
# Solid-State Lighting for Europe
# Newsletter #5
# July 2013

## Introduction

Welcome to the fifth and last Newsletter from the SSL4EU project!

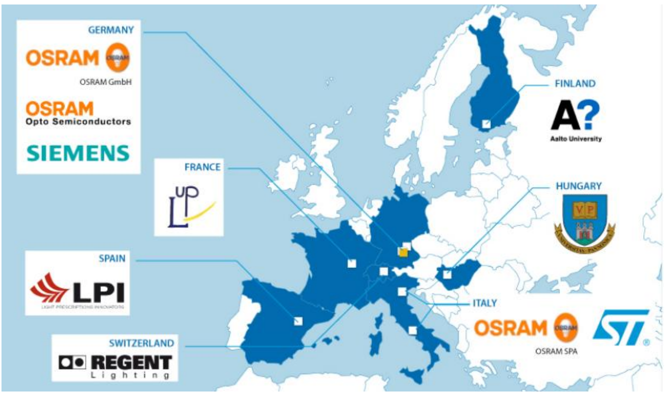
The SSL4EU Consortium is about to complete its project which has lasted for three years, until June 2013. Partners have accomplished encouraging results in exploring universally applicable LED light engines. They have largely promoted the SSL4EU goals and outcomes outside the Consortium. On the one hand, tangible research results have been published in journals and presented in several events. On the other hand, some Consortium Partners have been involved in the industry-wide Zhaga Consortium working internationally on specifications enabling interchangeability of LED light sources.

The SSL4EU consortium will gather for the last time on the 3rd Review Meeting on 30th & 31st July in Veszprem, Hungary.

Our last Newsletter focuses on the results achieved by partners during the third year and within the entire project duration. You will also find information on our workshop organised in Regensburg in June 2013.

We hope that we can maintain contact after the project's end. You can find us on our website: http://ssl4.eu/

## Consortium




The SSL4EU consortium has included large industrial companies, two SMEs and two universities:

OSRAM GmbH
OSRAM Opto Semiconductors
OSRAM IT
SIEMENS Corporate Technology
ST-Microelectronics
LPI
REGENT
Aalto University
University of Pannonia
L-UP

## Summary of progress since the last Newsletter

### *WP1 High Quality LEDs*

The main goal of WP1 for the period M31 to M36 was to finalize the assembly of the versatile multi chip LED spot light engines, both with fixed CCT and adaptable CCT.

The general feasibility of processing ceramic-based multilayers for light emitting diodes has been shown (SIEMENS AG). Several prototypes of spot light engines with highly packed chip arrays have been realized, both with conventional conversion technology and warm white ceramic conversion layers (Osram OS, Siemens AG).

For the first time, processing of ceramic multilayer composites by two chemically different phosphors was investigated for warm-white emitting diodes. Within the project time frame, feasible LED phosphor systems for warm-white conversion were selected and efficient powders for ceramic processing have been developed by OSRAM GmbH. A process route for ceramic multilayer processing has been developed at SIEMENS AG based on these new powders.

Spot light engines with light emitting surface diameters of 9mm and 13,5mm have been realized. Hereby a focus was on optimizing the topography of the light engine surface in order to enhance the reliability of the planar interconnect feed lines. The 9mm light engine with full warm white ceramic conversion showed a luminous efficacy of 52 lm/W at 4000lm output. The 13,5mm light engine with a silicon based phosphor showed a luminous efficacy of 116lm/W at 4000lm.

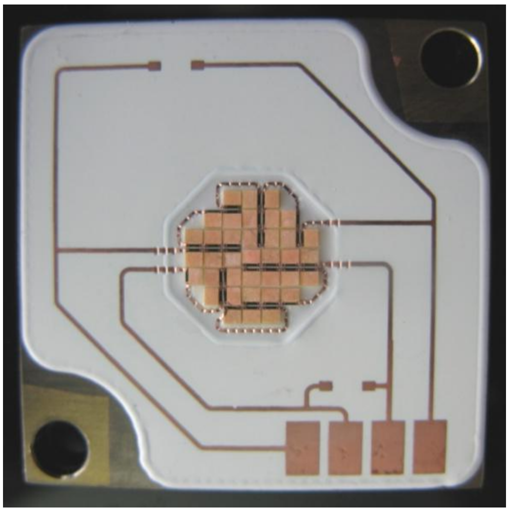


**Figure 1** ***37-chip spot light engine with 9mm diameter of the light emitting surface and warm white ceramic converter layers***

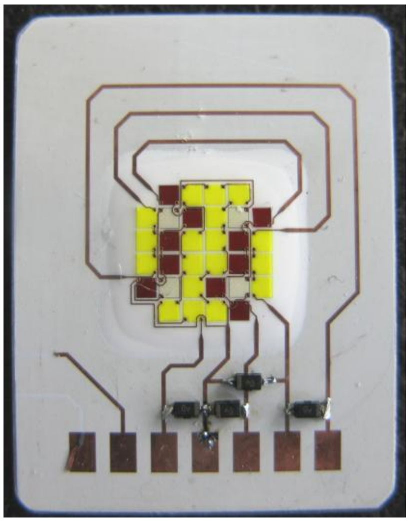


**Figure 2** ***32-chip multi color spot light engine with 9 mm diameter***

### *WP2.1 Electronics*

The activity carried out within the task 2.1 between M31 and M36 has been focused on investigating about:

1. Feasibility study on CCT (Correlated Colour Temperature) light control using optical feedback control loop.
2. Development and testing of high efficiency driver for the Sonotrode cooling system.
3. Development and testing of two-channel constant current power supply for warm white LEDs (derived from the three channel version developed during the previous period).

The CCT control can be obtain by two methods: using the LEDs mathematical thermal models (control technique implemented on the first tuneable white LEDs system, developed during the second year), or using an optical feedback control loop. The aim of the two control techniques is to keep fixed the colour point coordinates, allowing the compensation of the LEDs colour shift due to their temperature and aging variations.

The optical feedback control has been implemented using an optical sensor and a dedicated power supply able to communicate with the light-engine by a standard communication bus. Periodically, the driver asks to the light-engine the colour coordinates values of the light emitted (read by the optical sensor). Using these data, the power supply adjusts the LEDs output current of the different colour strings (using an amplitude modulation) in order to reach the output CCT desired.

Another task done during the last period is the Sonotrode driver development. The driver has been implemented using a half-bridge resonant converter in order to keep in track the sinusoidal power supply frequency at the mechanical resonant frequency, achieving the desired cooling effect with a high efficiency conversion. The compactness of the driver is one of key feature expressed by this development, minimizing both size and costs.

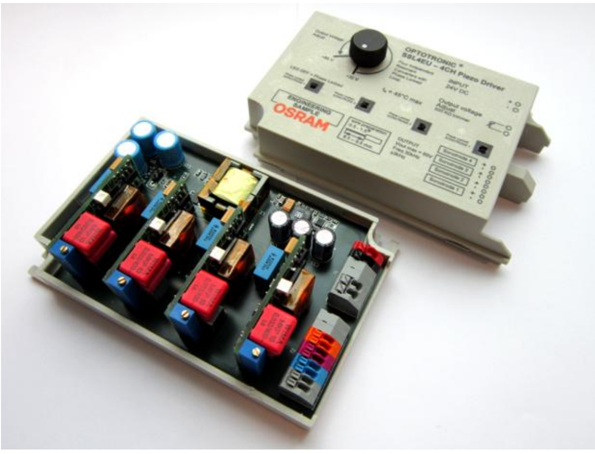


**Figure 3** ***SSL4EU Four- channel Sonotrode driver***

About the Warm White LEDs power supply, a two channel single stage Flyback converter has been developed using part of work done in the previous periods. Firmware, and part of the power supply hardware, has been re-designed. The driver achieves 91.38% of electrical efficiency at the nominal operating condition, fulfilling the high performance and efficiency required by the SSL4EU project. A final Two-channel LED driver with Sonotrode driver integration will be available before the end of the project.

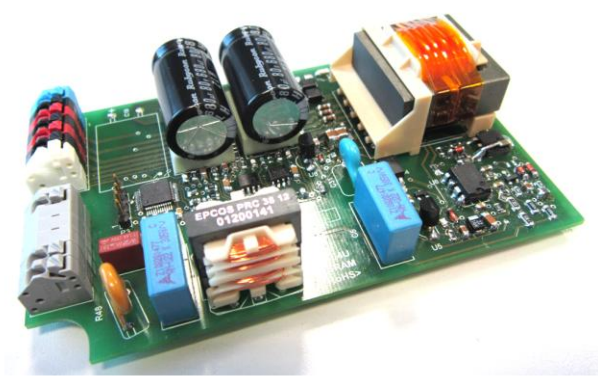


**Figure 4** ***SSL4EU Two-channel Warm-White LEDs power supply***

### *WP2.2 Thermal management*

Efficient and noiseless cooling provided by ultrasound had to be used for demonstrator cooling. A mechanical resonator had to be optimized which helps to increase the vibration amplitude of the piezoelectric actuator. To maximize the ultrasonic cooling effect, both efficient sonotrodes with high vibration amplitudes had to be developed, adequate heat sinks had to be found and in the end appropriate ultrasonic resonators had to be built up for the demonstrator cooling.

Drum sonotrode concepts have been investigated in respect to compact and efficient cooling systems. With these concepts, in the frequency range of 30 to 50 kHz, vibration amplitudes up to 28 µm have been measured by applying a low input power of around 2 Watt.

The Big Drum sonotrode, with an overall size of 50mm x 8mm, offers a flat design suitable for a cooling demonstrator. The cooling performance was demonstrated with a rather flat heatsink (size: 40x51x16mm[3]) in a number of different geometrical configurations. The sonotrode disc shape and rim has been optimized in view to efficient and stable cooling conditions. Systematical experiments on the ultrasonic cooling system have been carried out. At an input power of around 2 Watt the thermal resistance $R_{th}$ could be decreased from 12 to 7 K/W.

Between the sonotrode and the heat sink air curls are observed, therefore sufficient space between the sonotrode and the heat sink seems necessary to allow a proper air flow. Acoustic reflections from the end of the cooling fins, building an extra resonator, have to be avoided. Therefore heat

sinks with round or slanted fin rims have to be used. In combination with the sonotrodes the appropriate heat sink design for ultrasonic cooling has been developed. Based on the circular geometry of the sonotrode a circular heat sink design was build up which help the air curls to develop and propagate undisturbed.
A heat sink for demonstrator cooling based on the circular fin structure optimized for ultrasonic cooling has been build up and tested at different operating conditions. Four drum sonotrodes fixed in a mounting are operated in parallel with a piezo driver circuit developed by Osram.

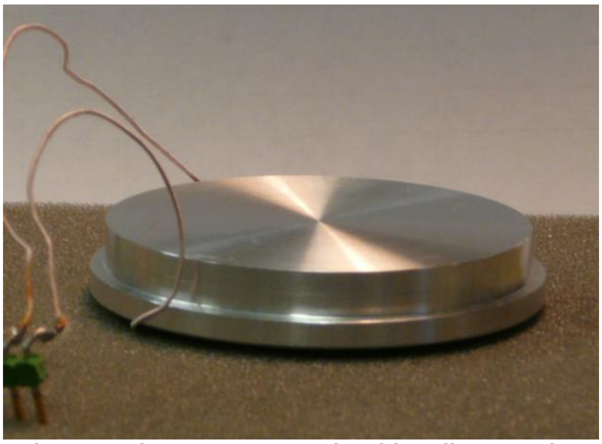


**Figure 5** ***Big Drum sonotrode with a diameter d = 50mm and a thickness h = 8mm. At a frequency near 33kHz a vibration amplitude of 28µm could be reached***

### *WP2.3 Optics*

From the optics standpoint, the main goal for the last period of the project was adding an optical feature to the shell mixer to enable light engine output color and luminance corrections in real time, without affecting the current shell mixer performance (efficiency, color mixing and high luminance). The color sensors selected (enabling colour and output flux corrections in real time) work with very low illuminance values and are sensitive to rays hitting the sensor under ±10deg. The final design, which "steals" a tiny portion of light emitted by each chip and conveys it to the sensor, is actually embedded into the shell mixer body, so both can be injected together in one shot. The sensor sits next to the chips, sharing the same LED package. The main challenges in the development of this colour tunable optical feature were:
- Make the system equally sensitive to all chips
- Minimum interference with the shell mixer performance
- Maximize light hitting the sensor within ±10deg
- Maximize Signal to Noise Ratio, to assure glare coming from scene or other parts of the shell would not interfere with light coming through the color tunable feature

Optics that meet these conditions is still a confidential technology, and has been included in the final light engine prototype.

Simulation results showed on the one hand that the shell mixer performance does not seem affected by the new optical feature and on the other hand, the feature seems to be more or less equally responsive to the light coming from all chips (Figure 6 & 7).

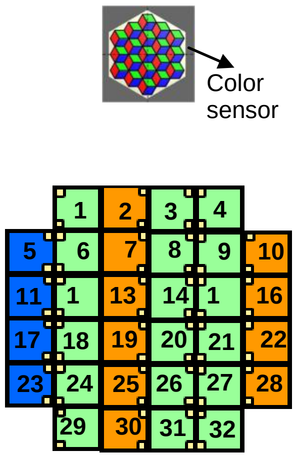



***Figure 6 Chip numbering to identify their locations in the right hand side bar plot***

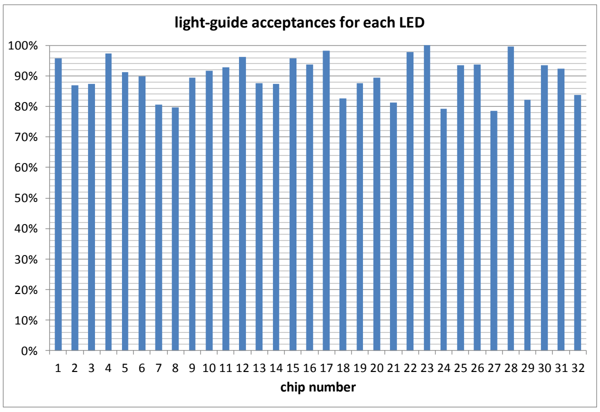



***Figure 7 Simulated light-guide acceptances for each chip that proves the sensor is sensitive to all chips locations***


***Figure 8 Pictures of a spot on the wall produced with set-up with reflective luminary and shell mixer with metalization on lightguide***

The last shell mixer prototype has shown similar efficiencies as previous designs (>90%) and has been demonstrated that adding the lightguide feature solves the colour tuning problem. Light-guiding feature can be produced to work by total internal reflection but this option can introduce some colour artifacts in the pattern due to the stray light going directly into it. Metalizing the upper light guide surface (entire or partial depending on application) stray light is being blocked and shell mixer performance is not affected (Figure 8).

### *WP2.4 High luminance light engines*

The major outcome of the project are two types of Zhaga compatible light engines including the light kernels from WP1. A 37 chip light engine for up to 4000lm with a LES (light emitting surface) diameter of 9mm (additionally with lens) and a 88 chip light engine with a LES diameter of 13mm (additionally with lens) for up to 7000lm.


***Figure 9 Chip light engine***


***Figure 10 Chip light engine***

For the 88 chip light engine we developed a housing concept that allows to mount the light kernel directly on the heat sink.

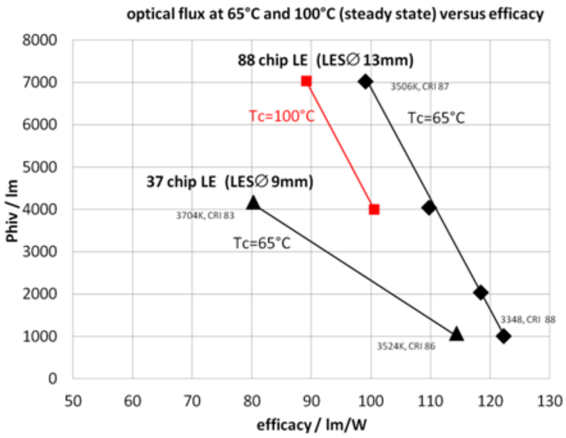



**Figure 11** ***Efficacy values for 37 and 88 chip light engine***

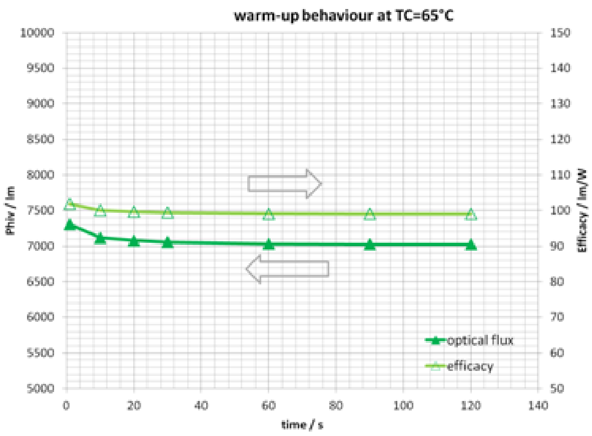



**Figure 12** ***Warm up curve for 7000lm***

Figure 11 shows the efficacy results for both light engines for a case temperature of 65°C (steady state). For 1000lm, 4000lm and 7000lm we

measure 122lm/w, 110lm/W and 99lm/W respectively. Even for a case temperature of 100°C we still measure 90lm/W for 7000lm.
The light engines have two interesting benefits compared to conventional COB solutions.
One interesting benefit of the SSL4EU light engines is the low thermal resistance. Because of the short thermal path (chip-Cu-board-heatsink) the thermal resistance is very low (measured: 0,1 K/W). This allows a very high case temperature and hence low heat sink costs. Looking at the warm-up curve even at 7000lm there is only a 3% drop during the warm-up phase (fig. 11).
The second benefit is the high luminance. Most shop lighting luminaires use HID lamps. Due to their high optical flux and low ball diameters even with a small compact reflector a high collimation strength can be achieved. The following study shows that nowadays commercially available COB light engines cannot really retrofit these HID lamps. But the SSL4EU light engine is the ideal HID retrofit.

For a typical spot light luminaire (fig. 12) with a reflector size ∅=100mm, height=45mm the most important performance parameters like centre intensity have been determined.

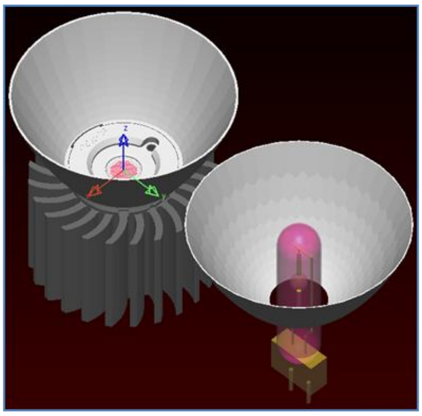


***Figure 13 Typical luminaire reflectors***

As reference we choose typical HID luminaires with 4000lm output and a ball diameter of 10mm. For COB comparison we choose standard (commercially available) COB light engines with 4000lm and LES diameter 22mm and 2000lm with LES diameter 15mm. Beside the flat HID-reflector we developed a higher reflector (∅=100mm, height=110mm) to get a better collimation of the bigger COB light engines (figure 13).
The figure 15 shows the results (HID luminaire results are simulated based on manufacturer data, light engine data is measured). The data in Row 1 to 4 shows different HID luminaries from super spot (beam angle 9°) down to medium spot (beam angle 26°). For the 10° spot we get a center intensities of 46kcd, for the 16° spot we get 29kcd.

***Figure 14 Small and big reflector for collimation measurements***

The standard COB LES∅15mm light engine shows comparable performance for centre intensity (appr. 32kcd) and beam angle (down to 7°) but the luminaire flux is low (up to 2000lm). The standard COB LES∅22mm shows comparable performance only for the big reflector (27kcd). But not many customers want to increase the luminaire size. For the smaller reflector the centre intensity is only 17kcd.
The SSL4EU light engine with LES∅9mm shows for both reflectors very competitive center intensities (47kcd and 49kcd respectively) at low beam angles (10° and 9° respectively). So only the high luminance SSL4EU light engine is a real HID retrofit.
For both light engines the drivers from WP2.1 are showing efficiencies of 92%.

| Name | Type | Lamp flux | Luminaire flux | Center Intensity |
|---|---|---|---|---|
| HID luminaire super spot I (HIT-CE 70W) | HCI | 3900 lm | 2079 lm | **39 kcd** |
| HID luminaire super spot II (HIT 70W ) | HCI | 6600 lm | 4234 lm | **46 kcd** |
| HID luminaire spot (HIT 70W ) | HCI | 6600 lm | 4201 lm | **29 kcd** |
| HID luminaire medium spot (HIT 70W ) | HCI | 6600 lm | 4535 lm | 16 kcd |
| Standard COB LES∅15mm (high) | COB | 2000 lm | 1800 lm | 32 kcd |
| Standard COB LES∅15mm (flat) | COB | 2000 lm | 1900 lm | 31 kcd |
| Standard COB LES∅22mm (high) | COB | 4000 lm | 3600 lm | 27 kcd |
| Standard COB LES∅22mm (flat) | COB | 4000 lm | 3800 lm | 17 kcd |
| SSL4EU LES∅9mm (COB 42W, high) | COB | 4000 lm | 3600 lm | 59 kcd |
| SSL4EU LES∅9mm (COB 42W, flat) | COB | 4000 lm | 3800 lm | 47 kcd |

| Name | Type | Lamp flux | Luminaire flux | Center Intensity |
|---|---|---|---|---|
| HID luminaire super spot I (HIT-CE 70W) | HCI | 3900 lm | 2079 lm | **39 kcd** |
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| HID luminaire spot (HIT 70W ) | HCI | 6600 lm | 4201 lm | **29 kcd** |
| HID luminaire medium spot (HIT 70W ) | HCI | 6600 lm | 4535 lm | 16 kcd |
| COB LES∅15mm (high) | COB | 2000 lm | 1800 lm | 32 kcd |
| COB LES∅15mm (flat) | COB | 2000 lm | 1900 lm | 31 kcd |
| COB LES∅22mm (high) | COB | 4000 lm | 3600 lm | 27 kcd |
| COB LES∅22mm (flat) | COB | 4000 lm | 3800 lm | 17 kcd |
| SSL4EU LES∅9mm (COB 42W, high) | COB | 4000 lm | 3600 lm | 59 kcd |
| SSL4EU LES∅9mm (COB 42W, flat) | COB | 4000 lm | 3800 lm | 47 kcd |

***Figure 15 Collimation comparison***

The upper results showed that the SSL4EU light engine is a high luminance light engine for highly intensive spots with small reflectors. To make this light engine even more attractive for our customers we investigated new possibilities to make a spot light luminaire with even no reflector. Figure 16 shows the latest development within the SSL4EU project: a microlens optic for the SSL4EU light engine. This solution perfectly retrofits a medium spot light with a beam angle of 26°, shown in the light intensity distribution in fig. 17.

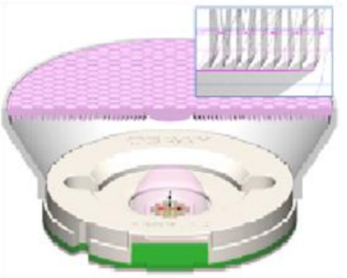

***Figure 16 Microlens optic***

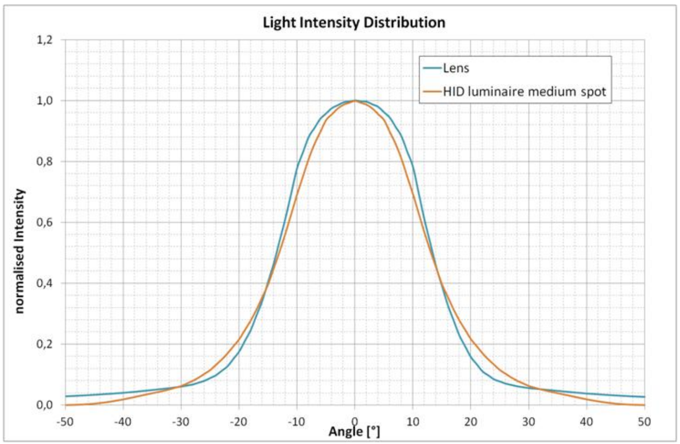


***Figure 17 Light intensity distribution for a medium spot and for the microlens solution***

## *WP3 luminaires*

For the final luminaire with the 88 chip light engine from WP1 (light emitting surface diameter: 13mm) and the three channel driver from WP2.1 a system efficacy of more than 100 lm/W has been measured for 4400lm output.


***Figure 18 Final spotlight demonstrator***

## *WP4 Acceptance studies*

WP4 of the project deals with Acceptance studies. The general aim of WP4 is the following:

1. To find user preferences for room lighting with different light levels, lighting distribution and colour characteristics with respect to office, residential and shop lighting.
2. To find correlations between light intensity and spectrum for different activities in the room.
3. To determine optimum light source spectral power distribution (SPDs) for different human tasks, as well as for living and working situation.

Three groups are working together to achieve these goals: Aalto University in Finland, Pannon University in Hungary and OSRAM OS in Germany. At all three locations first booth experiments were performed to get information on preferred spectra, then – based on these investigations full scale room models were built with widely changeable illumination.

<u>Test facilities</u>

At Aalto University two test office rooms were established, where in one of them traditional fluorescent lamp lights were installed, in the other one LED luminaires in which spectral distribution could be varied in 20 channels. Figure 19 shows the two identical test office rooms with different illumination, where two office environments were built up, one for desk-top work and one for a meeting environment.

a) b)

***Figure 19 Full scale experiment rooms: a) room illuminated with fluorescent lamp; b) room illuminated with LEDs***

At University of Pannonia also two test rooms have been set up, but here for home environment: one room was furnished as a living room, and the other as a kitchen and dining area. Figure 20 shows parts of these two model rooms. In these rooms illumination could be set by using similar 20 channel LED luminaires as at Aalto, and incandescent light luminaires equipped with tungsten halogen lamps of 3000 K correlated colour temperature in the living room environment and halogen incandescent lamps with cold mirror reflectors with 4000 K correlated colour temperature in the kitchen/dinging room area.

***Figure 20 Living room and kitechn/dining area mock-up at University of Pannonia***

At OSRAM OS experiment were carried out for commercial enterprises. To investigate full scale vegetable displays a salad-bar in the canteen of the enterprise was illuminated for longer periods with different lights: traditional fluorescent lights and two types of LED luminaires.

***Figure 21 Salad bar in a typical setup during lunch time***

As a second experiment a clothing department store display was mimicked. For this display one of the full-scale mock-up rooms at the University of Pannonia was used. Here four mannequin were dressed with colourful garments and observers had to rate the different illumination scenarios for vividness and preference.

***Figure 22 Setup of experimental room - Shop environment with four mannequin***

Experiments and results

Light source spectral were constructed according different colour appearance metrics. Metrics tested included several forms of the NIST Colour Quality Scale (Qp, Qg), the Feeling of Contrast Index (FCI), and naturally as reference the CIE CRI. A high number of observers filled in Questionnaires where questions like vividness, naturalness, pleasantness were asked.


## Aalto experiments

The full scale Experiments clearly showed that for different tasks different spectral power distributions are optimal. Figure 23 shows, as an example, how observers rated for different questions (overall appearance, naturalness, colourfulness) the different illuminations in the office environment at the work desk and the meeting table.

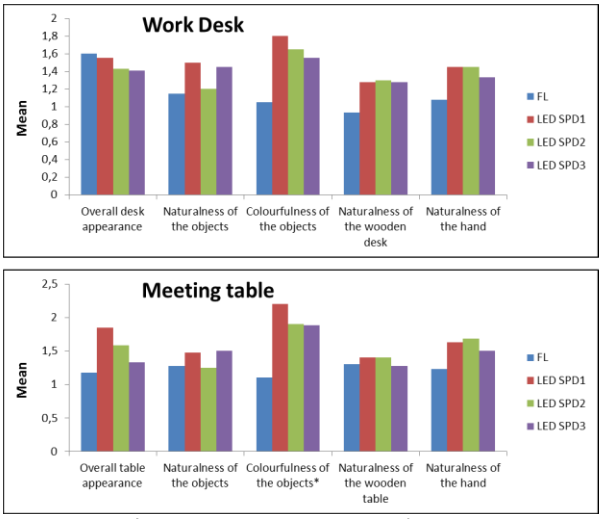


***Figure 23 Observer's mean rating for naturalness, and appearance of objects at work desk and meeting table under fluorescent SPD and LED SPDs at 4000K and 500 lx level***

Figure 25 shows the colour characteristics of the LED SPDs and fluorescent lamp at 4000 K. Compared to the reference fluorescent lighting in this experiment the LED SPD No. 1 and 2 were definitely preferred. The results confirm the outcome of the booth experiments: the Qp, Qg and FCI metrics correspond best to the visual observations.

| | CCT[K] | Duv | Ra | R9 | CQS v7.5 | CQS v9.2 | Qp v7.5 | Qg v7.5 | FCI |
|---|---|---|---|---|---|---|---|---|---|
| LED SPD1 | 4089 | -0.0042 | 79 | 56 | 84 | 83 | 98 | 117 | 145 |
| LED SPD2 | 4089 | 0.0036 | 80 | 58 | 86 | 87 | 97 | 113 | 141 |
| LED SPD3 | 4026 | -0.0033 | 82 | 48 | 86 | 85 | 96 | 111 | 132 |
| FL 4000 K | 3800 | 0.0047 | 81 | 7 | 80 | 81 | 80 | 96 | 105 |

***Figure 24 Colour characteristics of the LED SPDs and fluorescent SPD at 4000 K***

SPD1 and SPD2 are realized with several different LED colors. Making a commercial product is difficult because LEDs with different emission wavelength usually have a different temperature characteristic. That means if temperature changes the color point shifts significantly. Therefore an expensive control electronic with optical control loop is necessary. Therefore SPD3, realized by two blue LEDs (one with greenish phosphor) and one red one, has been developed and tested. As one can see, even with such a simplified spectrum some very promising visual results can be achieved.

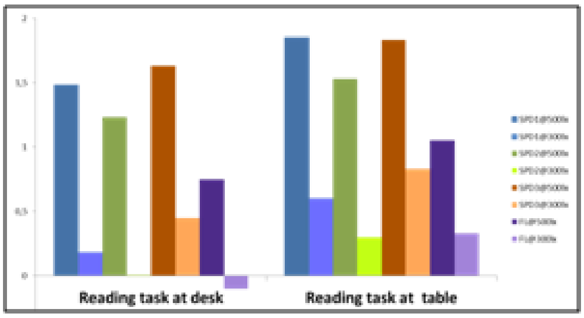


***Figure 25 Observer's mean rating for perceived brightness of lit environment under fluorescent SPD and LED SPDs at 4000K at two illuminance levels (500lx and 300lx)***

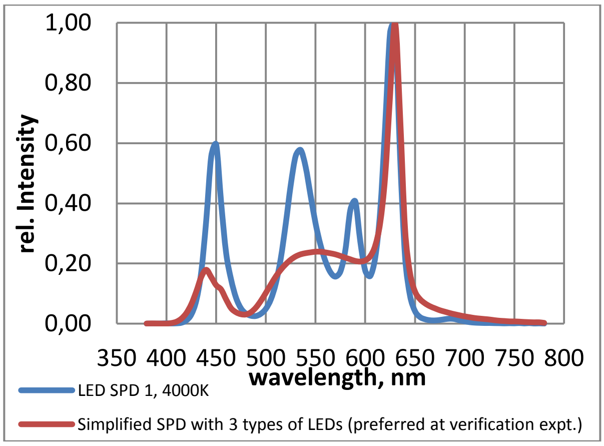


***Figure 26 Best LED spectrum (LED SPD1) and simplified SPD (LED SPD3) with 3 types of LED at 4000 K***

Beside the question about light quality the full scale study also tested the perceived brightness of different SPDs. Although different light sources can have the same luminous flux the perceived brightness can be very different. Figure 24 shows the observers mean ratings for the different SPDs at 4000K. The result clearly shows that the LED SPDs are much brighter than the fluorescent SPD. It is interesting to note that for the lower


illuminance at 300lx the simplified 3-LED SPD is the brightest one.

Verification experiments were conducted at Aalto to compare the preferred spectra from Aalto booth experiment with simplified SPD (but having similar color quality values as Aalto preferred spectra). From the results it can be seen that simplified SPD, although being more efficient, simpler, and cost effective, provided similar or better colour quality compared to the complex preferred spectra. Figure 27 shows the most often used colour quality metric values for most preferred SPD at office lighting experiments and simplified SPD preferred at verification experiment.

| | LED SPD 1, 4000K (Most preferred at full scale expt.) | Simplified SPD at 2700 K with 3 types of LEDs (preferred at verification expt.) |
|---|---|---|
| Duv : | -0,004 | -0,005 |
| CRI Ra : | 79,2 | 86,4 |
| R(9-12) : | 61,7 | 80,6 |
| R9 : | 56,4 | 66,8 |
| CQS Qa : | 83,2 | 86,8 |
| Qf (without saturation factor) : | 78,6 | 83,0 |
| Qf2 (without saturation factor, simple average) : | 78,8 | 83,2 |
| Qp (credit increase of chroma) : | 93,6 | 95,6 |
| Qg : | 117,1 | 114,0 |
| FCI : | 145,5 | 142,2 |

***Figure 27 Comparison of most often used colour quality descriptors for two optimal office lighting LEDs***

Related publications for more information:
1. R. Dangol, P. Bhusal, M. Puolakka and L. Halonen. Subjective preferences for LED lighting in offices. Proceedings of CIE Centenary Conference “Towards a New Century of Light” CIE Central Bureau, Paris, April 15 -16, 2013, pp. 733-741
2. M. Islam, R. Dangol, M. Hyvärinen, P. Bhusal, M. Puolakka, and L. Halonen. Investigation of user preferences for LED lighting in terms of light spectrum. Lighting Research and Technology, published online 20 February 2013, DOI: 10.1177/1477153513475913
3. R. Dangol, M. Islam, M. Hyvärinen, P. Bhusal, M. Puolakka, and L. Halonen. Subjective preferences and colour quality metrics of LED light sources. Lighting Research and Technology, published online 4 January 2013, DOI: 10.1177/1477153512471520.

## Pannon University experiments

From the results of small scale experiments, it was clearly concluded, that gamut area and feeling of contrast index influences users preference and visual comfort in a room. The other important conclusion was that describing of light source colour quality is not possible with only single number: two (or more) light sources with same colour quality descriptor (i.e Ra) can result different visual appearance of objects, thanks to their different spectral power distribution. From the results of small scale studies, two major directions of research raised:

1. To find the correlation between gamut area (feeling of contrast) and users feelings of vividness, naturalness and preference. In order to investigate this phenomenon, test SPDs have been generated with same light intensity, same CCT and colorimetric parameters, but having different FCI values: 110, 120, 140, 150, 160.

2. After identifying the optimal feeling of contrast in experimental series 1, the aim of the other part of research was to investigate the dependence of users feeling of vividness, naturalness and preference in case of lights having different spectral power distributions, but having the same feeling of contrast (FCI) value. Test spectra with different short wavelength blue and long wavelength red LED light constructed keeping also the FCI at the 140 level. With this technique a source could be established that provide best preference in the living room environment (LC-5 spectrum), and in the kitchen/dining room environment (KC-5). Figure 28 provides the colour quality indices for these two sources. As could be expected the CIE colour rendering index (an index to describe colour fidelity not preference!) is relatively low for these sources. Again the different preference metrics do not differ from each other to be able to choose one against the other.

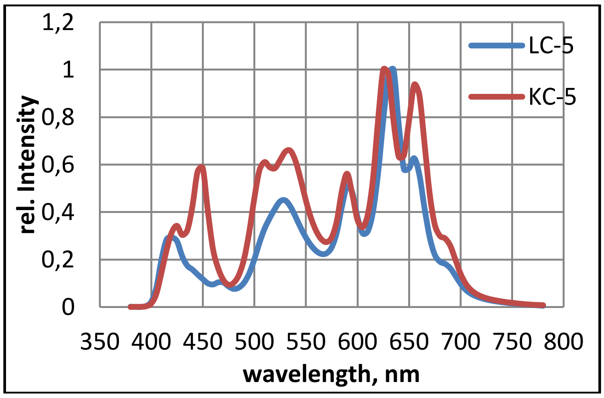


***Figure 28 Optimal spectral for living room and for dining room/kitchen environments***

| | **Living room Constant FCI LC-5** | **Kitchen Constant FCI KC-5** |
|---|---|---|
| CCT | 2981 | 4077 |
| Duv : | -0.0018 | -0.0010 |
| CRI Ra : | 79 | 76 |
| R(9-12) : | 61 | 58 |
| R9 : | 38 | 5 |
| CQS Qa : | 83 | 83 |
| Qf (without | 79.82 | 78.56 |

| | | |
|---|---|---|
| saturation factor) : | | |
| Qf2 (without saturation factor, simple average) : | 80.45 | 78.78 |
| Qp (credit increase of chroma) : | 91.70 | 93.25 |
| Qg : | 113.06 | 116.68 |
| FCI : | 142.34 | 140.04 |
| CRI2012 | 85 | 88 |

***Figure 29 Colour quality indices for the best living room and kitchen/dining area lights***

Related publications for more information:

1. F. Szabó, P. Csuti, J. Schanda, Spectrally tuneable LED lighting simulator laboratory room at University of Pannonia, Lumen v4, 2012, Bratislava, Slovak Republic
2. P. Csuti, F. Szabó: Preferred home lighting design, CIE Centenary Conference 2013: Towards a New Century of Light, Paris, France
3. F. Szabó, P. Csuti, J. Schanda: Spectrally tuneable LED Lighting Simulator Laboratory Room at University of Pannonia, Przeglad-Elektrotechniczny 2013, ISSN 0033-2097

### Osram OS experiments

In shop lighting the salad bar lighting was changed from a fluorescent lamp lighting to two different LED lights, one with a very high CIE colour rendering index, and one with high colour preference index. In this study not observers had to compare the different lighting situations, but the question was whether the different lightings will increase or decrease the sales of the salad dishes. This is a much more subtle question, thus the replies had naturally a much larger scatter. Figure 30 shows results of over 18 months of data gathering. Although after the use of the conventional lighting (June-Nov. 2012) sales figures increased for the high fidelity and high preference lighting, the data are still not statistically significant.

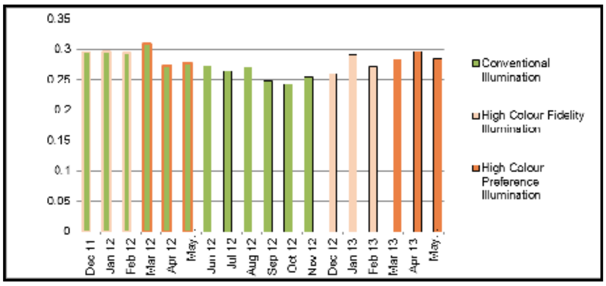


***Figure 30 Sales numbers of salads per person for each month***

For the illumination of the different dresses two series of investigations were performed: keeping the Ra value high, and changing the wavelength of the used blue LED, and keeping the Ra at 80 using lights with different FCI value. In all cases reference was a simulated incandescent light of 2975 K, with an Ra value of 95. The absolute winner was a light with FCI=140 and Ra 80.

The best spectra for the salad-bar and the shop lighting illumination are seen on Figure 31. The corresponding colour quality data are summarized in Figure 32.

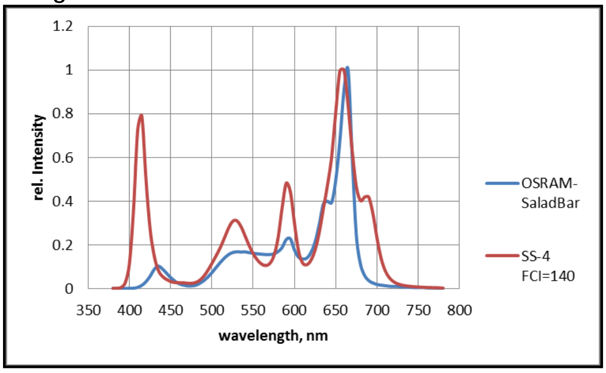


***Figure 31 Spectra for best salad bar and shop lighting illumination***

| | OSRAM-SaladBar | Shoplighting FCI=140, újraszámolva |
|---|---|---|
| CCT | 2700 | 3000 |
| Duv : | 0,0011 | -0,00388 |
| CRI Ra : | 80,0 | 80,0 |
| R(9-12) : | 64,0 | 53,1 |
| R9 : | 14,7 | 29,7 |
| CQS Qa : | 84,3 | 76,5 |
| Qf (without saturation factor) : | 80,6 | 72,9 |
| Qf2 (without saturation factor, simple average) : | 80,5 | 73,9 |
| Qp (credit increase of chroma) : | 93,3 | 87,2 |
| Qg : | 112,0 | 114,9 |
| FCI : | 146,1 | 140,0 |

***Figure 32 Colour quality values for the best spectra for the salad-bar and the shop lighting***

### Summary and conclusions

Main task in the three laboratories was to check in full-scale experiments the best preferred light source for the different tasks.

For a living room environment a light source (LC5) with an FCI of 142, with a correlated colour temperature of 2981 K and Ra = 79, Qa = 83 was found to be optimum. For the kitchen/dining room area a slightly lower FCI value seemed to be optimum (FCI=140, see KC5)at a 4077 K CCT. This optimum source had an Ra of 76 and Qa of 83.

Experiments showed that for the 4000 K group it was possible to construct an LED module containing only three types of LEDs, a mint one and two narrow spectra LEDs of 448 nm and 658 nm peak wavelength, that gave for some situations even more preferred values as the original SPD from which it has been modified. For this spectrum it was also found that observers had


the same feeling of amount of light in the room for lower illumination as with the fluorescent lighting.
In the shop lighting experiments tests were conducted for food lighting with lights of different colour preference. Direct visual experience in a salad bar environment showed considerable difference and nicer view for the high colour preference lighting, but in the sales figures this could not been proved till now, due to the high scatter of the sales figures.
For the textile samples a direct preference experiment was performed that showed that sources producing higher vividness were preferred. None of the known colour preference metrics described the results perfectly, and supplied comparative results.

## LEDs Events
## Innovation in a historic environment – SSL4EU Workshop in Regensburg


**Figure 33** ***The SSL4EU Workshop poster with logos of the project partners***

80 Participants from 51 companies out of 7 European countries followed the invitation and participated at the second SSL4EU Workshop which was hosted on June 20$^{th}$ 2013 in Regensburg. The workshop was held to disseminate the findings and results to the companies who are active in the field of solid state lighting in Europe.


***Figure 34 Presentations by SSL4EU partners***

***Figure 35 Presentations by SSL4EU partners***

After a short introduction of the SSL4EU project, its structure and the partners, the participants got a detailed and informative update on the current state of light engine design for spotlights followed by the superior results which could be achieved with the SSL4EU light engine concept. Since the currently available tunable white solutions are already requiring multiple colours and channels the talks about the electronic driving solution as well as the colour mixing optics are followed with great interest.
Colorimetrie, colour rendering and colour preference was the focus of the afternoon session. The words were not new to the audience but the latest developments in the field of colour measurement and especially the results of the acceptance study and the impact of light on the perception were followed with great curiosity and fascination.
During the complete day, and even during the talks, the participants had deep discussions with the project partners, the exhibitors of SSL related products like optics, drivers, thermal solutions and of course among each others.

**Figure 36** ***Time for exchanges and networking***

The day was a complete success with great opportunity for exchange and networking within the Solid State Lighting community. This unique opportunity to disseminate the project results surely initiated new innovations in Europe.

## LEDs News

LPI members R. Mohedano and J. Chaves are Co-chairs of the new Non Imaging Optical Design Technical group, belonging to the Optical Society of America (http://www.osa.org/en-us/communities/technical_communities/fdi/nonimaging_optical_design/). The public activities of this group started with Kick-off Webinar, held in June 18th, 2013, where three prestigious specialists in the field of Nonimaging Optics gave a glimpse of their view of this field.

The Zhaga Consortium and the Global Lighting Association will partner to distribute information about Zhaga LED light engine standards, and the organization has begun certification for Books 4, 7, and 8 covering more LED lighting applications.
Source:
http://ledsmagazine.com/news/10/6/12
http://www.zhagastandard.org/news/46/zhaga-starts-certification-for-books-4-7-and-8

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