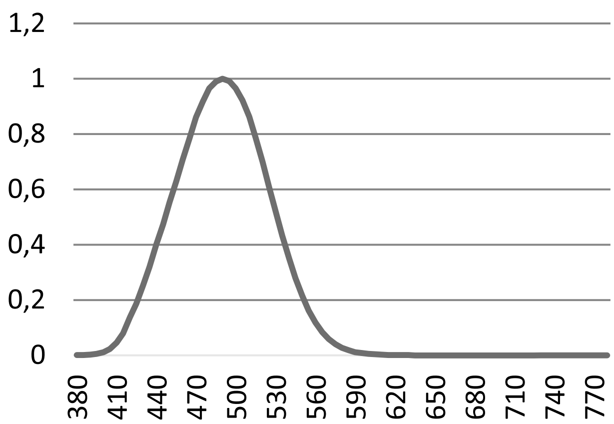

Fig.4. Melanopic curve

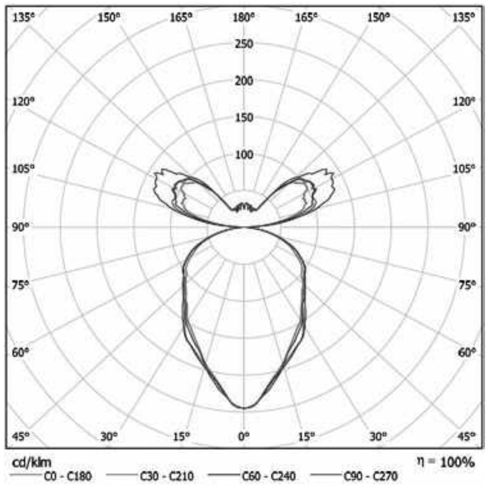

Fig. 3. Photometric results SKY LUM

can find/develop a satisfactory light engine only by combining various chips [3].

Considering NIF requirements and the process of hormone melatonin suppression and also rerelease of its secretion, we are looking at two corelated colour temperatures (CCT) of the light. For the evening and night time we require the spectrum with low energy emitted inside of C-lambda curve, so we need the light CCT from 2,700 K to 3,000 K. The tricky part comes when we want to have both good IF and NIF effect. For such examples, we need "colder" CCT, but most importantly, a high light energy emitter inside C- as well in V-lambda curves. We know that the ganglion cells are photosensitive and are mostly connected to blue cones. This means that the best effect on melatonin suppression will be in a narrow wavelength band of the blue spectrum. We need to combine two LED to satisfy both IF and NIF effect. By conducting a major research of the LED on the market. which can support the theoretical principle of NIF effects, we came up with a solution that completes the suppression and the secretion of melatonin in a most sufficient way. This result shows that the activation factor that we reached is 0,68 which is higher than most of the extreme cold white CCT solutions on the market.

$$a_{mel,v} = \frac{X_{e,mel} = \int_{\lambda_0=380nm}^{\lambda_0=580nm} X_\lambda * S_{mel}(\lambda) * d\lambda}{X_{e,\,vis} = \int_{\lambda_0=380nm}^{\lambda_0=780nm} X_\lambda(\lambda) * V(\lambda) * d\lambda}.$$

The grey line on the Fig. 1 presents the white LED of 4,000 K, while the dotted line presents the blue LED with a peak value of 468 nm. The CCT at

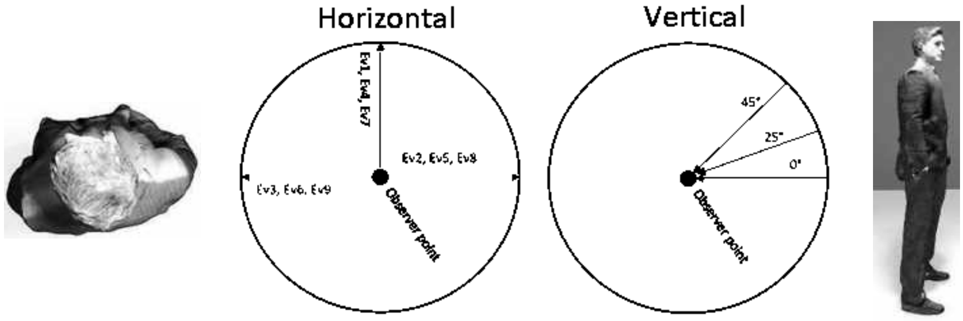

Fig. 5. Measuring points directions

this combination results in 5,300 K, and shows an interesting increase of the colour rendering index from 80, which we got from standard white LED of 4,000 K, to 91 just by adding the monochromatic blue LED. This results in an efficient solution for both NIF and IF processes. Energy emitted in interval of (455–480) nm was 5,016 mW with peak spectrum power density, Fig.2, at 465 nm, 218 mW/nm. This represents enough energy to suppress the melatonin, but the energy with this wavelength that we get from natural daylight is much bigger [8].

Although we are looking at the process of hormone melatonin, we need to take into consideration that when we are exposed to the achieved spectrum, the melatonin secretion will have to start before sleep. In this stage we need to change the spectrum to opposite, meaning we need to lower the spectral power density in wavelengths from 380 nm to 580 nm, resulting in use of LED with lower CCT of 2,700 K to 3,000 K.

However, the efficacy of a luminaire like this cannot be compared with a standard LED luminaire on the market. Using monochromatic LED with luminous efficacy of only 25 lm/W, we can reach the maximum efficacy from the luminaire to only 95 lm/W for the achieved spectrum. The warm white colour luminous efficacy, however, can reach up to 115 lm/W. When developing this kind of the luminaire and the spectrum we also have to understand the background of the process that is happening inside the human body’s circadian clock.

2.2. Luminaire Photometry

The second step in developing the luminaire is optical photometry, which must be satisfactory for both the IF and NIF. Luckily there are some parameters that go for both – no glare, no flicker, and no large variations in luminance within the field of view. This can be achieved with large light emitting surface where we need to consider direct as well as indirect lighting. The angles where the light enters our eyes is under 40° to 60° when exposed to natural skylight. These angles are affecting most of photosensitive ganglion cells and have an effect on melatonin suppression. The indirect lighting plays a very important role in achieving these angles. The second important thing about the photometry requirement is the low gradient between luminance on the ceiling and the luminance on the light emitting surface. For example, if we look at the downlight fixtures the gradient of luminance can reach 1:10.000, where with direct and indirect illumination this can be easily reduced to 1:40 or even below 1:10.

We chose to go with the indirect and direct photometric distribution where the ratio of up-light is 45 % and the down-light 55 %. The PMMA material with special laser printed pattern provides the batwing photometric shape on upper light and the narrow lambert on the down light, Fig.3.

The light is coming into the PMMA plate from the side, where the distance between Light Guide Panel and the LED diodes must be very precise. The distance for reaching minimal light losses should be from 0.4 to 0.8 mm.

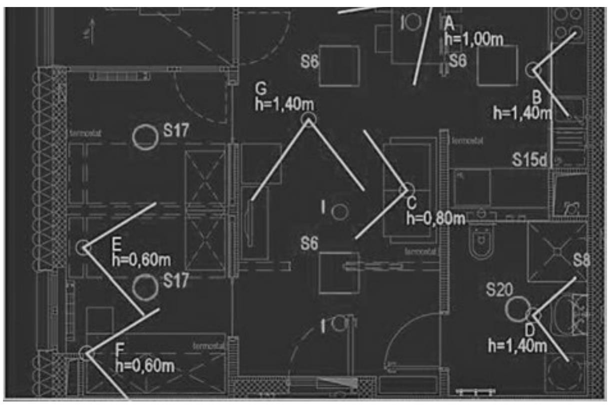

Fig.6. Measuring points in the room

Fig.7. SKY LUM ceiling lights providing low glare and minimalistic design

3. NURSING HOME PROJET

The product is called SKY LUM, and the first project was made for a nursing home. After a few months of using the luminaire, we agreed to make measurements where we were observing the illuminance at different angles and the Equivalent Melanopic Lux (later EML). EML is the calculation the flux emitted inside of Melanopic curve shown in the Fig.4. The concept of EML is discussed in American WELL Building standard and shows the amount of light that affects our circadian rhythm.

The measuring points were considered in three different conditions – as height of the eyes of tenants, angle for spectrometer device and the direction of viewing angle according to the tenant's position in the room, Figs.5,6

Below you can find examples of the measurements in the room, Table. They show the difference in the till angle of the spectrometer. Observing the values for point E, you will notice that the results are much different. This is caused by a classic ceiling fixture, with no increased blue spectrum for circadian light. The Melanopic ratio in this case is almost at half of the values comparing to the SKY LUM fixtures in the room.

4. CONCLUSIONS

The client request has challenged both the lighting engineers and designers. The challenge was not how to create the special spectrum, but to understand the NIF processes that are happening inside of our bodies. The amount of medical and technical

Fig.8. SKY LUM pendant luminaires provide low light gradient from the ceiling and the light surface, producing low glare and the right light angles for NIF processes

Table. Examples of the Measurement

Measuring angle 0°							
Measuring point	**Point height**	**Eh [lx]**	**Ev1 [lx]**	**Peak Wavelength [nm]**	**Energy [mW/ m^2nm]**	**EML [lx]**	**Melanopic RATIO**
A	1.2m	59	420	465.92	9.77	332.05	0.96
B	1.4m	1503.12	545.17	456.74	11.87	391.04	0.87
C	1.1m	548.63	371.62	465.92	8.27	285.61	0.94
D	1.4m	389.16	269.17	465.92	6.17	217.18	0.98
E	0.9m	403.52	229.87	606.13	4.79	101.52	0.54
G	1.4m	840.24	290.39	467.75	6.35	220.29	0.92
Measuring angle 25°							
Measuring point	**Point height**	**Eh [lx]**	**Ev4 [lx]**	**Peak Wavelength [nm]**	**Energy [mW/ m^2nm]**	**EML [lx]**	**Melanopic RATIO**
A	1.2m	591.7	673.61	465.92	16.3	549.67	0.99
B	1.4m	1503.12	659.35	458.57	14.31	494.27	0.91
C	1.1m	548.63	514.85	465.92	12.06	410.73	0.97
D	1.4m	389.16	375.39	465.92	8.8	307.92	1
E	0.9m	403.52	326.36	607.83	6.71	145.73	0.54
G	1.4m	840.24	334.38	467.75	7.7	263.11	0.96
Measuring angle 45°							
Measuring point	**Point height**	**Eh [lx]**	**Ev7 [lx]**	**Peak Wavelength [nm]**	**Energy [mW/ m^2nm]**	**EML [lx]**	**Melanopic RATIO**
A	1.2m	591.7	749.09	465.92	18.39	617.60	1
B	1.4m	1503.12	975.16	465.92	22.44	767.38	0.96
C	1.1m	548.63	597.94	465.92	14.29	484.40	0.99
D	1.4m	389.16	441.48	465.92	10.31	361.40	1.00
E	0.9m	403.52	392.6	602.72	8.06	175.52	0.54
G	1.4m	840.24	529.52	467.75	12.78	431.3	0.99

research reports on this issue is huge, but some of them can still be misleading. This might be because of weak (ground) basic understanding of the neurological and endocrinal facts by the researchers and the optical distribution of light from the installed fixtures [3,4,9].

The product that we successfully developed and installed in the nursing facility results in a new approach to using light which can help people that for different reasons cannot be exposed to adequate amounts of daylight. This is often due to insufficient number of personnel to assist and move elderly with handicaps. This spectrum has the effect of keeping the circadian clock in order, which has a positive effect on healing processes as well as improving the immune system, etc. The client Nepremičninski Sklad Slovenia (The Real Estate Fund of Pension and Disability Insurance) was pleased to build one of the first general projects in Europe that support the NIF processes through the artificial light. The measurement results show that lights are emitting the spectrum required, to have an impact on circadian rhythm. This confirms that we have succeeded in the development of lighting efficacy for NIF as well for IF processes.

REFERENCES

1. Wurtman Richard J. The Effects of Light on the Human Body. MIT. 1971.

2. Aging and Vision, Elsevier, 2010.

3. Brainard, Person, Czeisler, Foster, Peirson, Provencia et al. Measuring and Using Light in the Melanopsin Age, 2013.

4. Czeisler C. Sleep and Circadian Rhythms in Humans. Harvard Medical School, 2007.

5. Wetterberg L. Light and Biological Rhythms in Man. Pergamon Press,1992.

6. Lockley, Brainard, Czeisler, High Sensitivity of the Human Circadian Melatonin Rhythm to Resetting by Short Wavelength Light, Endocrine Society, 2003.

7. Lars-Olof Bjorn. Photobiology: The science of light and life. 3rd edition, ISBN-13:978–1493914678, University of Lund.

8. Figuero et al. Spectral sensitivity of circadian system. LRC, 2007.

9. Brainard G. Why is Blue Light before Bedtime Bad for Sleep? Thomas Jefferson University, A M Chang Harvard University, 2015

10. CIE227:2017, Lighting for Elderly people.

Gašper Čož,
an engineer, graduated from Faculty of Electrical Engineering, University of Ljubljana, Slovenia in 2015. He has been involved in LED technology for the past 6 years, studying and developing professional LED products. At present, he is a Product Manager at Lumenia d.o.o., mainly involved in studies of latest LED technology

Fig.7. SKY LUM ceiling lights providing low glare and minimalistic design

Fig.8. SKY LUM pendant luminaires provide low light gradient from the ceiling and the light surface, producing low glare and the right light angles for NIF processes