Main Supervisors: Dr Rolando Ferrini and Dr Oscar Fernandez - CSEM Center Muttenz

Academic Supervisor: Professor Christian Cajochen - Centre for Chronobiology at the University of Basel

Introduction

The industrial electrification and widespread adoption of incandescent bulbs at the end of the nineteenth century brought a profound reorganization of working places and schedules [1; p. 335]. Ever since, humans spend a considerable amount of time exposed to artificial lighting, especially at evenings and nights. Understanding and quantifying the potential benefits and detriments of artificial lighting is then paramount to optimize lighting solutions that boost the former and eliminate or substantially diminish the latter.

According to Professor Cajochen, *"Light is the most important "zeitgeber" for circadian rhythms of our inner clock"* [2][3] and it is, consequently, a powerful tool to trigger effects such as alertness,, sleepiness, cognitive performance and sleep. [3] There is also epidemiological evidence that light at nigh may negatively impact human health [3] being the physiological base for such effects apparently related to the recently discovered (non-visual) photosensitivity retinal ganglion cells (ipRGCs) [4]. Moreover, light has been used as antidepressant and mood enhancing stimulus not only patients with mood disorders but also in healthy people during winter season in our latitudes [5].

On the other hand, visual effects produced by artificial light influence human wellbeing, mood, comfort and work engagement as reported by Professor Scartezzini. [4]

The preceding paragraphs illustrate the urgent need to identify and optimize office lighting conditions, with respect to visual and non-visual functions.

The discovery of blue LEDs in the early 1990s opened the door to (white) LED technology for lighting applications. LED technology for lighting represents a revolution comparable to the invention of the incandescent bulb. Indeed, LEDs are penetrating in the lighting business quickly. For example, the international home-furnishing giant IKEA eliminated non-LED bulbs from its 2015-2016 catalogue and the same year General Electric announced its intention to stop producing CFLs in favour of LEDs. [6] Moreover, according to a recent study LED-based fixtures are expected to hit 80% volume share of the **Professional Lighting** market by 2020. [7]

Given the its market penetration and its high spectral and photometrical flexibility LED technology is the best tool to help the scientific community and lighting industry understand LED lighting-related effects on humans.

Current status and required further research

a) *Visual and non-visual effects*

Although quite an effort has been set, the problem in question is of multi-variable nature. Parameters such as light wavelength and intensity, time of exposure and duration as well as individual age and prior light-dark history all contribute. [3] Further research is therefore necessary in order to gain sufficient understanding to improve lighting fixtures that produce light beneficial to the users. This is of outmost importance since most of us spend an enormous amount of their lives time under artificial lighting environments. Thus, given the new flexibility of LED technology we have a tool in hand to impact on almost everybody's well-being at the work place. Indeed, first studies show that changing lighting conditions at the work place has beneficial effects on subjective feelings of alertness, performance, mood and sleep quality [8].

b) *Light and colour management of LED-based fixtures*

Regardless the many advantages of LEDs for lighting, the light produced by such high-intensity sources needs to be properly handled. Poor color rendition, improper color mixing and color fringes, multi-shadow effects, glaring, lack of directionality and spatially non-uniformly illuminated areas are common downsides of LED-based lighting devices.

CSEM has been involved in several SSL projects in the last few years in which it has developed a strong background in the area of light management solutions for solid-state lighting (see e.g. Figure1). CSEM has in-house capabilities for the design, simulation and characterization of light management solutions for solid-state lighting. Through partners CSEM has also access to the fabrication of the designed optical structures.

Project description

The objective of the proposed PhD project is to investigate and quantify visual and non-visual effects produced by LED lighting on humans across a wide spectral and photometric parameter space. The proposed research will combine the vast experience and facilities of Professors Cajochen and Scartezzini on the physiological aspects of lighting with those of CSEM in the field of integrated light management solutions for solid-state lighting.

The student will develop a LED-based luminaire and investigate the chronobiological effects in the laboratories of Professor Cajochen at the *Centre for Chronobiology in Basel*.

In the initial phase of the project, the parameter space of interest will be defined with respect to spectral tuning, achromatic dimming and beam steering/shaping.

In a later stage, he/she will design and develop light management structures for beam shaping and spectral tuning so that the previously identified illumination parameter space can be reproduced as well as the electronics necessary to provide different illumination conditions in a dynamic and highly controllable fashion. This part of the Thesis will account for around 75% of the total work.

The fabricated luminaire will also be used to study visual (e.g. comfort) and non-visual effects of different artificial/daylighting combinations. In this regard, the student will be directly engaged on the development of a spectral sensing platform to realize a smart *active human* centric lighting solution. This part of the work will be supported by Professor Scartezzini at the *Solar Energy and Building Physics Laboratory at EPFL* and accounts for the remaining 25% of the effort.

The results obtained from the described experiments will be conveniently analysed in order to drawn relevant conclusions and make useful recommendations.

During the proposed work, collaborations can be envisaged with industrial actors in the region such as REGENT LIGHTING for the integration of the developed components into a luminaire and BASF with regards to their proprietary color changing foils for spectral tuning.

We strongly believe that the results of the proposed research will be of scientific interest as well as of enormous commercial value for the companies in the Professional Lighting Business.

The PhD student will perform the largest part of his/her research at CSEM facilities in Basel. In order to comply with legal and insurance regulations he/she will be an employee of CSEM.

References

[1] T. Q. Khanh, P. Bodrogi and T. Q. Vinh, *Color Quality of Semiconductor and Conventional Light Sources*, Wiley-VCH (2017)

[2] *Tech-Talks BREGENZ. Prof. Christian Cajochen*. LED Professional, Issue 58; pp. 26-31 (2016)

[3] C. Cajochen, S. L. Chellappa and C. Schmidt, *Circadian and Light Effects on Human Sleepiness-Alertness.* Chapter 2 in *Sleepiness and Human Impact Assessment* Edited by S. Garbarino, L. Nobili and G. Costa, Springer (2014)

[4] A. Borisuit, F. Linhart, J.-L. Scartezzini and M. Münch, *Effects of realistic office daylighting and electric lighting conditions on visual comfort, alertness and mood*. Lighting Res. Technol. 47; pp. 192-209 (2015)

[5] Handb Clin Neurol. 2012;106:697-713. doi: 10.1016/B978-0-444-52002-9.00042-5. *Chronotherapeutics (light and wake therapy) as a class of interventions for affective disorders*. Wirz-Justice A1, Terman M.

[6] P. Daukantas, *Illuminating the New Century.* Optics & Photonics, November 2016; pp. 29-35

[7] The Boston Consulting Group, *How to win in a transforming lighting industry.* Available online: https://www.bcgperspectives.com/Images/BCG-How-to-Win-in-a-Transforming-Lighting-Industry-Nov-2015.pdf

[8] Scand J Work Environ Health. 2008 Aug;34(4):297-306. Epub 2008 Sep 22. *Blue-enriched white light in the workplace improves self-reported alertness, performance and sleep quality*. Viola AU1, James LM, Schlangen LJ, Dijk DJ

Figure 1: Top) 20x20cm² LED-based lighting module with (left) and without (right) a multilayer light management solution developed by CSEM in the European project LASSIE-FP7. The multilayer solution transforms the non-homogeneous light pattern produced by the point-like LED sources into a spatially uniform emitting surface. The module height, 18mm is lower than the LED pitch (30mm). The light engine contains white, red and green LEDs for color tuning. Bottom) Emitting surface of the module tuned to different colours demonstrates that CSEM light management solution offers also excellent light mixing characteristics.