Investigation of colour rendering of white pc LEDs according to TM-30-15 and CIE-CRI-Ra

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Light is OSRAM

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Agenda

1.	Introduction
2.	Hypotheses
3.	Experimental Setup
4.	Results

Introduction

- LEDs become more and more the main light source for a lot of applications
- White light for indoor lighting is produced with phosphor converted LEDs
- With different phosphor combinations the spectral distribution can be tuned to achieve certain values in case of light quality
- To improve phosphor development it is neccessary to target the right value of a correct description of color quality
- A new way to describe color quality is the TM-30-15 from IES

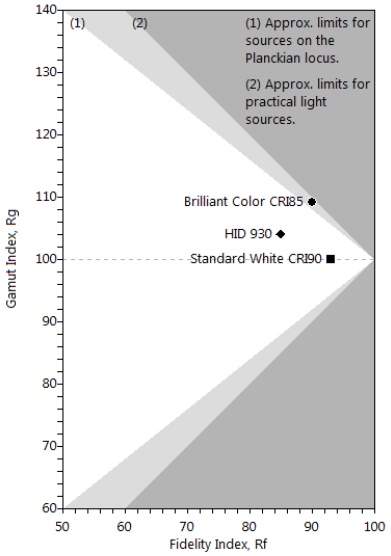
TM-30-15

- **Beside the latest scientific transformation formulas and color spaces the TM-30-15 provides two different indices:**

➢ ***R_f = Color fidelity index similar to CRI R_a***
➢ ***R_g = Color preference index based on color gamut***

- **By evaluating color fidelity and color preference at the same time one can analyze and judge the light quality of the light source.**

- **Compared to the CRI R_a the TM-30-15 R_f is using 99 test color samples instead of 8**



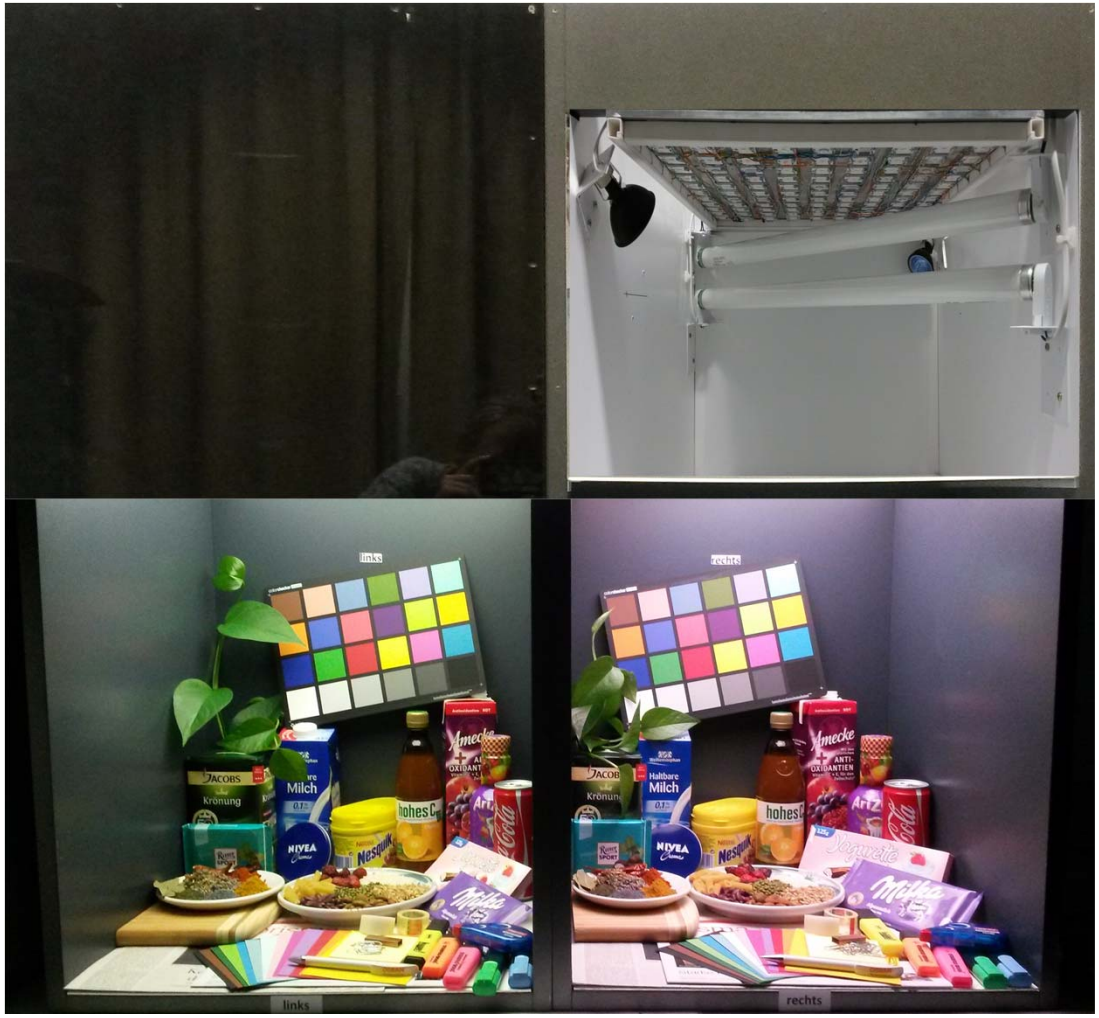
Investigations & Hypotheses

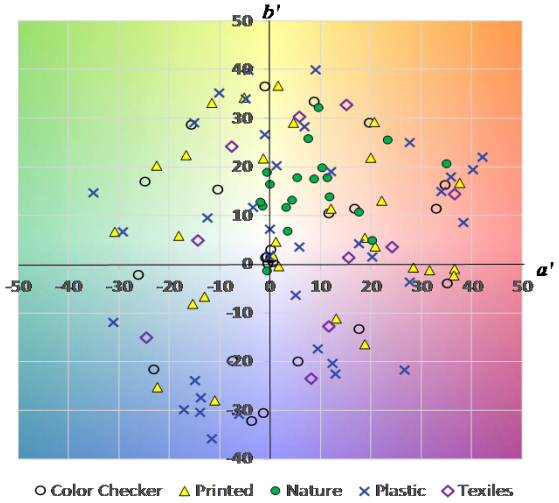
- **Results of a first investigation of ROYER showed that LED luminaires with a $R_f \geq 75$ and $R_g \geq 100$ are preferred by subjects**

Hypotheses:

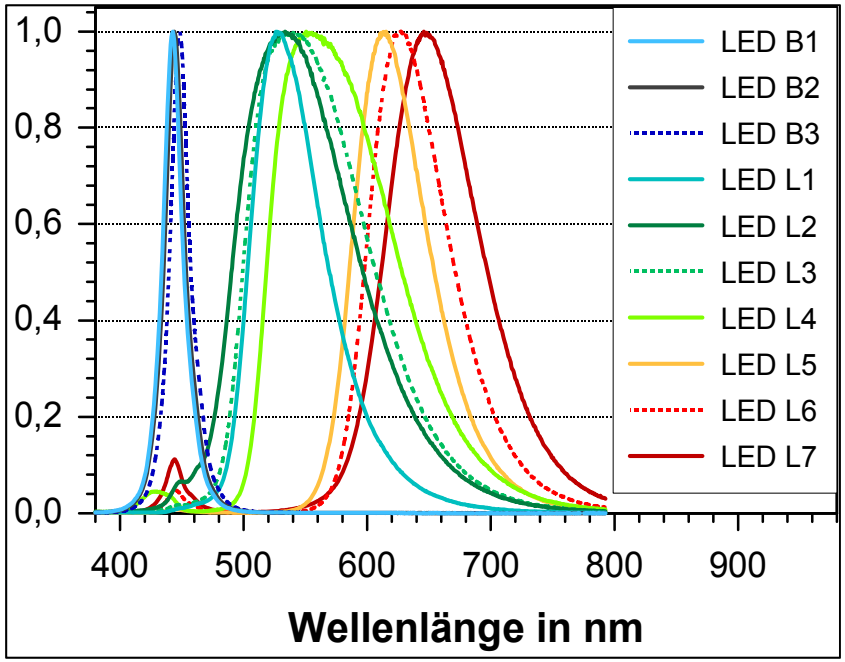
- **It is possible for phosphor converted LEDs to fulfill the recommendations of ROYER**
- **The R_f and R_g values will show a high correlation to the rating of color rendering by subjects**
- **In comparison to fluorescent lamps phosphor converted LEDs with identical R_f and R_g values will be preferred**

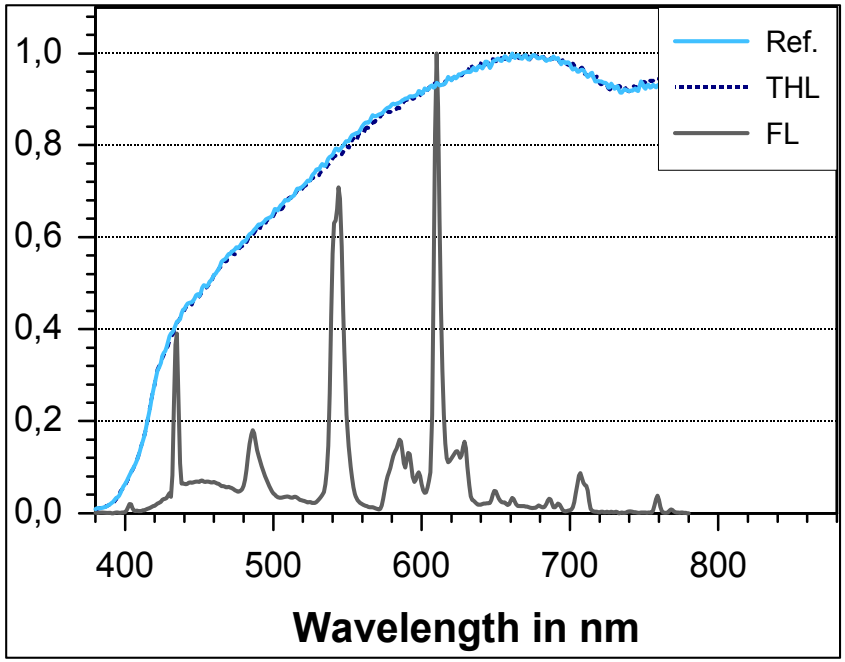
Experimental Setup





Spectral Distributions and Target Combinations





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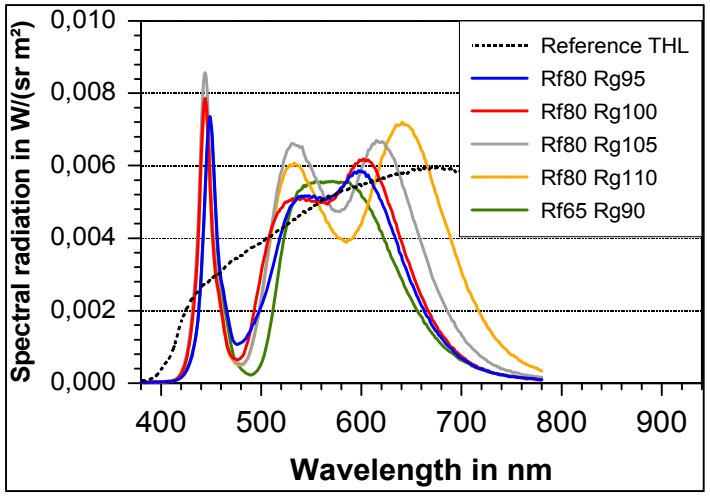
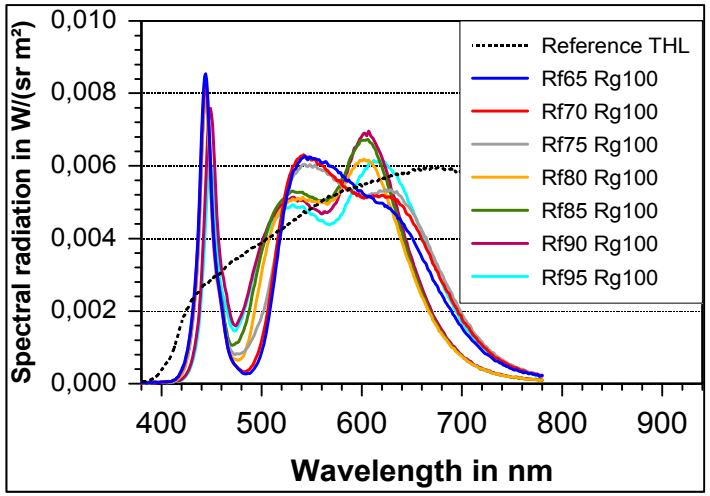
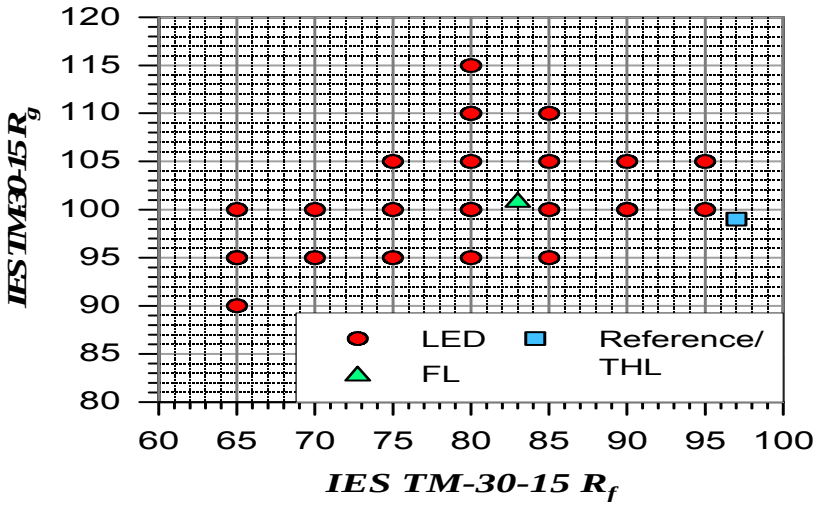






No.	21
R_f	66 – 97
R_g	92 – 114
CCT	3800K

Subject Study

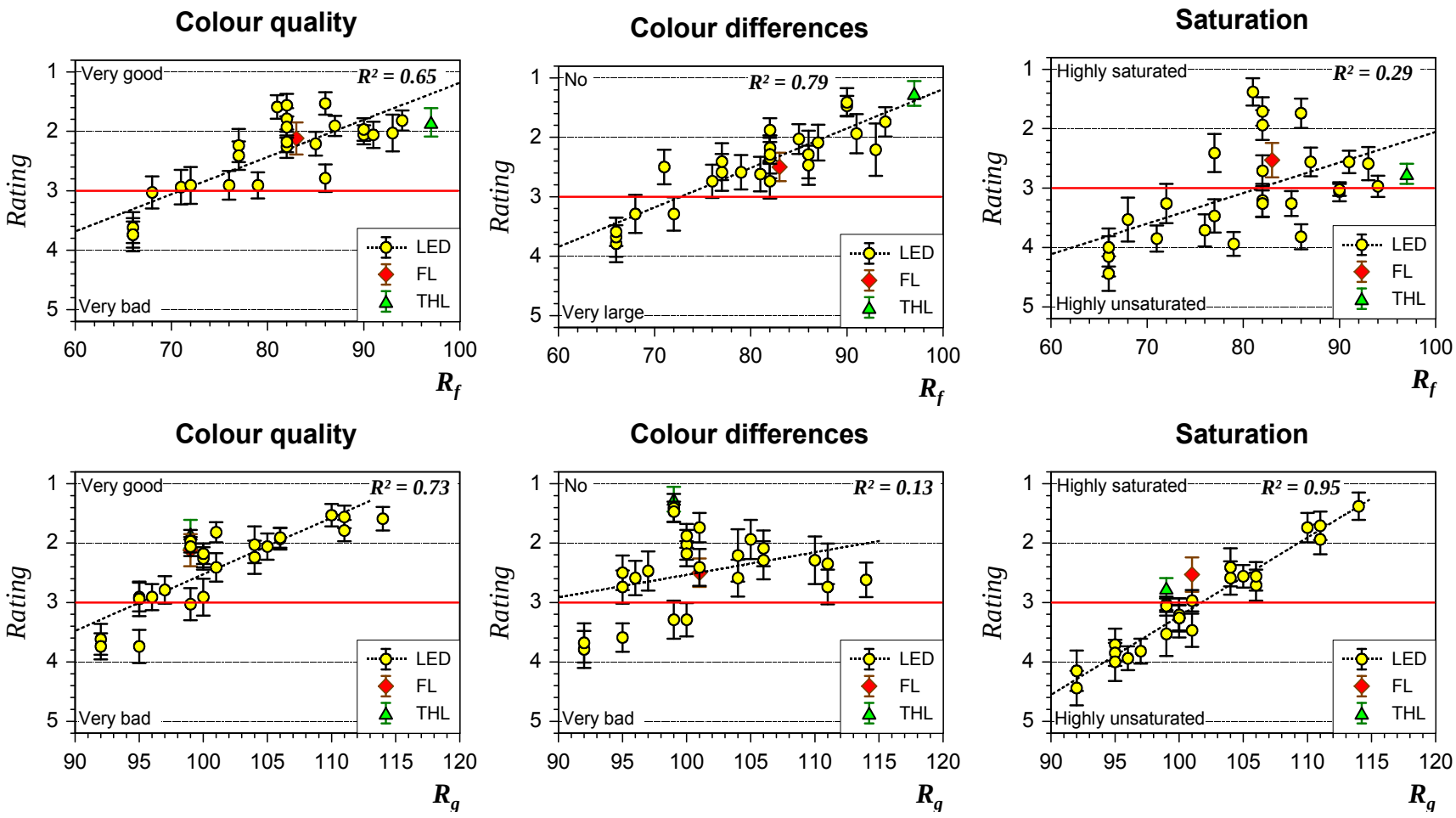
- **34 Subjects**
- **Age: 23 – 48 (∅ 35)**
- **10 female, 24 male**

In a questionnaire the subjects had to rate

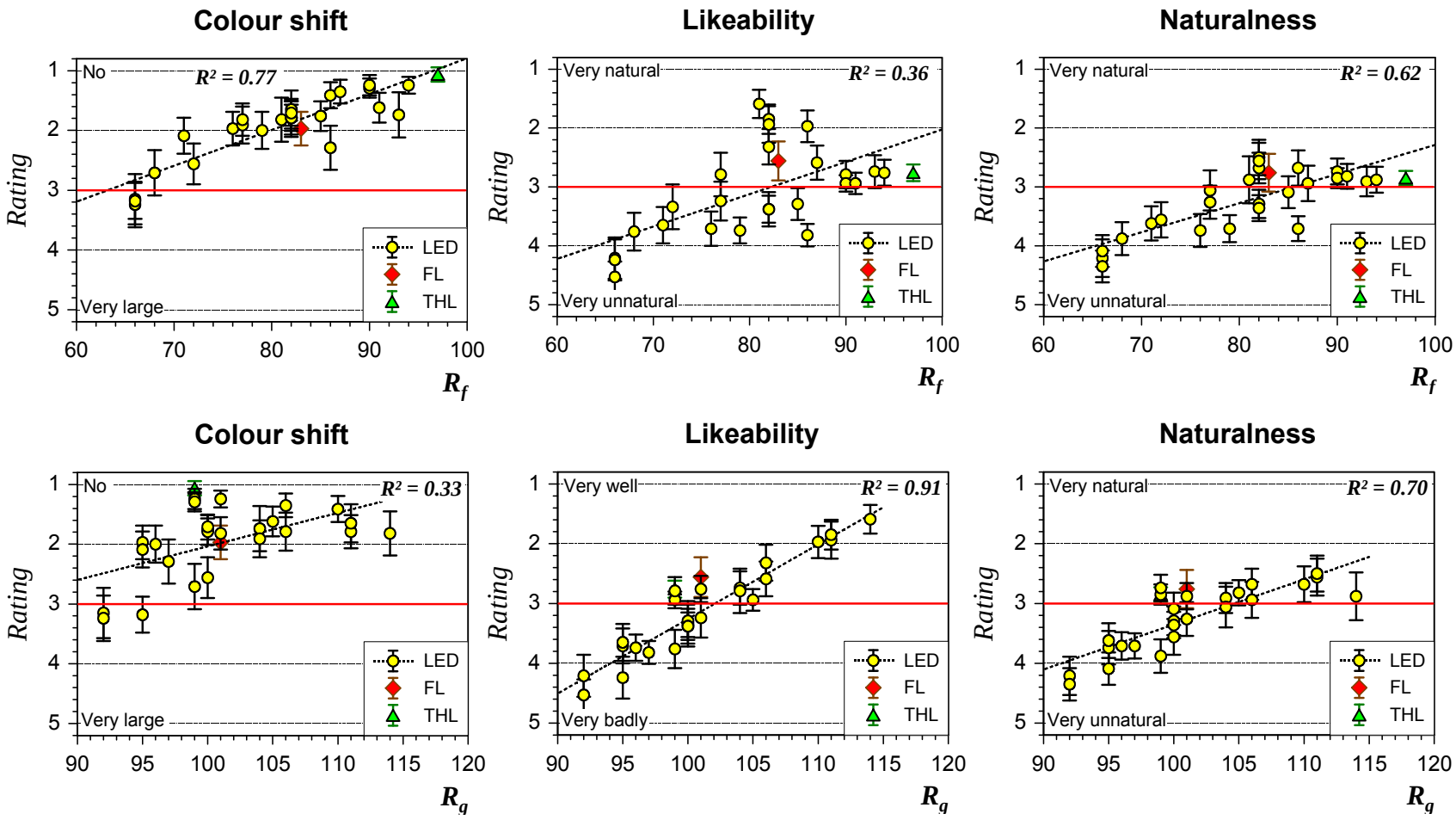
- ***Color quality***
- ***Color difference***
- ***Saturation***
- ***Brightness***
- ***Temperature***
- ***Likability***
- ***Naturalness***
- ***Own idea of color***
- ***General color quality***

of objects under LED spectra compared to the reference light source

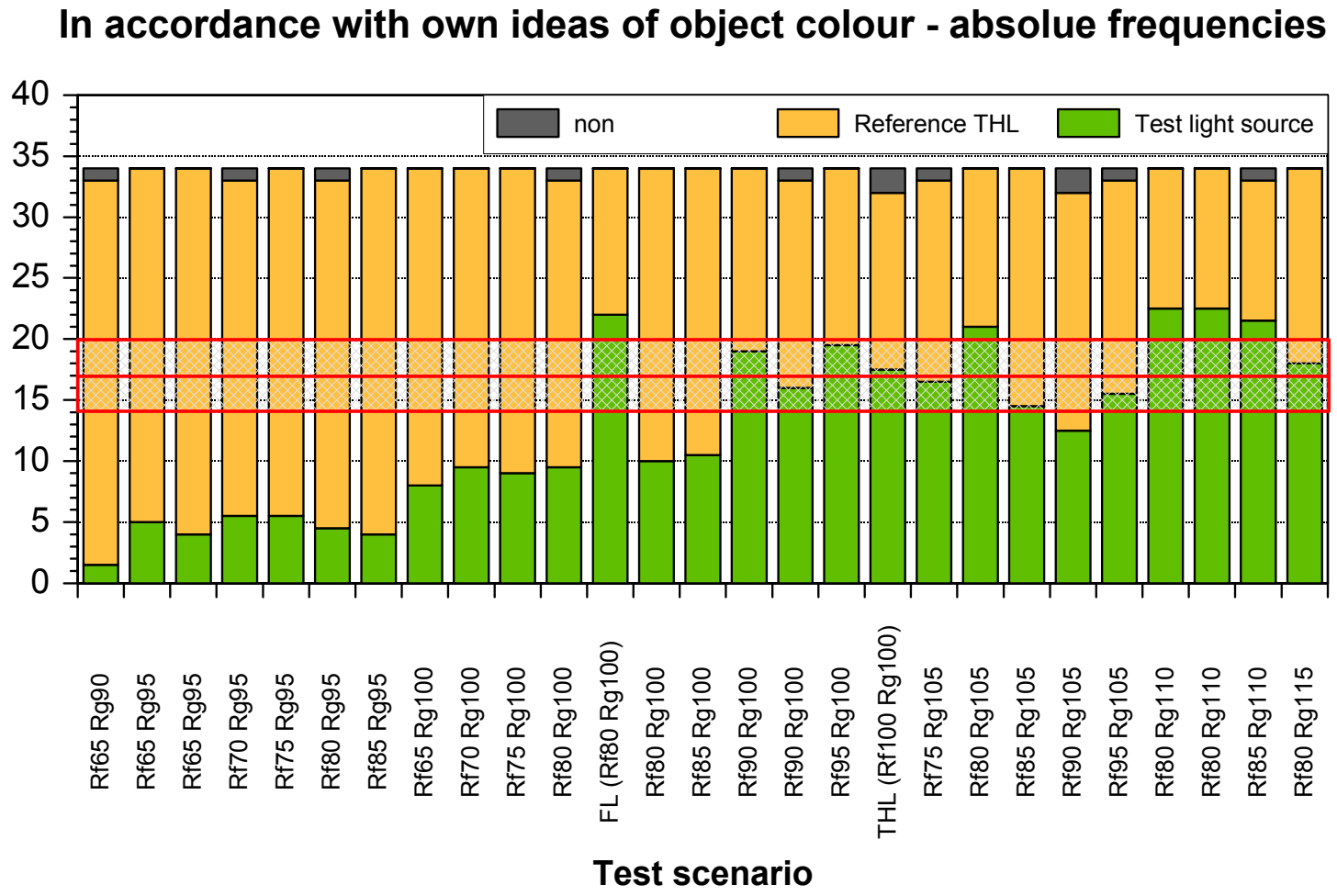
Results


Colour quality
Very good
R^2 = 0.65
Very bad
Rating
R_f
Colour differences
No
R^2 = 0.79
Very large
Saturation
Highly saturated
R^2 = 0.29
Highly unsaturated
Colour quality
Very good
R^2 = 0.73
Very bad
R_q
Colour differences
No
R^2 = 0.13
Very bad
Saturation
Highly saturated
R^2 = 0.95
Highly unsaturated
LED
FL
THL

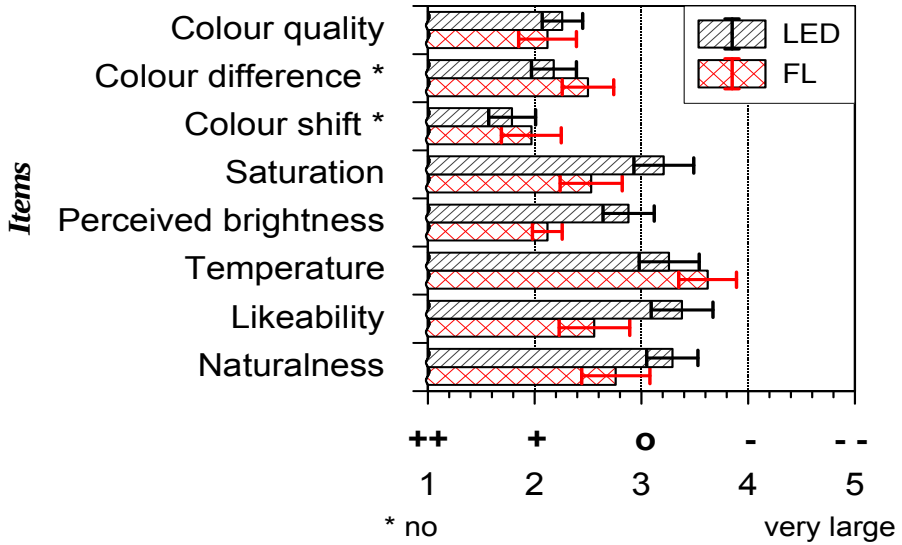
Results


Colour shift
Likeability
Naturalness
Colour shift
Likeability
Naturalness
Rating
R_f
R_g
R^2 = 0.77
R^2 = 0.36
R^2 = 0.62
R^2 = 0.33
R^2 = 0.91
R^2 = 0.70
No
Very natural
Very well
Very large
Very unnatural
Very badly
LED
FL
THL

Results


In accordance with own ideas of object colour - absolue frequencies
non
Reference THL
Test light source
40
35
30
25
20
15
10
5
0
Rf65 Rg90
Rf65 Rg95
Rf65 Rg95
Rf70 Rg95
Rf75 Rg95
Rf80 Rg95
Rf85 Rg95
Rf65 Rg100
Rf70 Rg100
Rf75 Rg100
Rf80 Rg100
FL (Rf80 Rg100)
Rf80 Rg100
Rf85 Rg100
Rf90 Rg100
Rf90 Rg100
Rf95 Rg100
THL (Rf100 Rg100)
Rf75 Rg105
Rf80 Rg105
Rf85 Rg105
Rf90 Rg105
Rf95 Rg105
Rf80 Rg110
Rf80 Rg110
Rf85 Rg110
Rf80 Rg115
Test scenario

Results
Comparison of LED and Fluorescent lamp



Rg	95			100					105		
Item/ Rf	**75**	**80**	**85**	**75**	**80**	**85**	**90**	**95**	**75**	**80**	**85**
Colour quality CQ	*0,000*	*0,000*	*0,000*	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Colour difference CD	1,000	1,000	1,000	1,000	0,082	0,277	*0,000*	*0,000*	1,000	1,000	0,622
Colour shift CS	1,000	1,000	0,910	1,000	1,000	1,000	*0,000*	*0,002*	1,000	1,000	*0,030*
Saturation S	*0,000*	*0,000*	*0,000*	*0,000*	*0,000*	*0,002*	*0,037*	0,303	1,000	1,000	1,000
Likeability LA	*0,000*	*0,000*	*0,000*	*0,026*	*0,000*	*0,009*	1,000	1,000	1,000	1,000	1,000
Naturalness NN	*0,000*	*0,000*	*0,000*	0,185	*0,036*	1,000	1,000	1,000	1,000	1,000	1,000
Interpretation	*FL significant*			*LED significant*				No sicnificant difference			

Results - Hypotheses

- **It is possible for phosphor converted LEDs to fulfill the recommendations of ROYER**

  Yes, phosphor converted LEDs can achieve the recommended values of $R_f \geq 75$ and $R_g \geq 100$.

- **The R_f and R_g values will show a high correlation to the rating of color rendering by subjects**

  R_f and R_g values have a correlation with the perception of naturalness of object colors. R_f can not describe color preference only the perception of color differences compared to a reference light source.

- **In comparison to fluorescent lamps phosphor converted LEDs with identical R_f and R_g values will be preferred**

  Compared to the reference and the LEDs with same R_f and R_g values (R_f=80 & R_g=100) the fluorescent lamp was preferred. The same likability is achieved by LED spectra with R_f=75 & R_g=105 and R_f=80 & R_g=105.

Summary

- Perception of Color Quality is not an one dimensional problem. All aspects have to be considered and eather R_f nor R_g can describe color quality as a single value.
- With Rf, similar to Ra, optimization of spectra has always the target to meet the spectrum of reference. This fact says nothing about likeability of object colors.
- As a result for optimization values $R_f \geq 80$ and $R_g \geq 100$ are recommended. Spectra with this value have been rated better in likeability of colors compared to the reference.

Thank you.

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