Colour and Colorimetry Multidisciplinary Contributions

Vol. XII B

Edited by Davide Gadia

GRUPPO DEL COLORE
ASSOCIAZIONE ITALIANA COLORE

www.gruppodelcolore.it

Regular Member
AIC Association Internationale de la Couleur

Colour and Colorimetry. Multidisciplinary Contributions. Vol. XII B
Edited by Davide Gadia – Dip. di Informatica – Università degli Studi di Milano

Layout by Davide Gadia

ISBN 978-88-99513-04-7

Piazza C. Caneva, 4
20154 Milano
C.F. 97619430156
P.IVA: 09003610962
www.gruppodelcolore.it
e-mail: redazione@gruppodelcolore.it

Printed in the month of October 2016

Colour and Colorimetry. Multidisciplinary Contributions Vol. XII B

Proceedings of the 12th Conferenza del Colore

Joined meeting with:
AIDI Associazione Italiana di Illuminazione
Colour Group Great Britain (CG-GB)
Centre Français de la Couleur (CFC-FR)
Colourspot (Swedish Colour Centre Foundation)
Comité del color (Sociedad Española de Óptica)
Groupe Français de l'Imagerie Numérique Couleur (GFINC)

Politecnico di Torino
Turin, Italy, September 08-09, 2016

Organizing Committee

Davide Gadia
Anna Marotta
Roberta Spallone

Program Committee

Alessandro Farini
Massimiliano Lo Turco
Veronica Marchiafava
Marco Vitali

Organizing Secretariat

Veronica Marchiafava – GdC-Associazione Italiana Colore
Marco Vitali – Politecnico di Torino

Scientific Committee – Peer review

Organizers:

GRUPPO DEL COLORE
ASSOCIAZIONE ITALIANA COLORE

AIDI

Centre Français de la Couleur

POLITECNICO DI TORINO
Dipartimento di Architettura e Design

POLITECNICO DI TORINO
UNIVERSITÀ DEGLI STUDI DI TORINO
Dipartimento Interateneo di Scienze, Progetto e Politiche del Territorio

GFINC

Patronages:

AIAr
Associazione Italiana di Archeometria

ANVER
Associazione Nazionale Verniciatori
Associação Italiana das Empresas de Pinturas Industriais

assodel

1916 2016

FEDERCHIMICA
AVISA
Associazione nazionale vernici, inchiostri, sigillanti e adesivi

Gruppo Italiano Ricercatori Pattern Recognition

POLITECNICO DI TORINO
Dipartimento di Architettura e Design
Dipartimento Interateneo di Scienze, Progetto e Politiche del Territorio

SIOF
Società Italiana di Ottica e Fotonica

PROVANDO E RIPROVANDO
Società Italiana di Fisica

Index

Warm white, neutral white, cold white: the design of new lighting fixtures for different working scenarios

Daria Casciani, Fulvio Musante, Maurizio Rossi
Dept. of Design, Politecnico di Milano, daria.casciani@polimi.it, fulvio.musante@polimi.it, maurizio.rossi@polimi.it

1. Introduction

Nowadays office lighting is fundamental for vision and for increasing wellness and working performances by considering the physiological and psycho-perceptual, social, behavioural and postural factors in relation to the working luminous environment.

1.1 Trends: the future of office working activities and environments

The design of the future workspaces should take into account the overall management of work and the social aspects that are established in the workplace. The work done in offices is becoming more nomadic, less tied to the needs of a fixed workstation and predetermined, but potentially executable everywhere in the office space or out of it, globally, in every part of the world.

The work is an inherently social process which requires that people quickly pass from a focused job (individual tasks of processing, concentrating or relaxing moments), to team working (creative collaborations), to sharing activities (meeting with communications and presentations)[1]. Each of these activities can be configured in different physical postures and requires different luminous atmospheres that are consistent with the context, the purpose and performed work activities. The use of new technological tools is inducing new ways to move and work in the office environment, in the micro space of the human body postures and in the macro environment of the entire workspace[2,3]: the multimodal use of different technological devices for reading and working (pc displays, keyboards, tablet etc.) is determining different visual field and tasks[4]. Work environments nowadays require flexibility in the arrangement of furnishings and the increased possibility of reconfiguring the space, in addition to the need of managing the personal space in a situation where the job done individually is reduced in favour to shared and team activities[5]. Recent studies of office future trends reveal the importance of creating healthy spaces in which workers can be "energized" or "relaxed", passing from concentration to relaxation, where they can suspend their activities for periods of "daydreaming" to refresh mentally and to be more productive in the long term[6].

1.2 More than functional lighting

Traditionally, office lighting fixtures are focused on limiting glare, providing energy efficiency and durability: in the majority of offices they are equipped with fluorescent tubes with correlated colour temperature (CCT) 4000K and very limited controllability. On the other hand, more than only achieving the required illuminance on the work/task area, lighting should be adjustable in relation to individual physiology, age and health. Nowadays, lighting research and design are focused on two macro-themes that converge and intersect: the new Solid State Lighting technology (SSL) and Human Centric lighting (HCL)[7] with its strategic importance both in driving the correct application of the new SSL technologies and also in improving the quality of life (wellbeing, mood, health) of individuals. Office lighting can influence people wellbeing and behaviours through circadian rhythm activation/suppression by synchronizing the timing of the biological clock. Previous studies show that specific circadian lighting receipts (quantity, spectrum, distribution at eye level, timing, duration) are important for helping people in concentrating and improving cognitive performances at work, improving alertness and vitality, providing better sleep quality[8] and enhancing the general mood[9] .

The luminous environment can enhance people mental and cognitive regeneration[10, 11] and contribute to the wellbeing and productivity of individuals. Numerous studies have explored the issue of the regenerative potential in the workplace[12,13] but a limited number of studies has focused on the importance of lighting in reducing mental fatigue and increasing cognitive performances[14,15,16]. Despite of this, for enhancing the wellbeing of people, an environment should visually reconnect to nature both with natural lighting[17] (access to daylight through the window)[18,19] and with artificial lighting, creating non-rhythmic sensory stimulation through the dynamics and variation of spectrum and distribution. This performance reconnects the individual to natural performances by creating a more complex and intriguing visual scenario through biomorphic shapes and patterns[20]. Several experiments and studies demonstrate that office workers prefer lighting which is distributed in a direct-indirect way, with some of the light being reflected off the ceiling and surrounding surfaces[21,22,23].

The quality of life of individuals can be enhanced also if they can control their lighting: research demonstrates that, when people work in environments that can be changed according to their personal preferences, they evaluate the lighting as of higher quality and the office as more attractive. In such an environment, they tend to develop a more positive mood, to work in a more focused way and this can influence their general wellbeing.[24]

1.3 Controllable lighting at work

In order to ensure that individuals are able to experience their favourite lighting levels and luminous atmospheres to accompany different working activities and tasks, lighting should be flexible by providing a certain degree of control in terms of illuminance[25], white tuning or spectral tuning[26,27,28,29] but also lighting distribution[30]. The individual control of lighting is positive not only for personal customization of the lighting atmosphere and for influencing positively the mood of people contributing to personal and environmental satisfaction[31] but also in terms of energy efficiency by reducing the energy use in comparison to the typical fixed light level provided in offices[32,33].

By allowing a wider level of controllability and new lighting functionalities, the new SSL based lighting fixtures need more precise digital controls, more calibrated lighting performances and more complex, but user-oriented interfaces which ensure the complete freedom with usability and recognition of functions, experience/pleasure of use and satisfaction in the control[34].

In particular, advanced systems are required in order to guarantee the understanding of multiple functionalities and control possibilities: the user interface and the user interaction are a wide and new field of investigation in the lighting design field. In particular, with tangible user interfaces (TUI), such as innovative remote controls, and with surface user interfaces (SUI), such as displays of tablet and smartphones, the user can control the lighting in a more precise way by adjusting single lighting parameters or in a more abstract way by setting up preset-based lighting scene (where all the parameters are changed simultaneously) based on lighting atmosphere or work activities. In addition, the literature[35] shows that it is preferred to save personal lighting scenes for later recall.

2 Research scope

This article would analyse in detail the importance of implementing LED lighting engines that provide white tuning by describing and comparing the characteristics of two experimental prototypes realized at the Laboratorio Luce – Politecnico di Milano: COOELO and ASTERISM. Conceived as innovative lighting fixtures, they include the possibility to vary the intensity from a maximum to a minimum value and the Cold - Warm White tuning by running on a daily schedule, with an internal timer, or modifiable at a personal level through direct interaction. These luminaries could be applied for activate or suppress circadian stimulation, for behavioural control, for matching the colours with natural lighting (daylight during day, warmer dimmer light in evening), for cooling or warming the room to counteract exterior temperatures and for tuning lighting atmosphere according to users' preferences. COOELO and ASTERISM were developed for research scopes in order to test the photometric, optical, quantitative and qualitative performance of the tuning of white shades close to the black body curve in an efficient way. In addition to this, the prototypes were used to implement several hypothesis of user interaction with the lighting system.

3 Method

The lighting engines, COOELO and ASTERISM were designed and prototyped for technological assessment to test different lighting scenarios that have been defined through the previously presented extensive literature review. The different possibilities of dynamic lighting concerns:

- dimming from 0 (OFF) to 100 (ON);
- white tuning;
- control of direct and indirect lighting distribution independently;
- variation of lighting scenarios.

By measuring, evaluating and analysing these lighting prototypes, this paper aims at highlighting the following issues: colour mixing in relation to the optical systems, range of colour tuning in relation to efficiency and Colour Rendering Index (CRI), lighting functions and user interface.

4. COOELO

The prototype COOELO is a semi-direct suspended lighting fixture for a single working location in a small office. It consists of four parts:

- Box for LED driver, Arduino and XBee Shield mounted on the ceiling;
- Reflective structure for direct and indirect light distribution;
- Lighting engine with Blue LEDs and Remote Phosphor (3000K-5000K);
- Management and control system.

The overall dimensions of the lighting system are 630 x 346.5 x 152 mm (height).

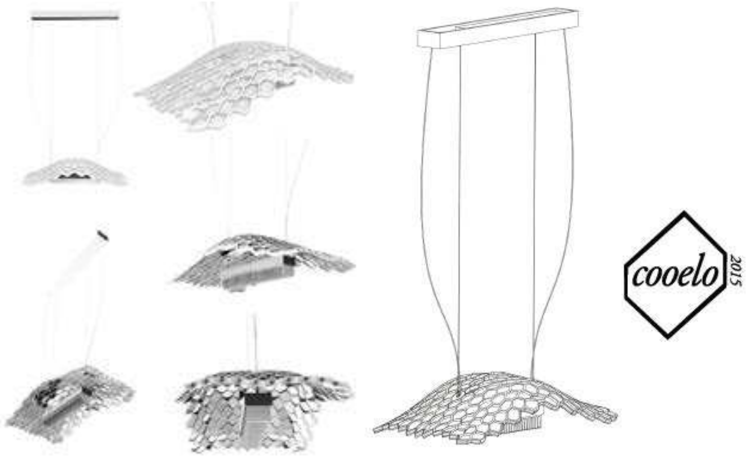

Figure 1 - COOELO lighting prototype

4.1 Lighting performances

The lighting engine is characterized by royal blue LEDs (48 LED Luxeon Rebel LXML–PR01-0425), four separated mixing chambers coated with a highly diffusive material for a better white lighting uniformity and remote phosphors of two different CCT (Intematix Corporation CL-830-L225-PC and CL-750-L225-PC).The lighting engine addresses its emission to a faceted reflector which is inspired by nature in the geometric repetition of the hexagonal pattern and reflect light while generating glitter effects and the scattered image of the emitting lighting source. In addition, the central part of this structure is characterized by transparent facets in order to have lighting on the ceiling of the room.

COOELO meets the parameters of maintained average illuminance, uniformity and comfort in terms of glare in accordance with the UNI EN 12464-01. Its lighting performance is direct downwards lighting (60%) and indirect upwards lighting (40%), in order to avoid the "cave effect" . The device, installed at 1.2m from the workplane, provides an average level of illuminance of 280 lux with a uniformity of E_{min}/E_{ave}=0.6 on the visual task (1.6m x 0.8m) and an average level of 140 lux on the surrounding area (2.6m x 1.8m), with a uniformity value of E_{min}/E_{ave}=0.45. The UGR index value is below 19 calculated for 5 different observers located (sitting or standing) in the simulated room. The lighting performance can be controlled by dimming the intensity from 0 to100 and tuning the CCT from 3000K to 4900K. The diminished value of the cold CCT is derived by the known phenomena of interaction between the plastic material and the incident light beam: the plastic used in the prototype structure (obtained through rapid prototyping techniques such as stereolithography) has modified the CCT, by warming the tone of white of 100K.

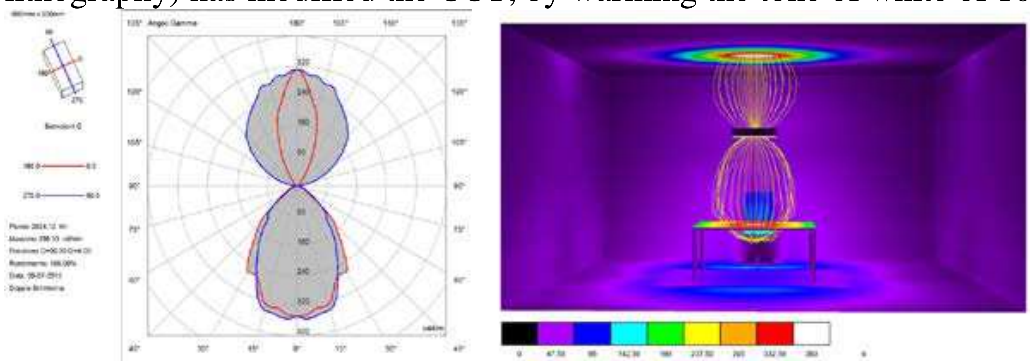

Figure 2 - COOELO lighting performance: photometric distribution and illuminance false colours representation

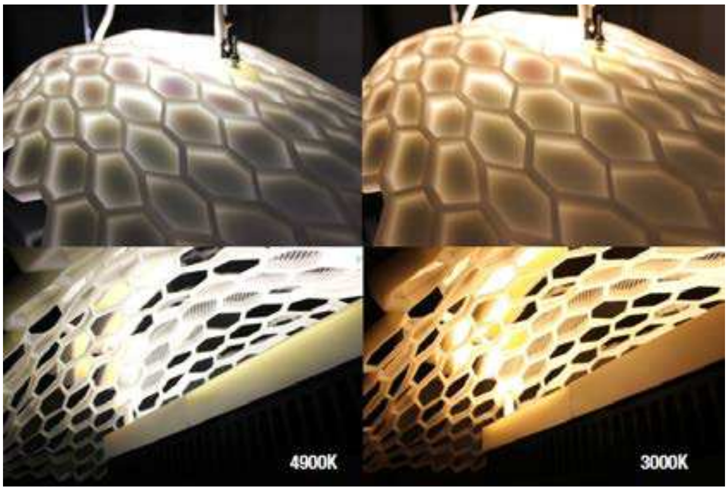

Figure 3 - COOELO lighting performance: direct –indirect lighting prototype with different CCT

5. ASTERISM

ASTERISM was conceived as a modular lighting fixture for the multifunctional desk, able to evolve in different shapes and configurations, by taking into account different working scenarios, from individual to collective working modalities. Unlike a monolithic lighting system, it is composed by several functional modules which ensure the maximum flexibility of installation in terms of spatial composition and lighting distribution/variation in relation to working activities.

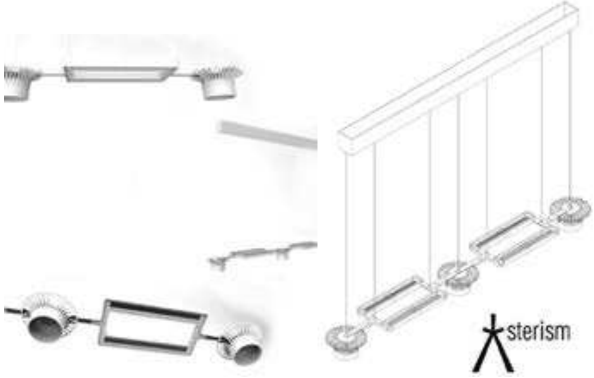

Figure 4 - Asterism lighting prototype

Asterism consists of a supporting structure with connected lighting modules to create a constellation of luminous elements. The main elements are:

- box for LED driver, Arduino board and XBee Shield mounted on the ceiling;
- three modules for direct illumination (down-light);
- four modules for indirect lighting (light-up);
- management and control system.

5.1 Lighting performances

The device consists of a direct emission, realized by means of three spots equipped with 4 LED CREE MC-E Dynamic White and a LENS LEDIL C10702-Rocket-4-W with a measured beam aperture equal to 2x22°. The indirect emission is ensured by 8 modules with 18 Mid-Power 3030 LED SEOUL STW8C2SA in two CCT and they are equipped with asymmetric optics (LEDIL C12446_SOPHIE).

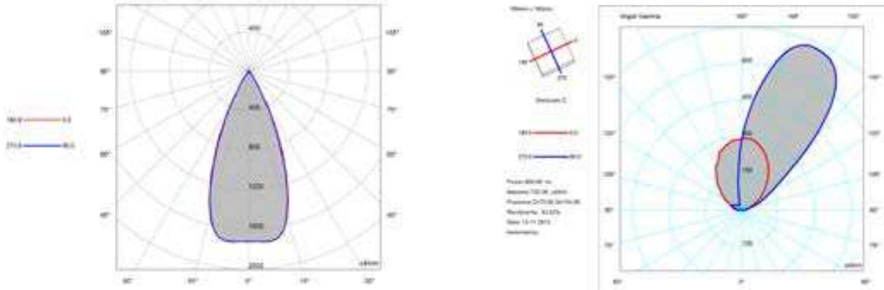

Figure 5 - On the left: photometric distribution of the direct lighting module; on the right: photometric distribution of the indirect lighting module

All the modules for direct and indirect lighting can be controlled autonomously in term of dimmability from 0 to 100 and white tunability between 3000K to 6000K.

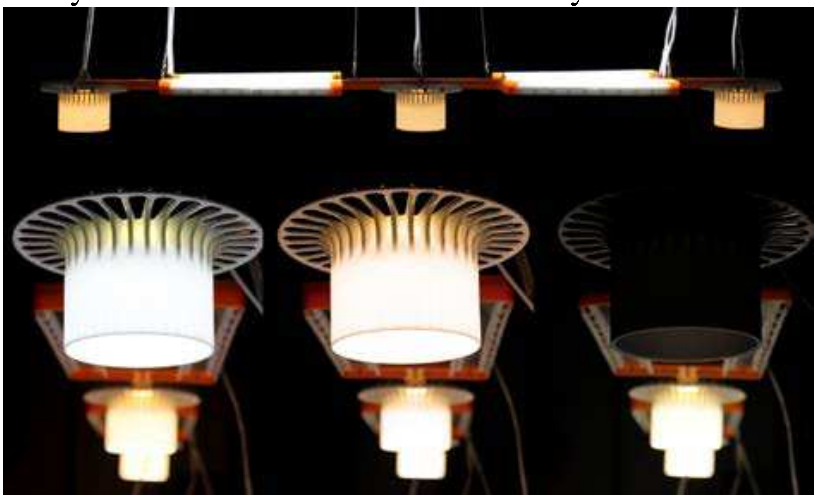

Figure 6 - ASTERISM lighting performance: direct –indirect lighting prototype with different CCT and single modules controllability

Asterism can be controlled by varying the following lighting scenarios (Figure 7):

- Scenario 1–Workshop supports the multifunctional work in teams during meeting and networking situations or processing group activities. Each direct lighting module is individually controllable (lighting levels and CCT). The indirect lighting guarantees visual clarity with a neutral CCT, increasing the perceived space for a welcoming public dimension.
- Scenario 2–Focus ensures the creation of an environment suitable for individual work, where the increased focus on the visual task implies higher level of illuminance and neutral/cold CCT (central direct module) in the area where the user is working. The surroundings are evenly lit from indirect lighting (neutral/cold CCT) ensuring a balance of luminance with the background.
- Scenario 3–Haven configures a private working environment, with lighting direct on the work surface of the desk, ensuring moderate levels of illumination in the visual task. Indirect lighting is off or dimmed at low levels in order to reduce the perceived space of the room, creating a confined environment for a subjective solitary concentration.
- Scenario 4–Relax defines a relaxing work environment ideal for a break from the pace of a daily working routine and for the attention restoration after a prolonged mental and visual fatigue. Lighting would be mainly indirect (3000K) exploiting the ceiling and walls while direct lighting will be turned off or adjusted to a minimum.

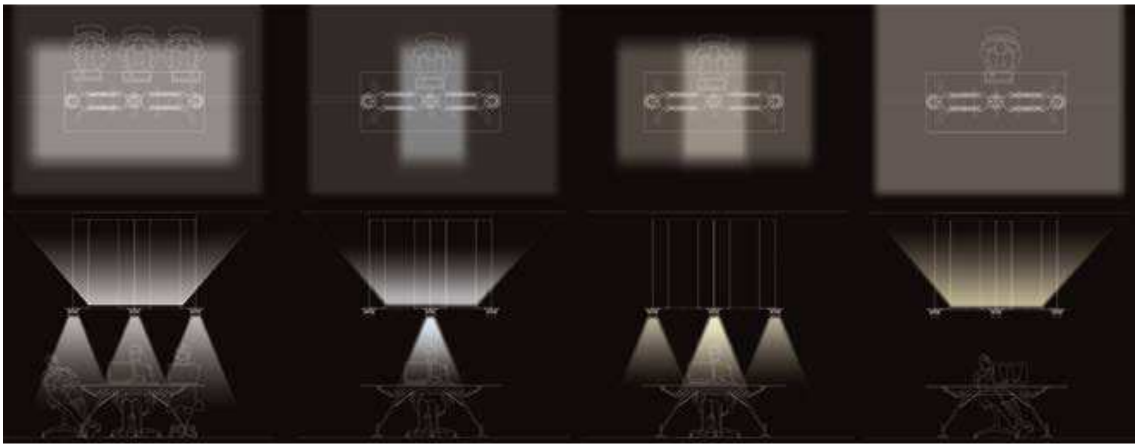

Figure 7 - From left to right: Scenario 1-Workshop; Scenario 2-Focus; Scenario 3 –Haven; Scenario 4-Relax

6. Measurements

In relation to the evaluation of the luminous performance of the devices, a series of laboratory measurements were carried out to verify the chromatic performances of the lighting prototypes.

The results reported in this paper are limited to the prototype Asterism, considering only direct emissions on the reference plane, for which a deviation between the measured and predicted values would be more critical. For this reason, the direct lighting module of the prototype Asterism was measured in accordance to the following protocols:

- Measures of the spectral power distribution for the assessment of chromaticity, CCT and CRI, considering different settings of the luminaire in terms of emitted luminous flux and tone of light. The measurements were conducted by measuring the emission in the axis of the device, at a distance of 0.75m.
- Measures for evaluating colour uniformity of the incident light on a target screen, changing the CCT and leaving constant the value of the emitted flux (in first approximation, it is assumed that the regulation of emitted luminous flux does not modify the activation proportions of the two channels). The screen was placed at 0.75m from the luminaire.

7. Results

Figure 8 shows the extent of the deviation of the CCT emitted from the direct beam with respect to the nominal value: in an ideal luminaire, the curve should be a straight line tilted at 45° with respect to the abscissa axis independently of the adjustment for the emitted flux. As shown in the Figure 8, we can conclude that the adjustment is very good for large values of the emitted luminous flux (100% and 75%), while it tends to worsen for cold CCT, when the emitted luminous flux is reduced to 10% compared to the maximum value.

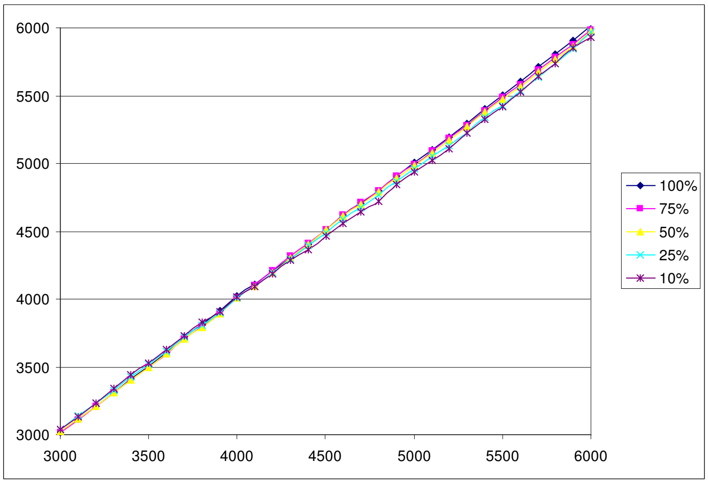

Figure 8 - Trend of measured colour temperature (ordinate axis) in accordance with the corresponding rated value (abscissa axis)

For a proper evaluation of the influence of this deviation from a perceptual point of view, the following procedure was used:

- Determination of relevant parameters (semi-axes and inclination) for a 3-step MacAdam ellipses corresponding to the chromaticity measured by setting the device to the maximum output flux and by adjusting the CCT between 3000K and 6000K in steps of 500K
- Fixed a CCT inside the specified range, the values of chromaticity were measured changing the percentage of emitted flux (75%, 50%, 25%, 10%)
- It was then established that, all chromaticity values obtained by dimming, fall within the corresponding ellipse.

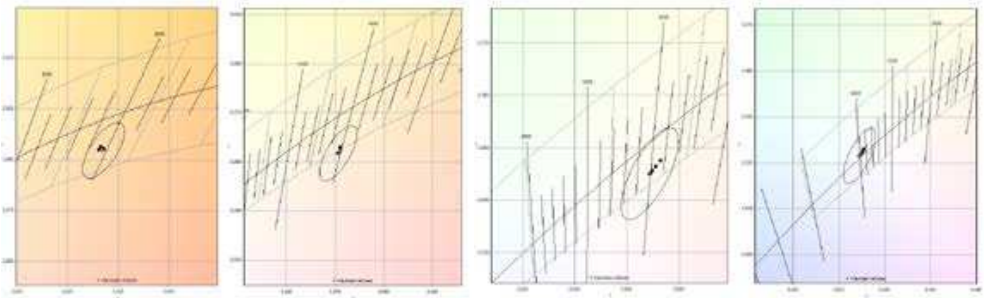

Figure 9 - Evaluation of the constancy for the chromaticity of emitted light changing the percentage of emitted flux. Measurements from left to right of 3000K-4000K-5000K-6000K

Figure 9 shows the results obtained by applying the described method: with the variation in flux, chromaticity remains almost constant with respect to the value obtained at maximum output, regardless of the value of the selected colour temperature.

7.1 Colour mixing in relation to the optical systems

The colour's uniformity of the emitted beam was evaluated by observing the image formed on a screen perpendicular to the axis of the luminaire placed at a distance of 0.75m: the results are generally good for all the CCTs (Figure 10). The result essentially depends on the used lens and the aperture of the light beam which is not excessively wide; indeed very narrow opening would make critical mixing between the emissions of dies pairs that constitute the MC-E LED Dynamic White.

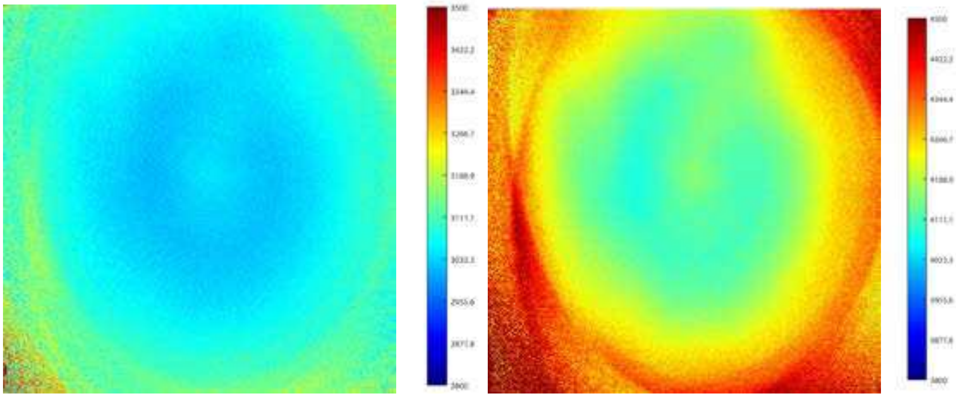

Figure 10 - Distribution map of CCT measured with 2D Colour Analyzer CA-2000 by Konica Minolta: on the left, Asterism direct lighting emission at 3000K; On the right 4000K

7.2 Range of colour tuning in relation to emitted luminous flux, efficiency and CRI

The percentage change of the lighting levels as function of the CCT is contained in approximately 2%, irrespective of the value of emitted flux (the chart in Figure 11 shows the results for 5 different settings of the emitted flux). Best results would be possible considering a more fine tuning of the management system settings, but it was not considered necessary since the differences are not visually perceptible.

The CRI R_a, defined according to the CIE publication 13.3 of 1995, varies in a range between 80 and 75, as function of the considered CCT: the index assumes the highest values for lower CCT values and decreases when the CCT increases.

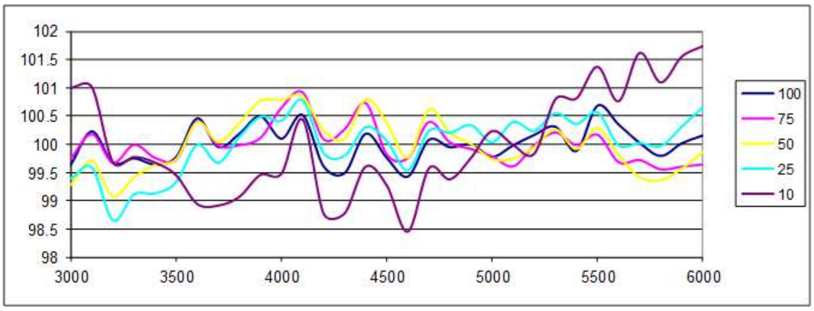

Figure 11 - Percentual variation of illuminance changing the CCT for different levels of dimming

The performance obtained is shown in Figure 12 (on the left). On the right the Figure 12 shows the index trend R_9 according to the CCT: the decreasing trend of the graph with increasing CCT is mainly due to the growing proportion of cold light with increasing CCT. The two trends shown in the graphs are essentially due to the colour rendering characteristics of the used LEDs and not very dependent on the power supply system and the technique of adopted current regulation.

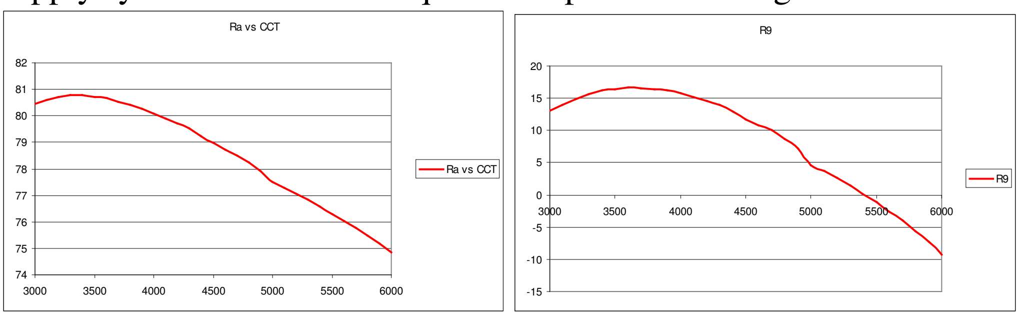

Figure 12 - On the left: CIE color rendering index R_a as a function of CCT;
On the right: Results of special colour rendering index R_9 as function of CCT

7.3 Lighting functions and user interface

Controls were a critical element in managing white-tuning of the prototypes and giving an intuitive user interface. Both the control platforms of the two lighting systems were enabled to tune smoothly through the CCTs without changing the total light output over the colour range. In addition to this, they allowed the control of the luminous output by maintaining stable the CCT and without causing flicker. Despite of the fact that both systems were equipped with two different controls (sliders), one for power and intensity level and the other for CCT, they show different levels of complexity in providing information and controlling different functionalities. In fact, the more complex are the lighting performance achievable, the more complex the user interface becomes.

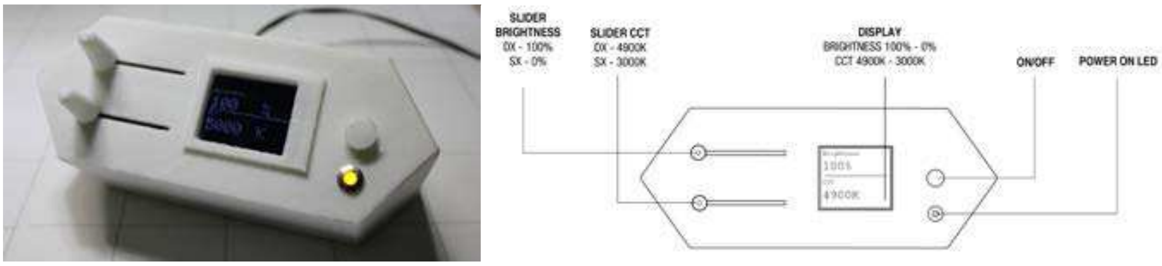

Figure 13 – COOELO interface and control system

The COOELO control platform (Figure 13) has a display to give direct visual feedback about the specific CCT and intensity level (in percentage). The ASTERISM control platform is more complex since each lighting module can be separately controlled with the possibility to play or record lighting scenes. The interface is provided with a visual diagram of switches representing the lighting modules of the prototype: each button allows to control each module differently in manual mode, adjusting both CCT and lighting levels.

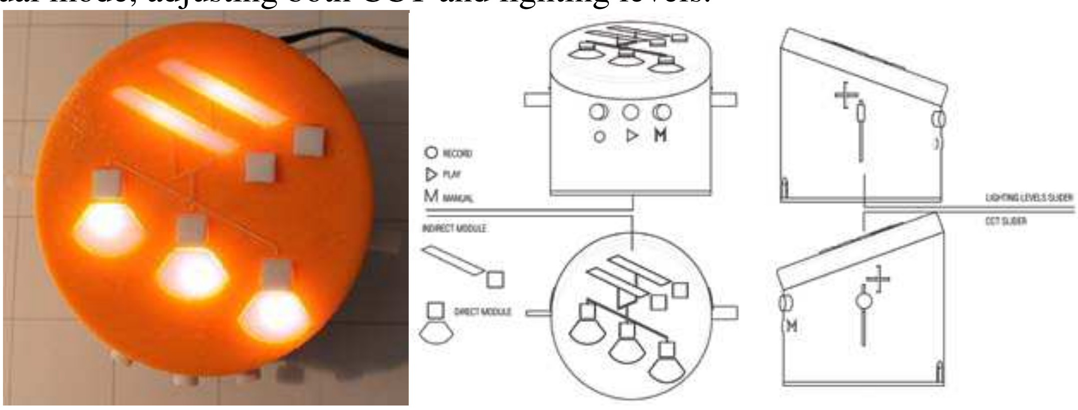

Figure 14 - ASTERISM interface and control system

In addition to this there are other controls that allow to switch from manual mode to record mode (it allows to record the lighting scenes) and play mode (it allows to play lighting scenes previously recorded).

8. Conclusion

The white tuning of the two prototypes was achieved in two ways:

- COOELO: Phosphor conversion in which two different remote phosphors were placed above blue LED to convert the coloured light into white light;
- ASTERISM: phosphor-converted LEDs with two different CCTs.

The described measured lighting prototype (Asterism) was equipped with 2 LEDs white primaries and it is evident that the white tuning between 3000K and 6000K is performing sufficiently in terms of smoothness between different CCT with constant emitted flux. On the other hand, the CRI R_a diminishes with higher CCT and this is primarily dependent on the LEDs quality. These performances were achieved just by compiling a lookup table and by using a current controller based on PWM with 16 bits.

With a more complex lighting engine, equipped with more than 3 LEDs primaries (e.g. RGBW – RGBA – RGBAW), it would have been possible to enhance specific parts of the spectrum in order to achieve better CRI and specific colour rendering properties such as enhancing the Gamut area. In this more complex systems, it could be more difficult to create a stable CCT at different lighting intensities with a stable CRI. If the chromaticity of two different lighting fixtures is perfectly the same, the SPD (Spectral power Distribution) of these two may not be: this can make objects look different (because of different colour rendering capability).With RGBW fixtures, the same luminaire can be set up to render objects' colours in a variety of ways, from oversaturating to desaturating them, meanwhile the CCT doesn't change. In those situations a retroactive system is required for controlling and adjusting the lighting output through a temperature sensor for measuring the T_j of each LED primary or a shielded colour sensor for measuring the direct lighting emission.

9. Acknowledgements

The work described here was funded financially by ENEA and MSE and with in-kind support of the companies (LEDIL, ELITALIA) that have provided components for building parts of the customized prototypes.

Bibliography

[1] O'Neill M. and Wymer T.(2010) Implementing Integrated Work to Create a Dynamic Workplace. Knoll

[2] Knoll Workplace Research (2013) Evolving Design of Faculty Offices. Space Efficient Planning Solutions for the Private Office,

[3] O'Neill, M. (2009). Future Work and Workplace. Knoll research white paper

[4] Global Posture Study – Steelcase by Steelcase WorkSpace. Futures researchers and the Steelcase Design Studio

[5] O'Neill, M. (2012) Adaptable by Design Shaping the Work Experience, Workplace Research Knoll, Inc.

[6] The Future Workplace – Key trends that will affect employee wellbeing and how to prepare for them today (2014) Unum

[7]Walerczyk S. (2012) Human Centric Lighting Architectural SSl (www.architecturassl.com) pp. 20 - 26

[8] MS Rea, MG Figueiro, and JD Bullough (2002) Circadian photobiology: an emerging framework for lighting practice and research, Lighting Research and Technology. September 2002; vol. 34, 3: pp. 177-187

[9] Stephenson K.M. Schroder C. M. Bertschy G. Bourgin P. (2012) Complex interaction of circadian and non-circadian effects of light on mood: Shedding new light on an old story Sleep Medicine Reviews 16 (2012) pp. 445 - 454

[10] Kaplan, S. (2001). Meditation, restoration, and the management of mental fatique. Environment & Behavior, pp. 480-506.

[11] Berto, R. (2005). Exposure to restorative environments helps restore attentional capacity. Journal of Environmental Psychology, pp. 249-259.

[12] Finnegan, M. C. & Solomon, L. Z. (1981). Work attitudes in windowed vs. windowless enviroments. The Journal of Social Psychology, 115, pp. 291-292.

[13] Farley, K. M. J., & Veitch, J. A. (2001). A room with a view: A review of the effects of windows on work and wellbeing (IRC-RR-136). Ottawa, ON: National Research Council Canada, Institute for Research in Construction. Retrieved April 16, 2007, from http://irc.nrc-cnrc.gc.ca/fulltext/rr136/.
[14] Kim, S.Y. & J.J. Kim (2007). Effect of fluctuating illuminance on visual sensation in a small office. Indoor and Built Environment 16 (4): pp. 331–343.
[15] Figueiro, M.G., J.A. Brons, B. Plitnick, B. Donlan, R.P. Leslie, & M.S. Rea (2011). Measuring circadian light and its impact on adolescents. Lighting Research and Technology. 43 (2): pp. 201-215.
[16] Beckett, M. & L.C. Roden (2009). Mechanisms by which circadian rhythm disruption may lead to cancer. South African Journal of Science 105, November/December 2009.
[17] Kaplan, R., & Kaplan, S. (1989). The experience of nature: A psychological perspective. New York: Cambridge University Press.
[18] Ulrich, R. S. (1984). View through a window may influence recovery from surgery. Science, pp. 224, 420-421
[19] A Borisuit, F Linhart, J-L Scartezzini and M Munch, (2015) Effects of realistic office daylighting and electric lighting conditions on visual comfort, alertness and mood, Lighting Research and Technology 2015; Vol. 47: pp. 192–209
[20] Browning, W.D., Ryan, C.O., Clancy, J.O. (2014). 14 Patterns of Biophilic Design. New York: Terrapin Bright Green llc.
[21] Zumtobel Research - Lighting quality perceived in offices Phase 1 | Data Analysis Europe. Fraunhofer IAO, Stuttgart | DE Zumtobel Lighting GmbH, Dornbirn | AT March 2014 Zumtobel Research ISBN 978-3-902940-50-6
[22] Boyce PR et al. (2006). Lighting quality and office work: Two field simulation experiments. Lighting Research and Technology, 38(3),pp. 191-223
[23] Veitch JA, Newsham GR (2000). Preferred luminous conditions in open plan offices: Research and practice recommendations. Lighting Research and Technology. 32, pp. 199-212.
[24] Veitch JA, Stokkermans MGM, Newsham GR. (2013) Linking lighting appraisals to work behaviors. Environment and Behavior. 2013;45(2): pp. 198-214.
[25] Boyce PR, Veitch JA, Newsham GR, Jones CC, Heerwagen JH, Myer M, Hunter CM. (2006). Occupant use of switching and dimming controls in offices. Lighting Research and Technology. 38(4): pp. 358-378.
[26] Veitch JA, Dikel EE, Burns GJ, Mancini S. Individual control over light source spectrum: Effects on perception and cognition. Proceedings of the 27th Session of the Commission Internationale de l'Eclairage, Sun City, South Africa Vienna, Austria: CIE; 2011, July. CIE 197:2011, Vol. 1, Part 1, pp. 213-8.
[27] Bieske K, Schierz C. (2010). Dynamic lighting—perception of luminous colour variation. In: Proceedings of CIE 2010 "Lighting Quality and Energy Efficiency." Vienna (Austria): CIE. pp. 290-297.
[28] Logadóttir Á, Fotios SA, Christoffersen J, Hansen SS, Corell DD, Dam-Hansen C. (2013) Investigating the use of an adjustment task to set preferred colour of ambient illumination. Color Res Appl. 38(1): pp. 46-57.
[29] Žukauskas A, Vaicekauskas R, Vitta P, Tuzikas A, Petrulis A, Shur MS. (2012) Colour rendition engine. Opt Express. 20(5): pp. 5356-5367.
[30] Van Boerdonk K., Mason J., Dzmitry A. (2011) User Interface for Task Lighting in Open Office Proceedings of the workshop on User Interaction Techniques for Future Lighting Systems pp. 23-27
[31] Veitch JA, Dikel EE, Burns GJ, Mancini S.(2011) Individual control over light source spectrum: Effects on perception and cognition. Proceedings of the 27th Session of the Commission Internationale de l'Eclairage, Sun City, South Africa Vienna, Austria: CIE; 2011, July. CIE 197:2011, Vol. 1, Part 1, pp. 213-8.
[32] Galasiu AD, Newsham GR, Suvagau C, Sander DM. (2007). Energy saving lighting control systems for open-plan offices: a field study. Leukos. 4(1): pp. 7-29.
[33] Maniccia D, Rutledge B, Rea MS, Morrow W. (1999) Occupant use of manual lighting controls in private offices. Journal of the Illuminating Engineering Society. 28(2): pp. 42-53.
[34] Dugar M. A. (2013) Lighting Control System and End Users – Establishing an Interactive relationship in Journal of Light & Visual Environment N. 2 & 3, 2013 pp. 70-77
[35] Van Boerdonk K., Mason J., Dzmitry A. (2011) User Interface for Task Lighting in Open Office Proceedings of the workshop on User Interaction Techniques for Future Lighting Systems pp. 23-27