Measured color changes under fluorescent and LED lamps

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1. INTRODUCTION

In the field of electric lighting, the increasing popularity and spread of the LED sources, together with the availability of traditional lamps with different spectral characteristics, compels the designer to consider in his choices not only aspects related to energy saving, but also to take into account lighting quality, meaning for it a correct and pleasant perception of the surrounding environment [1],[2],[3].

Once fixed the values of illuminance and luminance distributions, the parameters that characterize the sources regarding quality of light, according to European Standard EN 12464-1[4], and that strongly influence the perception of objects and colors are the color appearance, identified by Correlated Color Temperature (CCT), and Color Rendering Index (CRI). However in presence of sources with similar CCT and CRI but with different Spectral Power Distributions (SPD), different perceptual effects occur [5],[6],[7].

In this paper, the effects of two kind of sources, fluorescents and LEDs, both with high CRI, are examined by means of color measures on different objects.

2. EXPERIMENTAL SET-UP

2.1. DESCRIPTION OF THE TEST ROOM AND LIGHT SOURCES

The test room is quite 3.00m x 3.00m x 3.00m with completely blank walls (ρ_M = 70%) and a false ceiling with controlled lights. The furniture consists in a desk with a chair centrally located in respect to the lights. Luminaires consist in 2 fluorescent and 4 LED sources. Technical characteristics of each LED and fluorescent source provided by manufacturer are shown in the Table 1.

Table 1 – Technical characteristics of luminaires

	Fluorescent	LED
Lamp	4xT16/24W	1x1824/27W
Luminous flux	7000 lm	1824 lm
Efficacy	49 lm/W	64 lm/W
CRI	1B (80<Ra<90)	90-91

For the characterization of the sources, a Konica-Minolta CS2000 spectroradiometer was used; the instrument was pointed towards the lamps to obtain the SPDs.

2.2. DESCRIPTION OF LIGHT SCENES

Table 2 – Light scenes set-up

	CCT [K]	Dim [%]	E_m [lux]
Fluo 2700K	2924	100	653
Fluo 3000K	3011	93	549
Fluo 4000K	4178	94	558
Fluo 6500K	7100	100	621
LED 2900K	2940	97	634
LED 3150K	3020	94	545
LED 4200K	4199	95	548
LED 6100K	7195	100	628

Lights are connected to Luxmate Emotion information system by Zumtobel. Thanks to this device, it was possible to dim both lighting emissions and change color temperature, in order to obtain 8 light scenes with similar illuminance values on the desk, measured with 2 Konica-Minolta T10 lux meters centrally

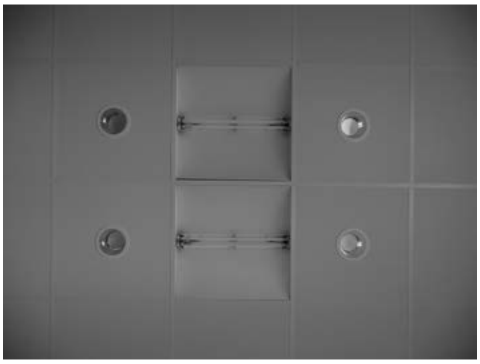


Figure 1 – Test room
Figure 2 – View of the false ceiling

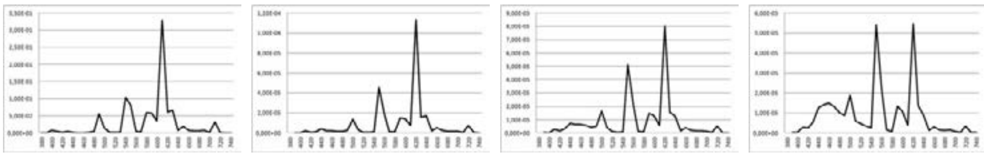


Figure 3 – SPD Fluorescent 2700K (A), 3000K (B), 4000K (C) and 6500K (D).

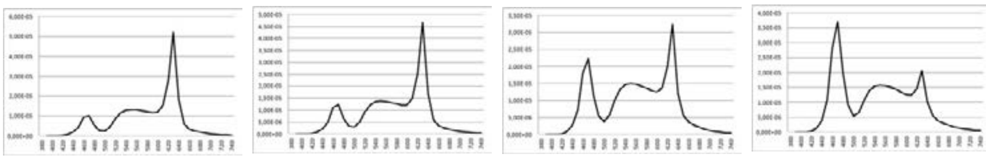


Figure 4 – SPD LED 2900K (A), 3150K (B), 4200K (C) and 6100K (D).

located in respect to the lights.

The following analyses have shown that light scenes with intermediate CCT (Fluo 3000K, Fluo 4000K, LED 3150K and LED 4200K) reported results less interesting than the other scenes: so only the results of Fluo 2700K and 6500K, LED 2900K and 6100K will be shown. As in Table 2, Fluo 2700K and LED 2900K scenes have nearly the same measured CCT, as also Fluo 6500K and LED 6100K: since now, *"warm lights"* will be referred to first ones while *"cold lights"* will be referred to second ones.

2.3. DESCRIPTION OF COLORED OBJECTS

On the desk 6 different colored objects (LEGO® blocks) were placed: blue, light blue, green, yellow, orange, red. For each one of them, spectral reflectance and color coordinates under illuminant D65 were measured.

3. ANALYSIS AND RESULTS

3.1. SPECTRAL DISTRIBUTION OF REFLECTED LIGHT ANALYSIS

Spectral reflectance of each colored object was measured with the spectrophotometer; lamps' SPDs were obtained with the spectroradiometer while spectral distribution of reflected light was obtained pointing the spectroradiometer on each colored object under each light scene. Results are reported in figures 5 – 10 in which not all but just the most interesting cases were represented.

For each figure, diagrams corresponding to (C) show clearly that they are the result of the combination of the previous two: where the block's spectral reflectance increases or decreases the value of emitted light for those wavelengths in the reflection diagram is

Table 3 – Color coordinates of LEGO® blocks

	Specular component					
	included			excluded		
	L^*	a^*	b^*	L^*	a^*	b^*
Blue	45.68	-7.48	-41.96	42.35	-8.55	-44.87
Light blue	63.76	-11.01	-27.64	61.34	-11.79	-28.95
Green	60.43	-51.72	36.90	57.98	-56.32	40.75
Yellow	80.84	8.48	78.32	79.15	8.65	85.39
Orange	66.60	45.37	55.38	63.63	47.94	65.07
Red	42.93	50.12	32.00	30.09	55.06	40.00

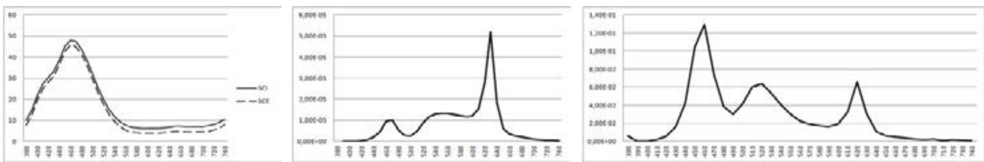


Figure 5 – Blue block spectral reflectance (A), LED 2900K SPD (B) and spectral distribution of reflected light (C). According to the spectral reflectance, in all light scenes red component is reduced while blue one is maximized, even with warm lights as shown in the example.

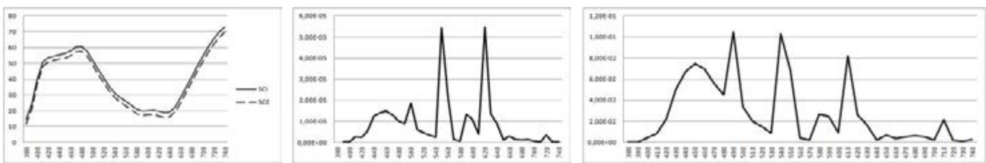


Figure 6 – Light blue block spectral reflectance (A), Fluo 6500K SPD (B) and spectral distribution of reflected light (C). Spectral reflectance shows high values of both blue and red component, increasing block's reflection values in low and high wavelengths.

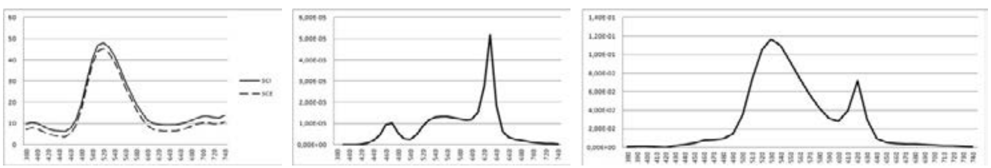


Figure 7 – Green block spectral reflectance (A), LED 2900K SPD (B) and spectral distribution of reflected light (C). Green component of all lights' SPDs is maximized while blue and red ones are reduced, especially with LEDs.

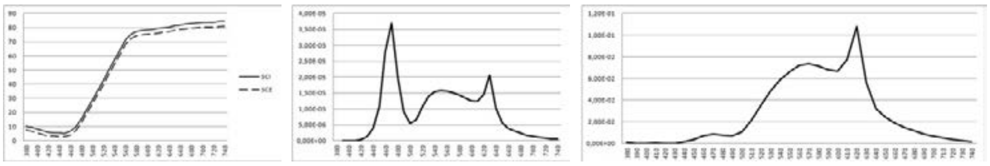


Figure 8 – Yellow block spectral reflectance (A), LED 6100K SPD (B) and spectral distribution of reflected light (C). In these cases, the only notable change between lamps' SPDs and reflection diagrams is the reduction of the blue component.

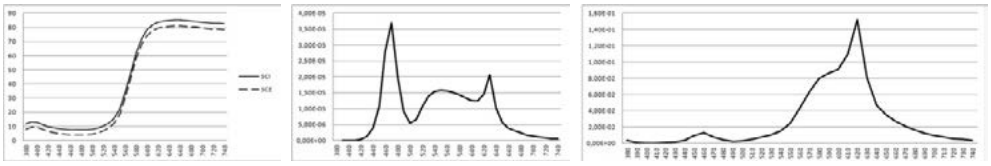


Figure 9 – Orange block spectral reflectance (A), LED 6100K SPD (B) and spectral distribution of reflected light (C). As for the yellow block, in the reflection diagrams it's just the blue component of lamps' SPDs to be reduced.

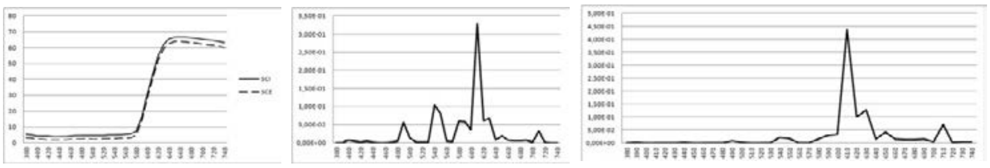


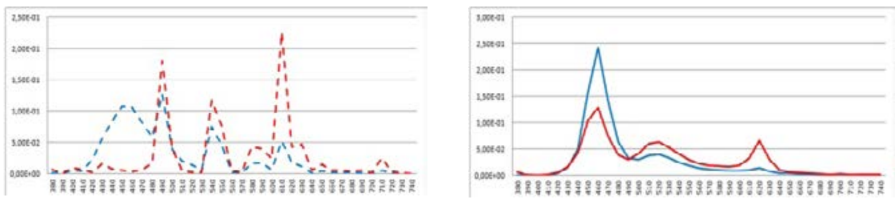
Figure 10 – Red block spectral reflectance (A), Fluo 2700K SPD (B) and spectral distribution of reflected light (C). The red block case is similar to the yellow and orange ones.

amplified or reduced.

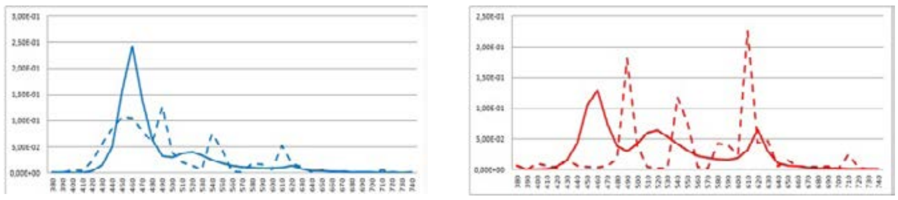
As general rule, we can say that: blue prefers cold lights; light blue is better under cold lights but it doesn't change too much with the other light scenes; green prefers cold lights; yellow is better under warm lights; orange and red are good under every kind of light.

3.2. CCT AND TECHNOLOGIES COMPARISONS

After that, for each color two different comparisons were made: Correlated Color Temperature with the same technology and technology comparison with the same CCT. This analysis helped to find the best and the worst kind of light for each color.



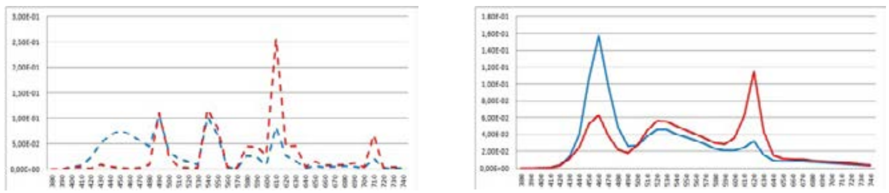
CCT comparison for blue



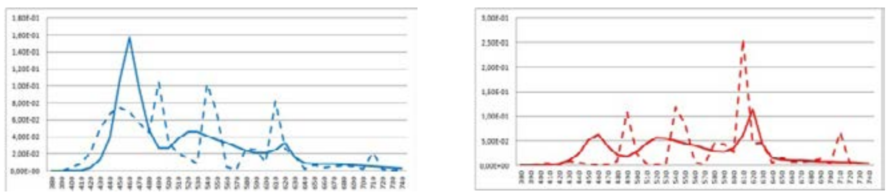
Technologies comparison for blue

Fluo 2700K   Fluo 6500K   LED 2900K   LED 6100K

Figure 11 – Fluo 6500K lamp has a wide range of blue wavelenghts while Fluo 2700K lamp have peaks in other colours; LEDs have quite the same trend but with higher values for blue and lower for red compared to the fluorescent sources. Cold lights are preferred, with LED 6100K as best source and Fluo 2700K as worst.



CCT comparison for light blue



Technologies comparison for light blue

Fluo 2700K   Fluo 6500K   LED 2900K   LED 6100K

Figure12 – As for blue, in light blue reflection diagrams fluorescent sources have other colour components while LEDs don't have the previous trend, with LED 2900K having a peak in red. Technologies comparison shows how all the lights cover a wide range of wavelenghts with a preference for LED 6100K.

Figure 13 – CCT comparison shows how lights with the same technology have quite the same trend for green. However it's possible to observe how cold lights have more green component than warm lights that increase red component. In this case Fluo 6500K has a peak in green wavelenghts more than LED as in previous cases

CCT comparison for green

Technologies comparison for green

– – Fluo 2700K – – Fluo 6500K —— LED 2900K —— LED 6100K

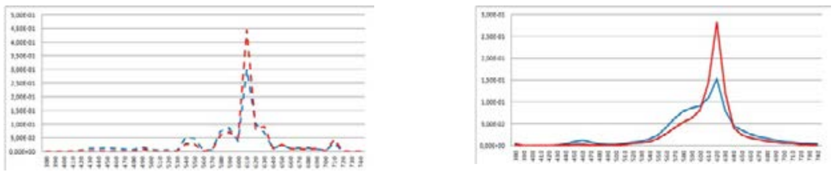
Figure 14 – Considerations made about green reflection diagrams could be applied to yellow's too: CCT comparison shows how lights with the same technology have quite the same trend, with a preference for warm lights. In particular, technologies comparison shows how similar is the trend of the two sources.

CCT comparison for yellow

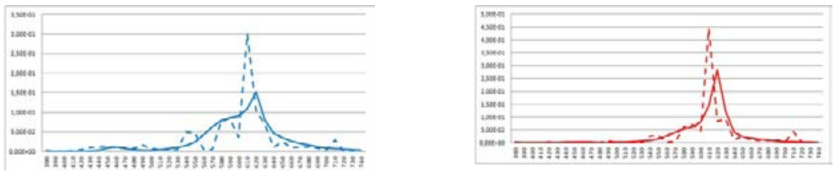
Technologies comparison for yellow

– – Fluo 2700K – – Fluo 6500K —— LED 2900K —— LED 6100K

Figure 15 – CCT comparison shows how lights with the same technology have quite the same trend for orange reflection but it's possible to see how cold lights have a wider range of wavelenghts than warm lights, in which orange and red component is maximized.



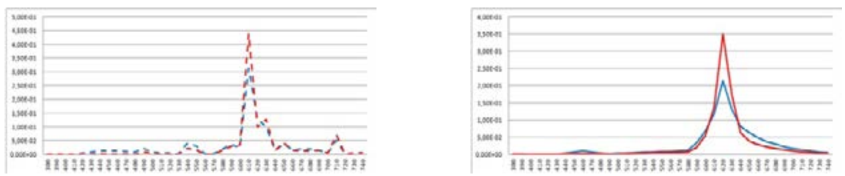
CCT comparison for orange



Technologies comparison for orange

– – Fluo 2700K – – Fluo 6500K —— LED 2900K —— LED 6100K

Figure 16 – Considerations made about orange reflection diagrams could be applied to red's: in this case too, warm lights should be preferred to cold ones.



CCT comparison for red

Technologies comparison for red

– – Fluo 2700K – – Fluo 6500K —— LED 2900K —— LED 6100K

3.3. CHANGES OF CHROMATICITY COORDINATES UNDER DIFFERENT LIGHT SCENES

CIE XYZ values of each colored object and XnYnZn of reference white were measured under each light scene and normalized by the reference white to calculate L*a*b* coordinates using CIELAB equations [8].

	L*	a*	b*	C^*_{ab}	h_{ab}
1.Fluo 2700K	40.74	-8.44	-32.79	33.86	1.32
2.Fluo 6500K	47.09	6.85	-73.70	74.02	-1.48
3.LED 2900K	34.53	-14.15	-65.54	67.05	1.35
4.LED 6100K	45.17	14.12	-60.83	62.45	-1.34

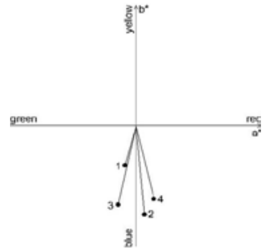


Figure 17 – L*a*b*coordinates, chroma and hue values of blue. As a general rule, fluorescent lamps give less redness-greenness to the perception of the colored object. Brightness is higher with cold lights. It seems that Fluo 6500K is the best one because it maximizes all values, in contrast with previous results (LED 6100K).

	L*	a*	b*	C^*_{ab}	h_{ab}
1.Fluo 2700K	60.43	-10.58	-16.84	19.88	1.01
2.Fluo 6500K	63.75	-7.45	-60.21	60.67	1.45
3.LED 2900K	58.57	-17.14	-38.36	42.01	1.15
4.LED 6100K	64.14	-3.68	-34.89	35.08	1.47

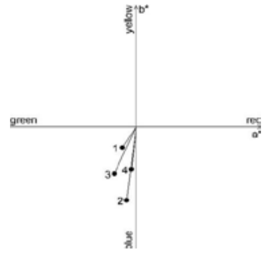


Figure 18 – L*a*b*coordinates, chroma and hue values of light blue. Brightness and hue are slightly higher with cold lights. Chroma is much more higher with Fluo 6500K.

	L*	a*	b*	C^*_{ab}	h_{ab}
1.Fluo 2700K	51.82	-46.39	40.21	61.39	-0.71
2.Fluo 6500K	31.51	-61.32	24.41	66.00	-0.38
3.LED 2900K	46.18	-61.33	37.27	71.77	-0.55
4.LED 6100K	48.58	-64.74	49.76	81.65	-0.65

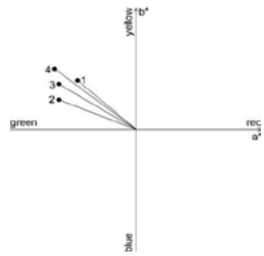


Figure 19 – L*a*b*coordinates, chroma and hue values of green. In this case, every light scene maximizes a different value, so it's not possible to define the best light, as it was noticed in the previous analysis.

	L*	a*	b*	C^*_{ab}	h_{ab}
1.Fluo 2700K	94.95	10.21	93.53	94.09	1.46
2.Fluo 6500K	83.97	-15.51	66.80	68.58	-1.34
3.LED 2900K	95.63	11.18	99.63	100.26	1.46
4.LED 6100K	90.14	-2.03	103.04	103.06	-1.55

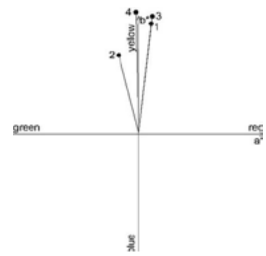


Figure 20 – L*a*b*coordinates, chroma and hue values of yellow. LED 6100K seems to be the best light since all the values are at their maximum, except for brightness that is maximized with warm lights. The only scene completely different from the others is number 2.

	L*	a*	b*	C^*_{ab}	h_{ab}
1.Fluo 2700K	90.49	50.73	76.57	91.85	0.98
2.Fluo 6500K	77.96	36.99	37.00	52.32	0.78
3.LED 2900K	91.74	49.75	87.60	100.74	1.05
4.LED 6100K	84.26	43.56	80.22	91.29	1.07

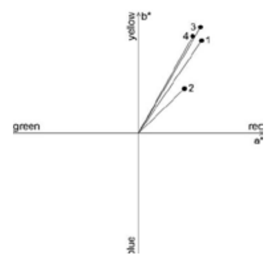


Figure 21 – L*a*b*coordinates, chroma and hue values of orange. As the graphic shows, there is not a big difference between scenes number 1, 3 and 4 (even if LED 2900K maximizes brightness and chroma), with the second scene different from the others once again.

	L*	a*	b*	C^*_{ab}	h_{ab}
1.Fluo 2700K	68.17	53.04	49.07	72.26	0.75
2.Fluo 6500K	56.54	40.84	15.46	43.66	0.36
3.LED 2900K	70.03	62.95	67.73	92.47	0.82
4.LED 6100K	58.95	58.80	51.42	77.11	0.72

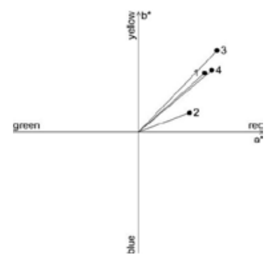


Figure 22 – L*a*b*coordinates, chroma and hue values of red. Looking at the values and the graphic, red is nearer to orange that to the red-a* axe: in this case too, LED 2900K maximizes brightness, a* value and chroma. Fluo 2700K and LED 6100K have good values too while Fluo 6500K is the worst light again.

The next diagrams are CCT and technology comparisons among the 4 scenes, showing all color coordinates for each light.

In the CCT comparison, warm lights tend to move to the yellow-red area, even if it's less evident for LEDs. In the second diagram, it's possible to note that LED 2900K reduces the distance among yellow, orange and red coordinates.

In the technology comparison, the diagrams have the same shape, with a bigger chromatic variety for LEDs. For cold lights, LED diagram is also moved towards yellow-red area.

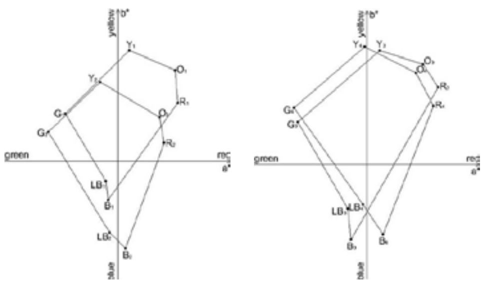


Figure 23 – CCT comparisons between Fluo 2700K and Fluo 6500K (A), LED 2900K and LED 6100K (B).

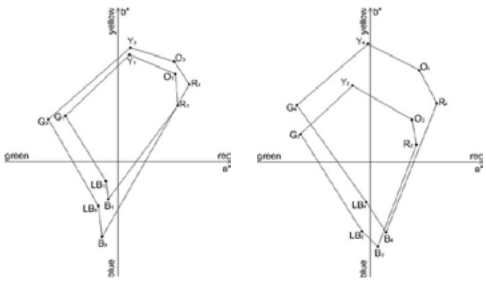


Figure 24 – Technology comparisons between Fluo 2700K and LED 2900K (A), Fluo 6500K and LED 6100K (B).

4. CONCLUSIONS

From the obtained results it can be inferred that:

- different lamps technologies with the same CCT produce different effects on colored objects;
- under the same technology, but with different CCTs, different effects are obtained as well.

Color differences regard chroma, hue and value and, under the same conditions, depend on the spectral reflectance of the considered object.

This study shows that the only use of parameters like CRI and CCT is not enough to evaluate effects on colored objects. Moreover, further research is necessary to compare these results to experimental evaluations.

ACKNOWLEDGEMENT

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