ENG3-9.6

German Federal Waterways and Shipping Administration

TRAFFIC TECHNOLOGIES CENTRE

Test Report

Use of optical filters with different light sources

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Document

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Content

1. Summary

In the revision of IALA guideline 1041 on Sector Lights [1] it was asserted that some of the filters used in marine signal lights for many years are no longer available [2]. For LED lights it was discussed whether white LED light should be converted to a signal colour by filtering or not.

The Traffic Technologies Centre investigated the use of filters with different light sources. As the result a list of filters is presented. For each filter the transmissivity and the chromaticity coordinates with the different light sources are shown and whether the resulting colours meet the IALA regions.

It was found out that filtering LED light is comparable to filtering incandescent lamps although their spectra are very different. Filtered light from metal halide lamps often do not give acceptable colours.

2. Introduction

Optical filters have been used for many decades to produce coloured signal lights. Nearly all light sources in use were showing white light, which had to be converted to a colour by filtering out specific parts of the spectrum.

With the upcoming LED technology intense coloured light sources became available and for many signal lights there is no reason for filtering anymore. The same is true for stage projectors where a lot of optical filters were produced for. As a result the market for optical filters is decreasing and only a few optical filters are still available.

However marine signal lights differ in many aspects from road traffic or railway signals. Many existing light house optics - for example sector lights [1] - require the use of filters and the luminous intensity is often much higher than for other signal lights.

In addition all major innovation on LED is for white LED only, so there are not many coloured high intensity LEDs, which comply with the recommended IALA colour regions [3].

Therefore, the Traffic Technology Centre as a supplier of signal lights in the German Waterway Administration investigated the availability of optical filters and their use with the most common light sources.

3. Filters

The following filters have been tested.

Colour	Name	Manufacturer	Material
Green	Supergel #94 Kelly Green	Rosco	Film
	EC 1177 Green	3M	Film
	Green 1428	TTV	PMMA plate
	Green 1440	TTV	PMMA plate
	Green 4422	Telle	PMMA plate
Yellow	Plexiglas GS Orange 2C04	Evonik	PMMA plate
Red	Supergel #26 Light Red	Rosco	Film
	EC 1172 red	3M	Film
	Red 1600	TTV	PMMA plate
	Plexiglas GS Red 3C33	Evonik	PMMA plate

4. Light sources

The following light sources were investigated.

Type	Colour temperature	Product	Manufacturer
Incandescent lamp	2300 K ([1])	Road Signal Lamp 40W	Dr. Fischer
Tungsten halogen lamp	3000 K	Projector Lamp 250W	Dr. Fischer
White LED PC ([2])	3000 K	E-Core	Toshiba
White LED PC ([2])	4000 K	Cree Mk-R 4000 K	Cree
White LED PC ([2])	5500 K	Parathon Classic cool white	Osram
White LED PC ([2])	9000 K	Ostar LE UWE3B	Osram
Metal halide lamp	3900 K	HQI-T 150W / NDL	Osram
Metal halide lamp	5800 K	HRI-T 2000W / N / I	Radium
Metal halide lamp	6200 K	HQI-T 400 W / N	Osram

Remarks:

([1]) Accepted white colour for road traffic white lights according to CIE-region B [4]

([2]) PC: Phosphor converted light

5. Measurement and calculation

The spectral transmission of the filters and the energy spectrum of the light sources were measured with a spectroradiometer (Instruments System CAS 140CT-151). All spectra were collected from 360 nm to 830 nm with a resolution of 1 nm. The radiation was measured in an integrating sphere.

Transmission: $\tau(Filter)_\lambda$ with $\lambda: 360nm \cdots 830nm$

Radiation: $p(Light\ source)_\lambda$ with $\lambda: 360nm \cdots 830nm$

From these values the spectrum of the combination of a filter with a specific lamp were calculated.

Filtered Radiation:

$\tilde{p}(Light\ source, Filter)_\lambda = \tau(Filter)_\lambda * p(Light\ source)_\lambda$ with $\lambda: 360nm \cdots 830nm$

From the calculated filtered radiation the chromaticity coordinates and the transmittance (transmission factor) were calculated.

6. Evaluation process

The product of the energy spectrum of the light sources and the transmission spectrum of the filters gives the energy spectrum of the filtered light. The resulting chromaticity coordinates were checked whether they are in the recommended IALA regions.

The transmittance describes the fraction of light in percent of the total light emitted by the light source. It is an indicator of how bright a light can be when the filter is used. Each combination of a filter and a light source has different values for transmissivity.

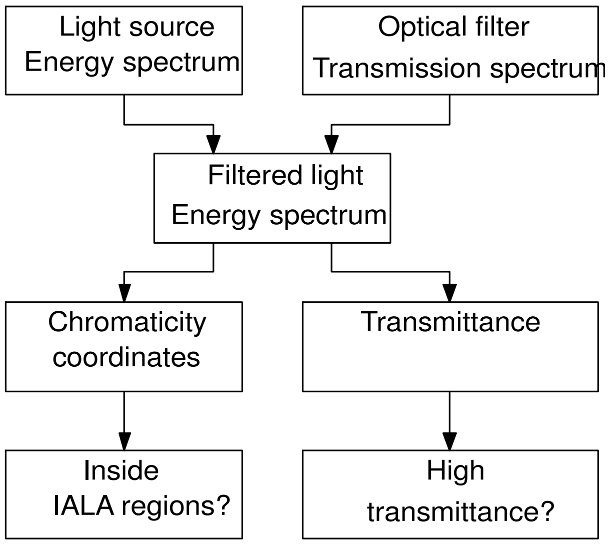

Figure 1: Evaluation process

7. Detailed results

The transmissivities of the filters for each light source are shown in a bar diagram.

- A bar with full colour indicates that the combination light source and filter produce a colour inside IALA Optimum regions
- A fasciated coloured bar indicates that the resulting light is outside IALA Optimum regions but inside the Temporary regions.
- A grey box indicates that the resulting light is of no acceptable colour.

In Figure 2 an example is shown with a filter that produce a colour in the optimum region with light source 1, a colour in the temporary region with light source 2 and a colour outside the IALA regions with light source 3.

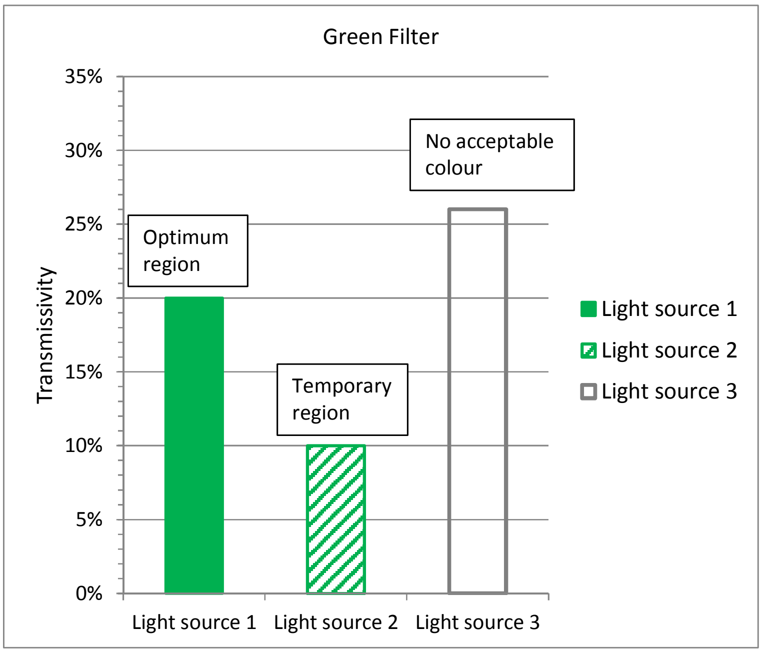

Figure 2: Example filter with three different lights sources

7.1. Green filters

7.1.1. Rosco Supergel #94 Kelly Green

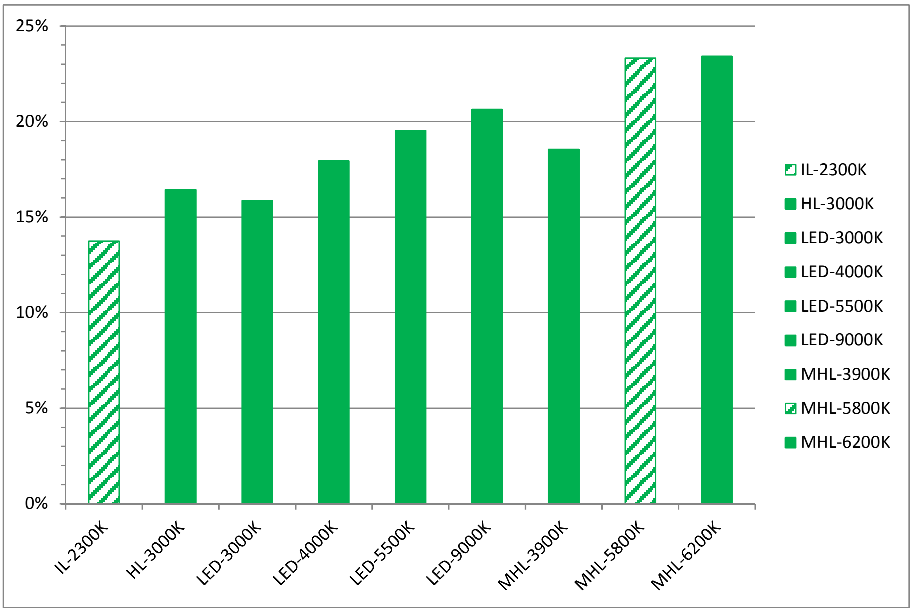

Figure 3: Transmissivity #94 Kelly Green

The filter has acceptable transmissivity and produces colours in optimum region for 7 different light sources, two in temporary region and none outside IALA regions. It has to be mentioned that the result for the metal halide lamp 5800 K is just at the border to the optimum region.

7.1.2. 3M EC 1177 Green

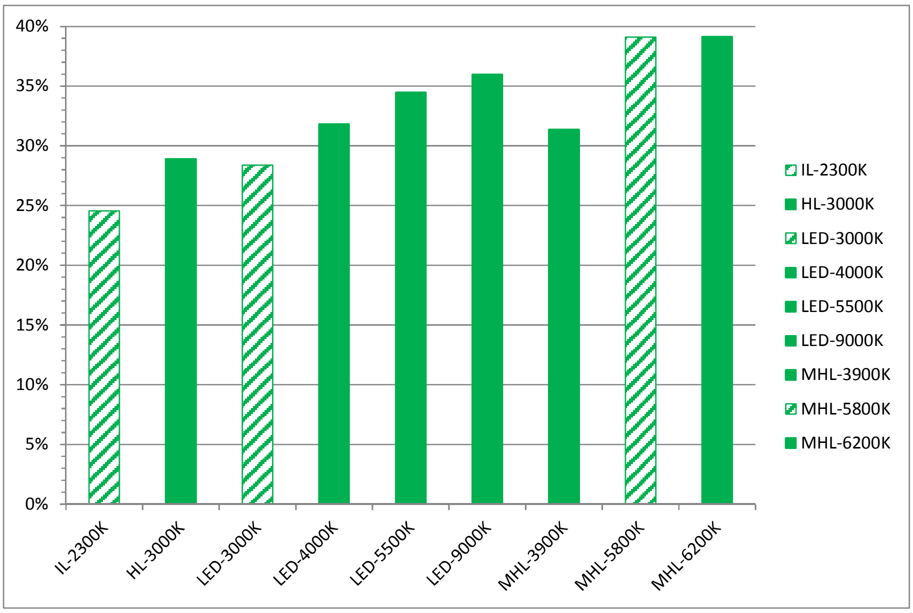

Figure 4: Transmissivity EC 1377 Green

The filter has a much higher transmissivity compared to the rosco product. The colour is slightly worse, but still produces optimum region for 6 light sources, and temporary for 3. It has to be mentioned that the result for LED 3000 K and metal halide 5800 K is near the border of the optimum region.

7.1.3. TTV 1428 Green

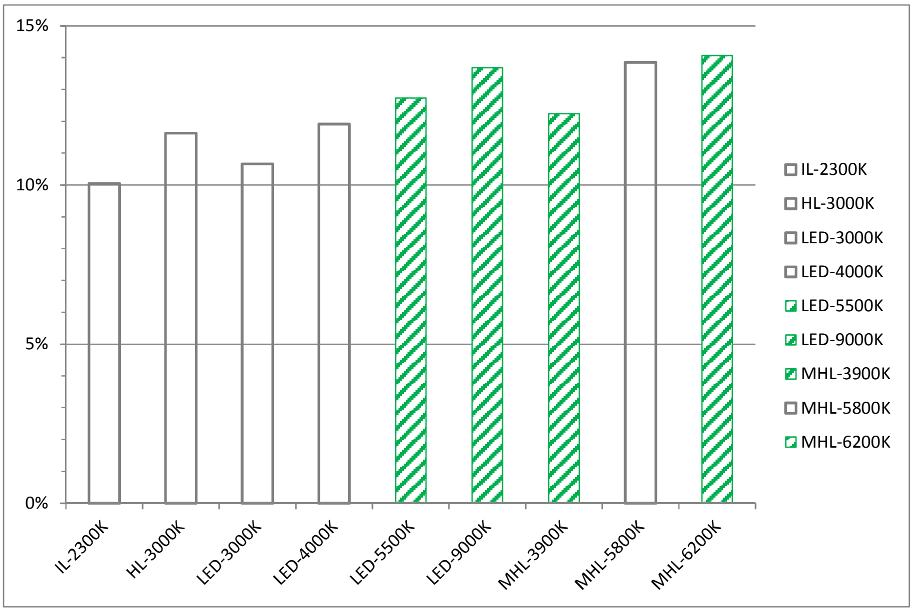

Figure 5: Transmissivity TTV 1238 Green

With this filter IALA temporary region can be achieved only for a few light sources.

7.1.4. TTV 1440 Green

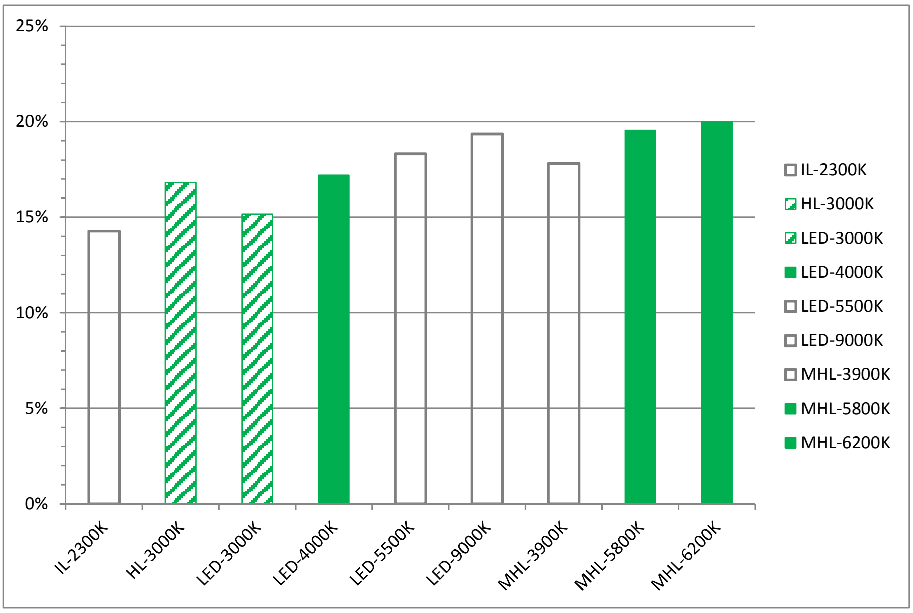

Figure 6: Transmissivity TTV 1440 Green

With this filter the IALA optimum region can be achieved with 4000 K phosphor converted LEDs and approx. 6000 K metal halide lamps.

7.1.5. Telle 4422 Green

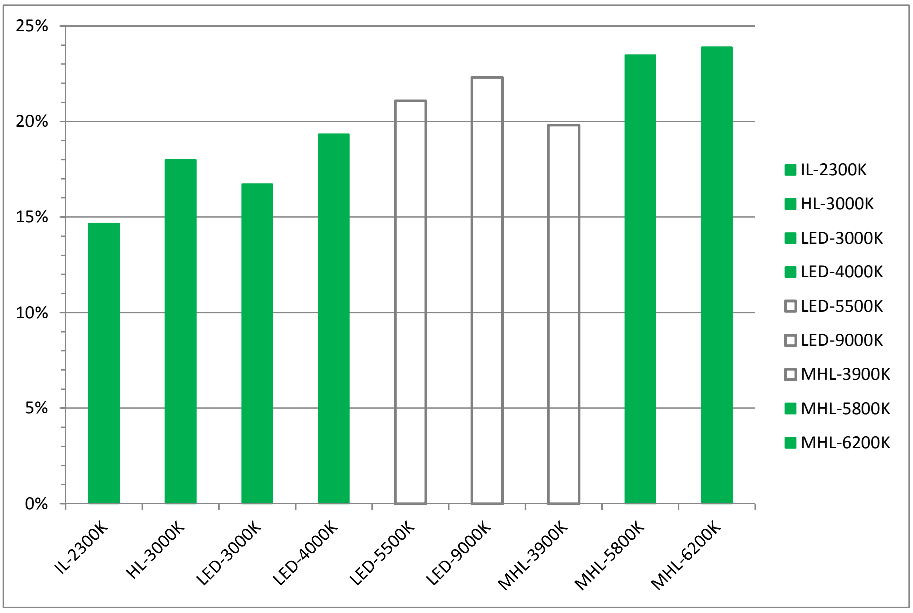

Figure 7: Transmissivity Telle 4422 Green

This filter provides IALA Optimum for a variety of light sources, but not for LED 5500 K and 9000 K and metal halide 3900 K.

7.2. Yellow filter

Evonik Acrylite Orange 2C04

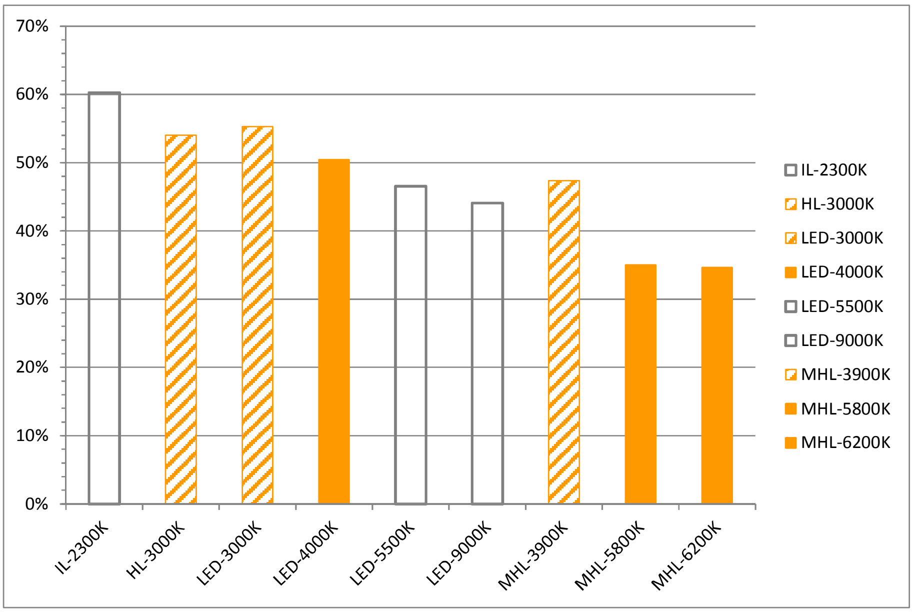

Figure 8: Transmissivity Orange 2C04

With this filter the IALA optimum region can be achieved with 4000 K phosphor converted LEDs and approx. 6000 K metal halide lamps.

7.3. Red Filters

7.3.1. Evonik Acrylite Red 3C33

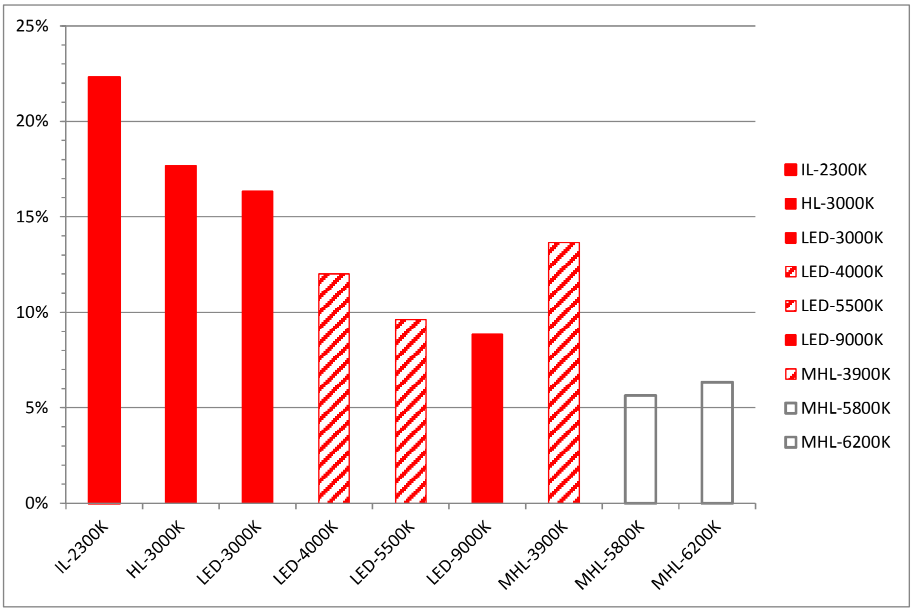

Figure 9: Transmissivity Red 3C33

This filter provides IALA optimum region for incandescent / halogenlamps and some LEDs. It does not produce IALA colours with metal halide lamps.

7.3.2. Rosco Supergel #26 Light Red

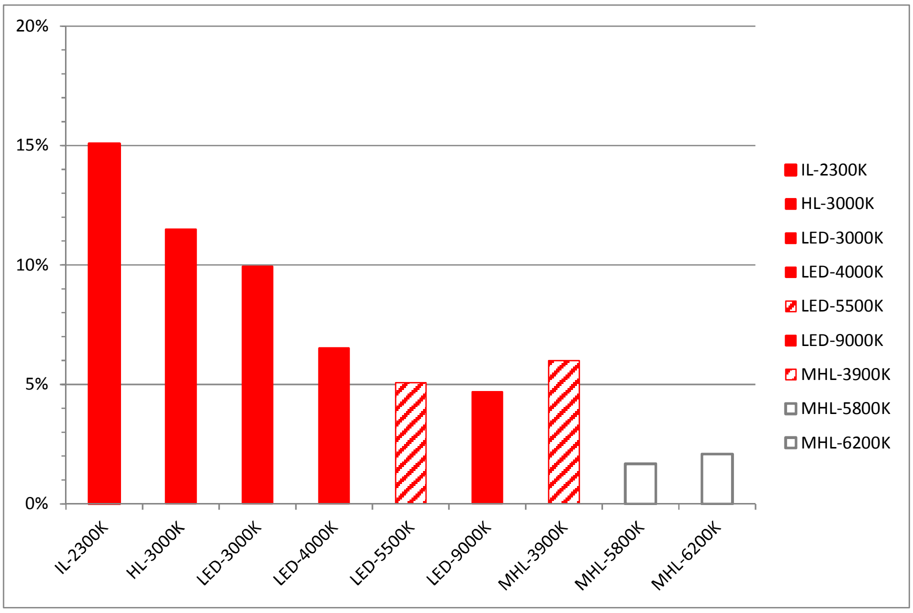

Figure 10: Transmissivity #26 Light Red

This filter fits to LED and incandesent / halogen lamp, but not to metal halide.

7.3.3. TTV 1600 Red

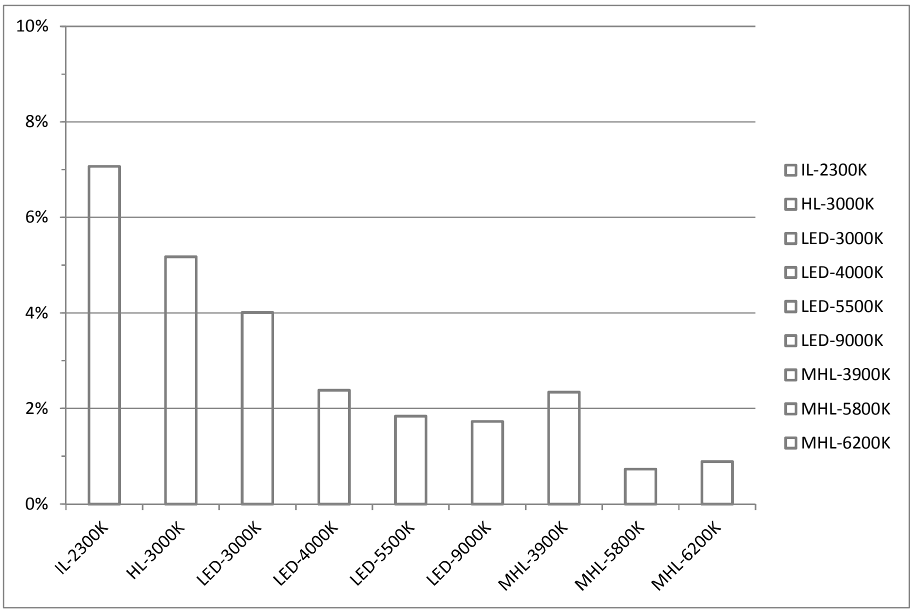

Figure 11: Transmissivity TTV 1600

This filter did not give acceptable colour regarding the IALA regions. The red colour has a very high dominant wavelength of about 640 nm and therefore produces colours with some light sources that would be accepted for a CIE-A-region.

8. Discussion

8.1. Colour

8.1.1. Red and Green

The acrylic filters from Evonik (green 6C01, yellow 2C04 and red 3C33) were used for a lot of light sources in the past. Whereas green was discontinued some years ago, red 3C33 ceased to exist in 2014. For incandescent and LED light sources it is possible to replace the filter with coloured films (3M, Rosco). For green the filter Telle 4422 can replace old Evonik green.

8.1.2. Yellow

Yellow may be treated unequally compared to red, green and white.

- Yellow should not be used in a sector light.
- Only special and new danger marks uses yellow and some nations deny yellow at all.

A yellow light may be used for illumination of structures or obstacles, to avoid conflicts with marine signal lights.

There are three acceptable methods to produce a yellow LED light.

- Yellow LED Chip
- Phosphor converted yellow LED
- Filtered white LED

The efficacy of a yellow LED chip is very low and when driven with a high current the colour tends to leave IALA optimum region towards red.

The two other methods may show a much higher efficacy.

Phosphor converted yellow LED may not produce a colour in IALA optimum region, but in CIE region which is larger. The IALA regions are defined for signal lights. This means that the observer (mariner) sees the light as point (viewing angle lower than 1 arcmin). For the illumination of structure it might be worth considering the larger CIE region.

When the white LED has its yellow peak in the vicinity of 590 nm, it can be converted to IALA optimum region by filtering easily. This was done with the 4000 K LED in this test report with a transmittance of 50% (Figure 8).

8.2. Material

The replacement of plastic colour plates with films is not straightforward.

- For many lighthouse optics the sectors were aligned by moving the plastic sheet. This is not possible when a sector light is built with a film inside the lighthouse glazing. As an alternative the film may be glued to a clear plastic plate.
- All filters used for signal lights are absorbing filters so most of the radiation is absorbed by the filter. This absorption will heat the filter or degrade the filter pigment. As the absorbing layer of a film (typ. 100 μm) is much thinner than for a filter plate (1 to 3 mm), a thermal damage of a film is more likely than for plates.
  The heating of the film will be less when it is glued (has thermal contact) to a clear plastic or glass plate. LED light has no infrared radiation and therefor the heating will be lower compared to incandescent and discharge lamps.

8.3. Filtering metal halide lamps

White metal halide light can be converted to the green IALA optimum region by filtering out the two peaks at approx. 450 and 540 nm. For yellow there is a single peak at approx. 590 nm in the metal halide spectrum which when filtered out gives IALA optimum region as well.

For red there is no simple solution. There are two peaks at 590 and 670 nm which could be combined to IALA red, but the luminosity function V(λ) of them is so different (590 nm: 76% and 670 nm: 3%) that an equal superposition requires a very specific transmission curve and would result in a small transmissivity. None of the filter tested could give IALA optimum region.

The best result for metal halide lamps was the 3900 K, which has a spectrum with lines and a continuum. However only IALA temporary region was achieved.

9. Appendix

9.1. Energy spectrum of the light sources

9.1.1. Incandescent lamps

2300 K: Incandescent lamp, road traffic signal lamp 230V / 40 W (E27), Dr. Fischer

3000 K: Halogen lamp 24V / 250 W (GY6,35), Dr. Fischer

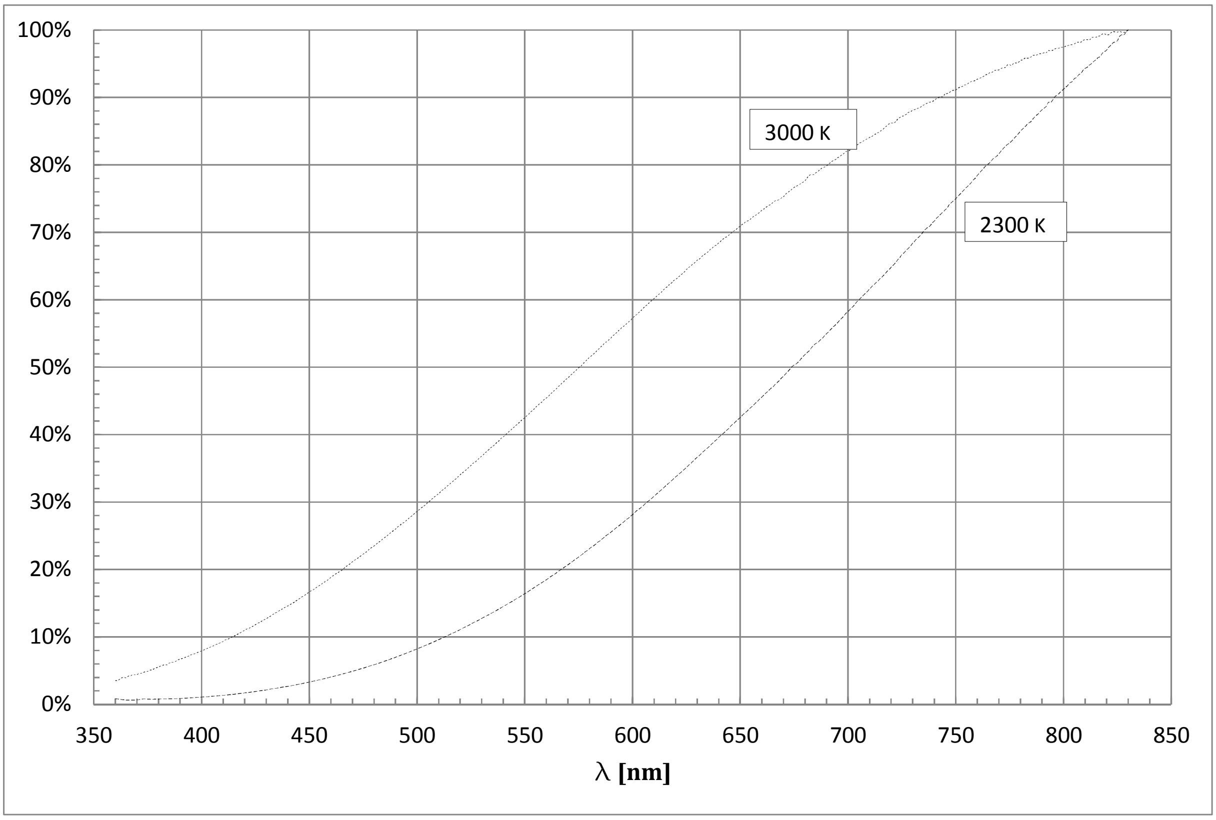

Figure 12: Spectrum incandescent lamps

9.1.2. Phosphor converted white LED

3000 K: Toshiba E-Core

4000 K: Cree Mk-R 4000 K

5500 K: Osram Parathon Classic, cool white

9000 K: Osram Ostar LE UWE3B

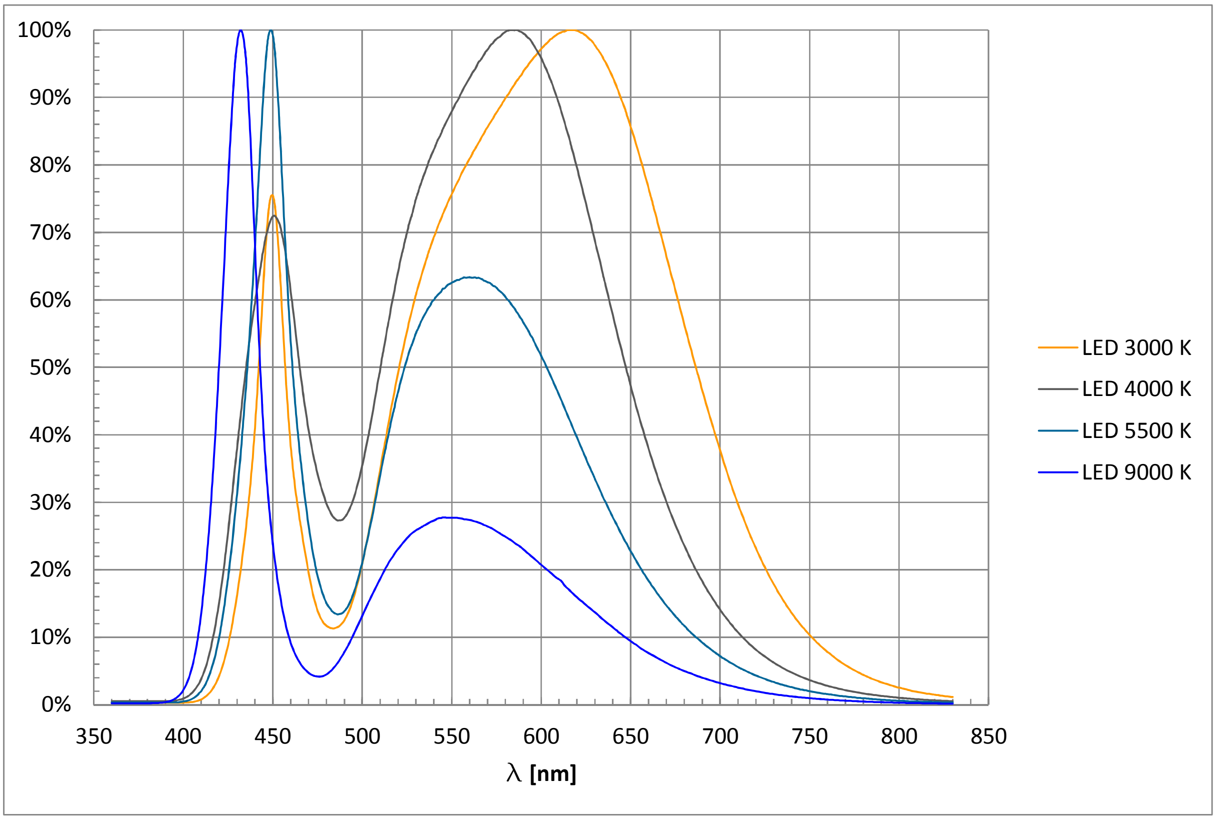

Figure 13: Spectrum white LEDs

9.1.3. Metal halide

3900 K: Osram HQI-T 150W / NDL

5800 K: Radium HRI-T 2000W / N / I

6200 K: Osram HQI-T 400 W / N

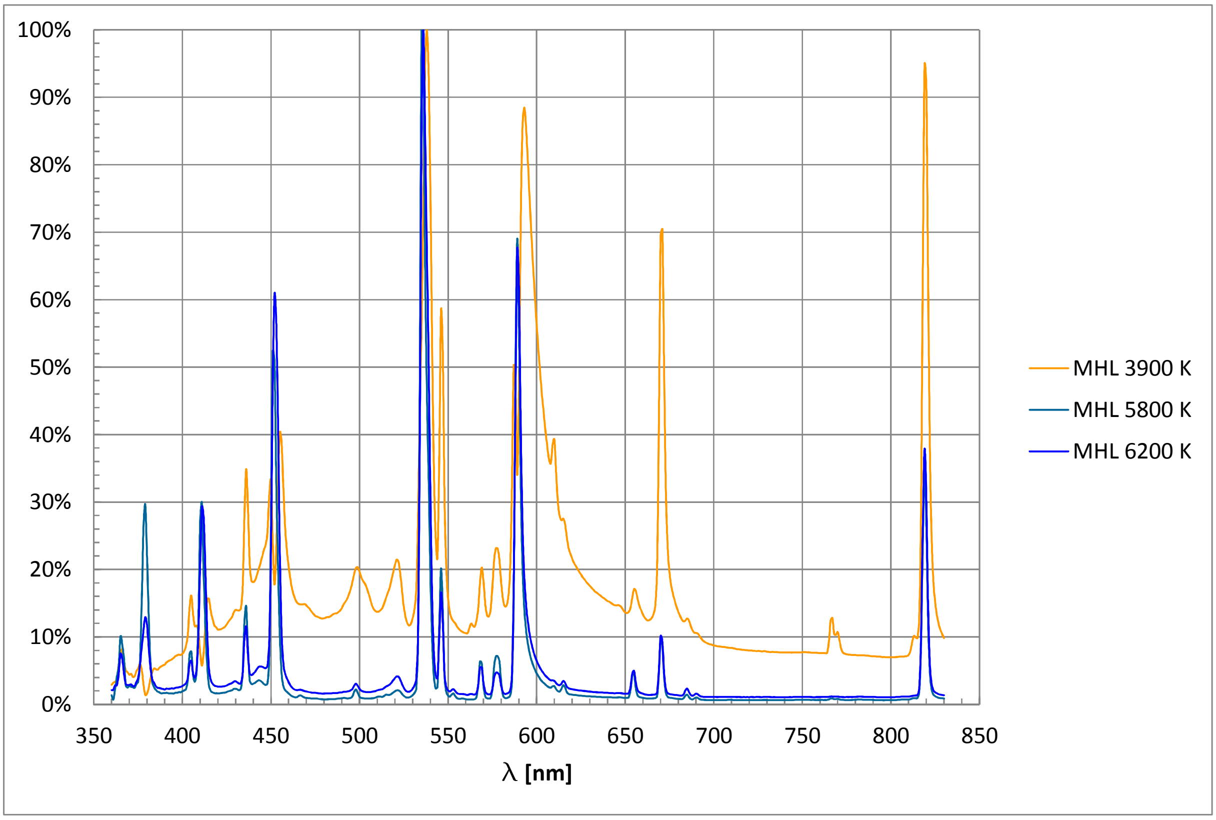

Figure 14: Spectrum metal halide lamp

9.2. Transmission spectrum

9.2.1. Red filter

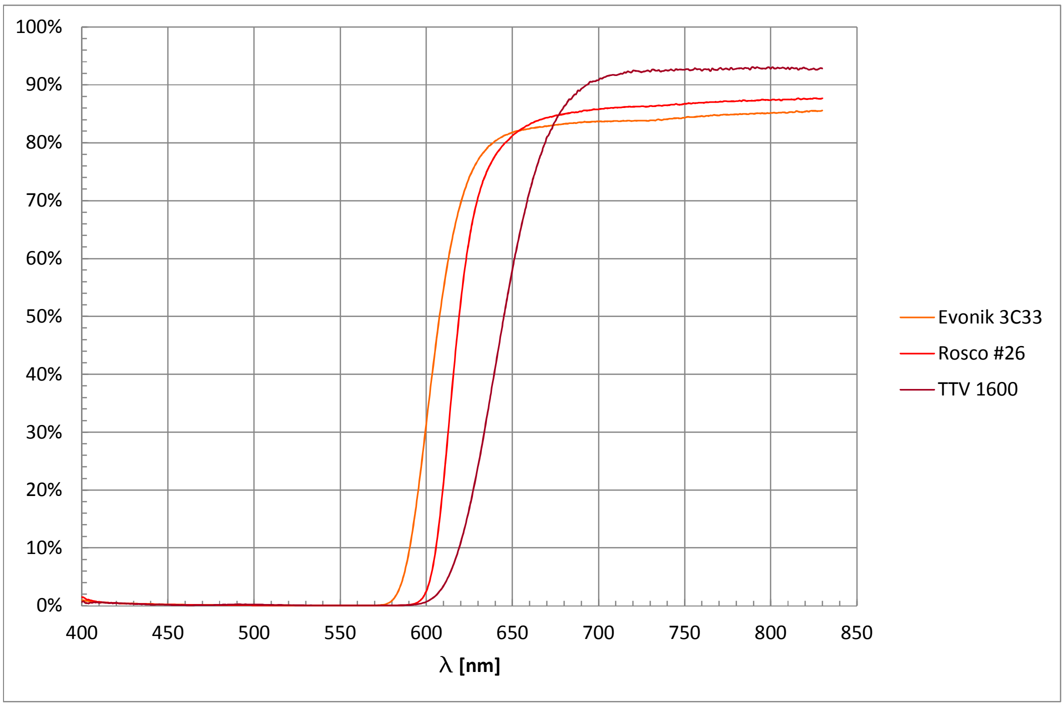

Figure 15: Red filter

9.2.2. Yellow filter

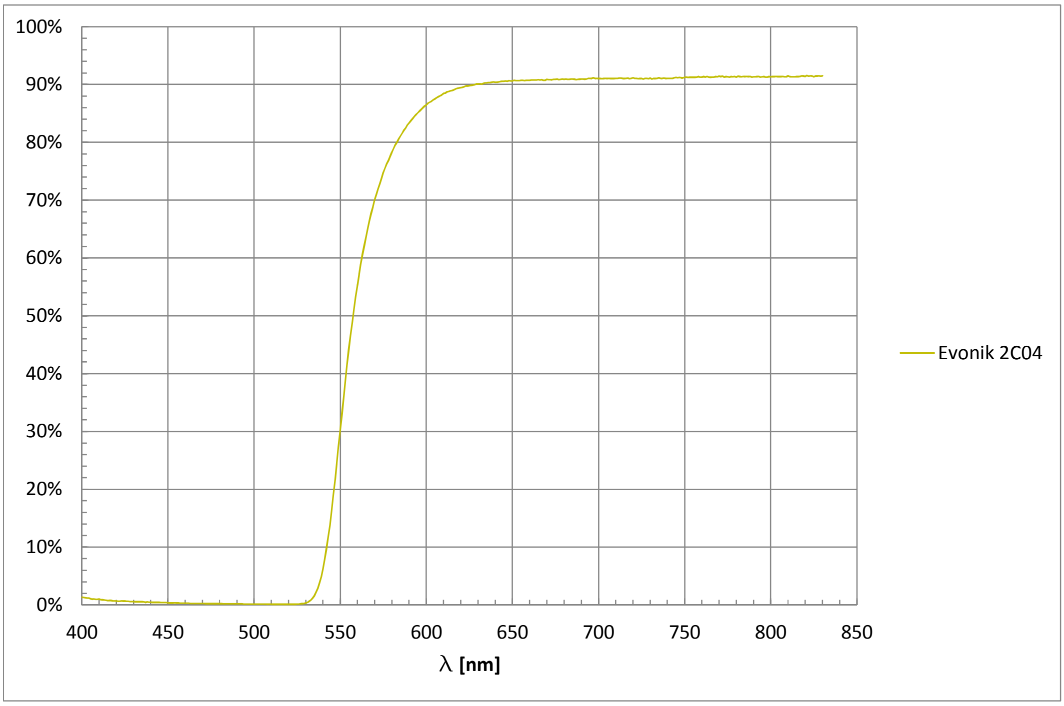

Figure 16: Yellow filter

9.2.3. Green filter

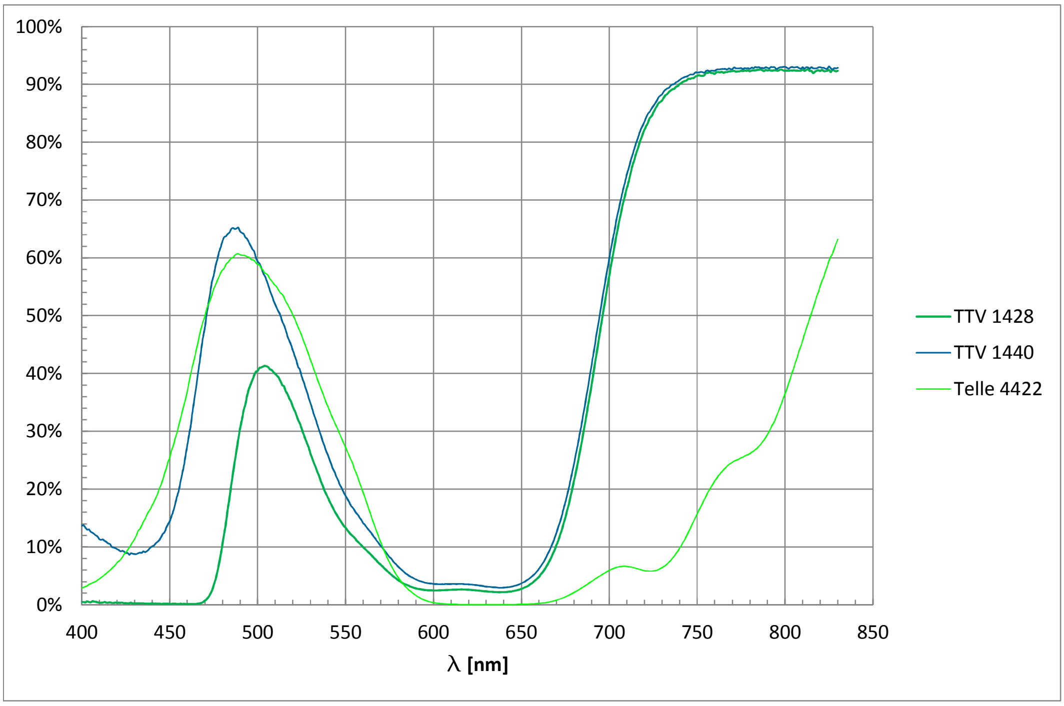

Figure 17: Green filter, PMMA plates

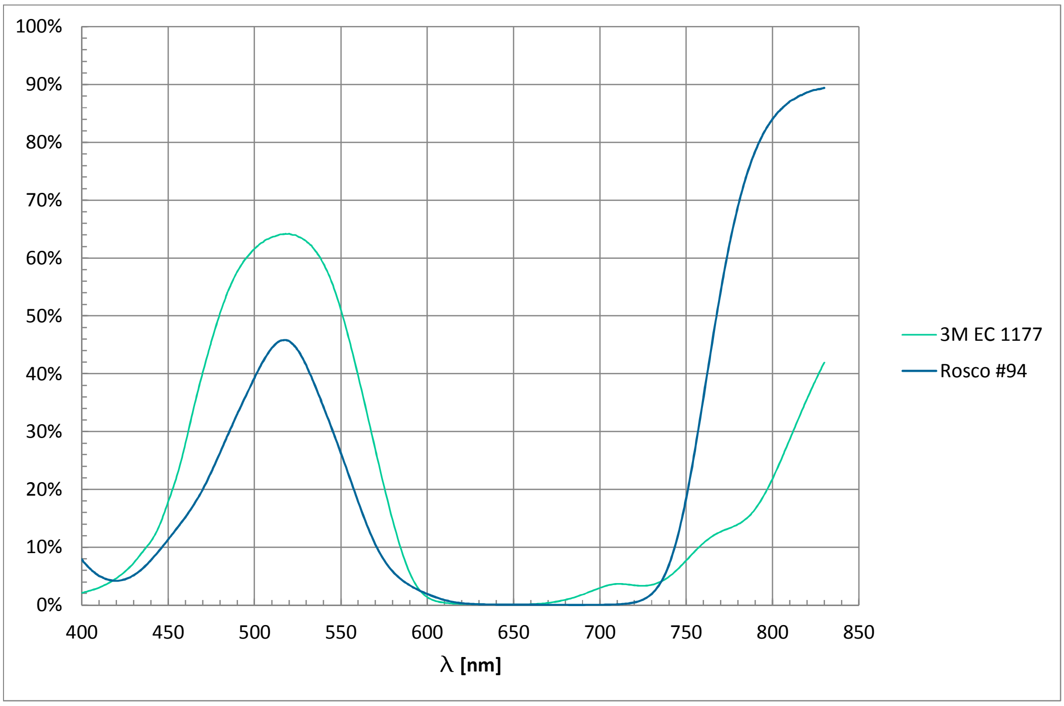

Figure 18: Green filter, films

9.3. Chromaticty Charts

9.3.1. Incandescent lamp 2300 K

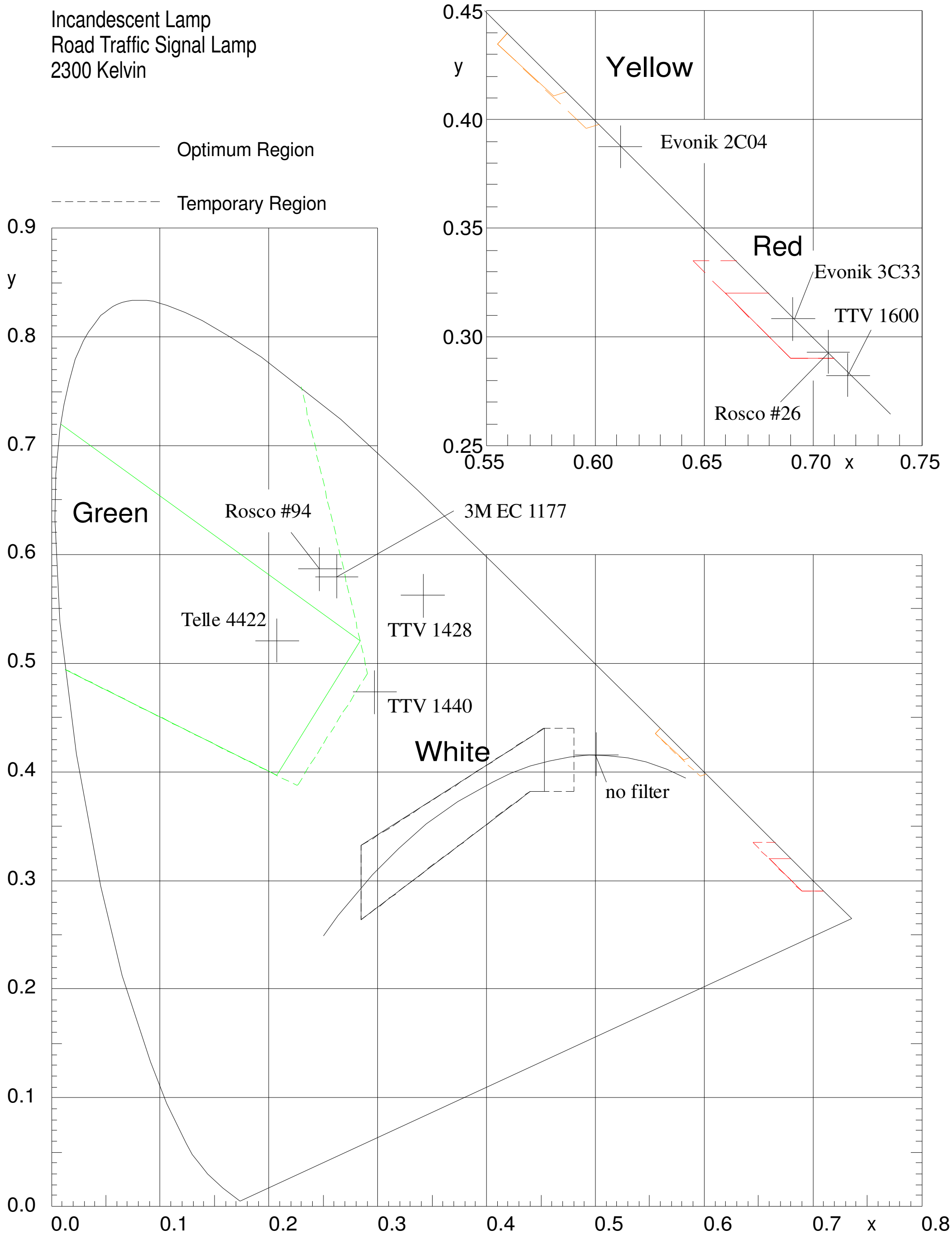

Figure 19: Resulting colours for incandescent lamp 2300 K

9.3.2. Tungsten halogen lamp 3000 K

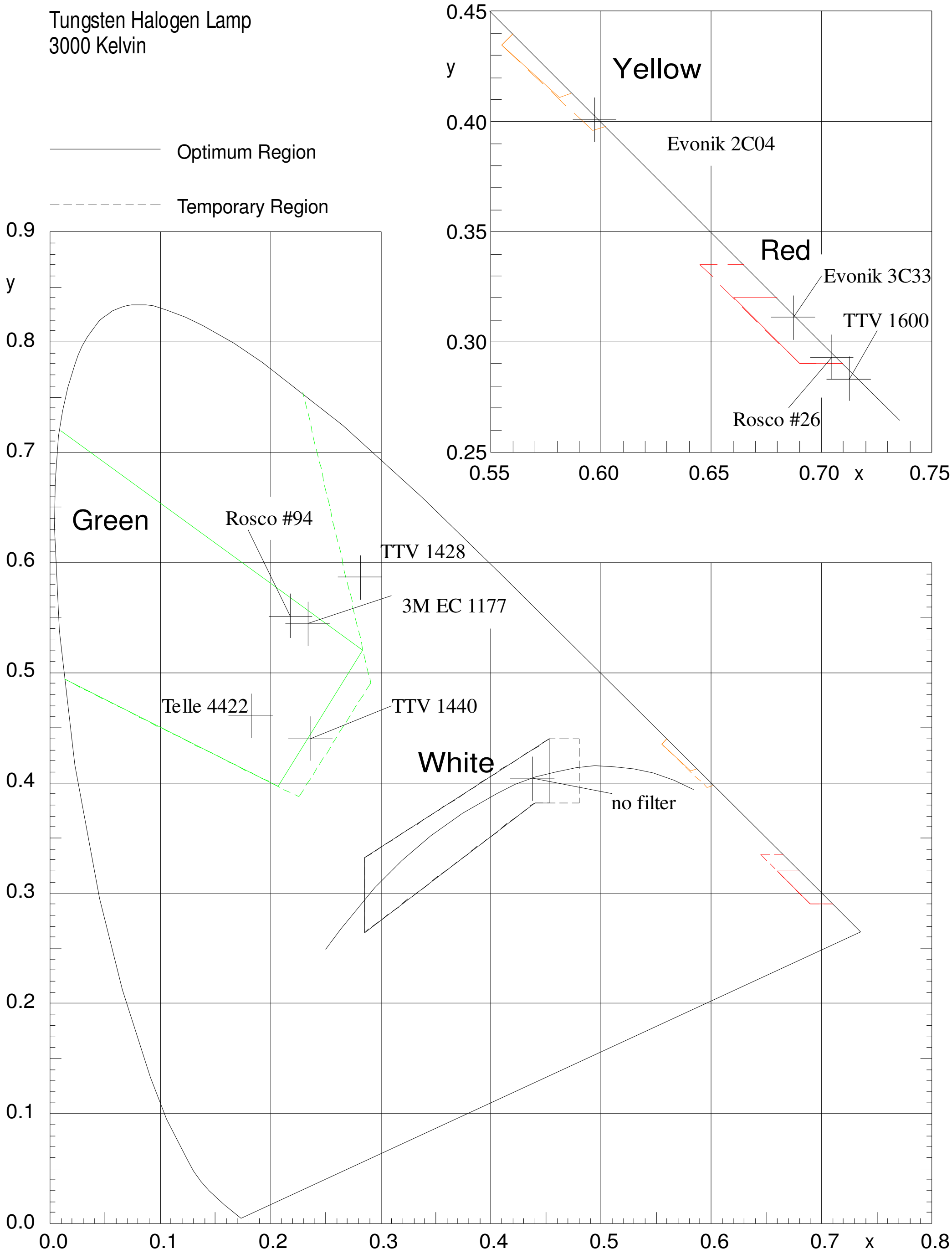

Figure 20: Resulting colours for tungsten halogen lamp 3000 K

9.3.3. PC LED 3000 K

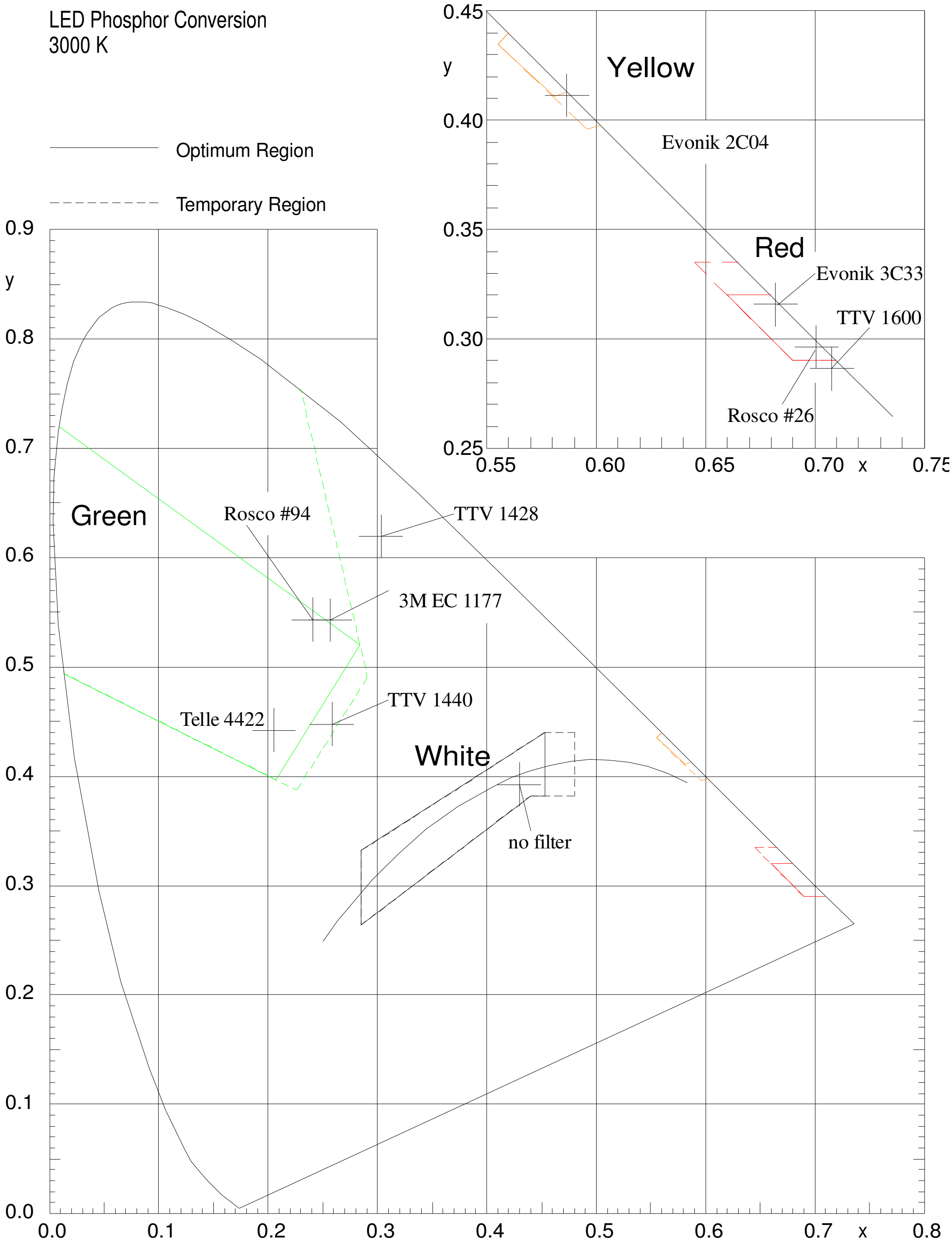

Figure 21: Resulting colours for PC LED 3000 K

9.3.4. PC LED 4000 K

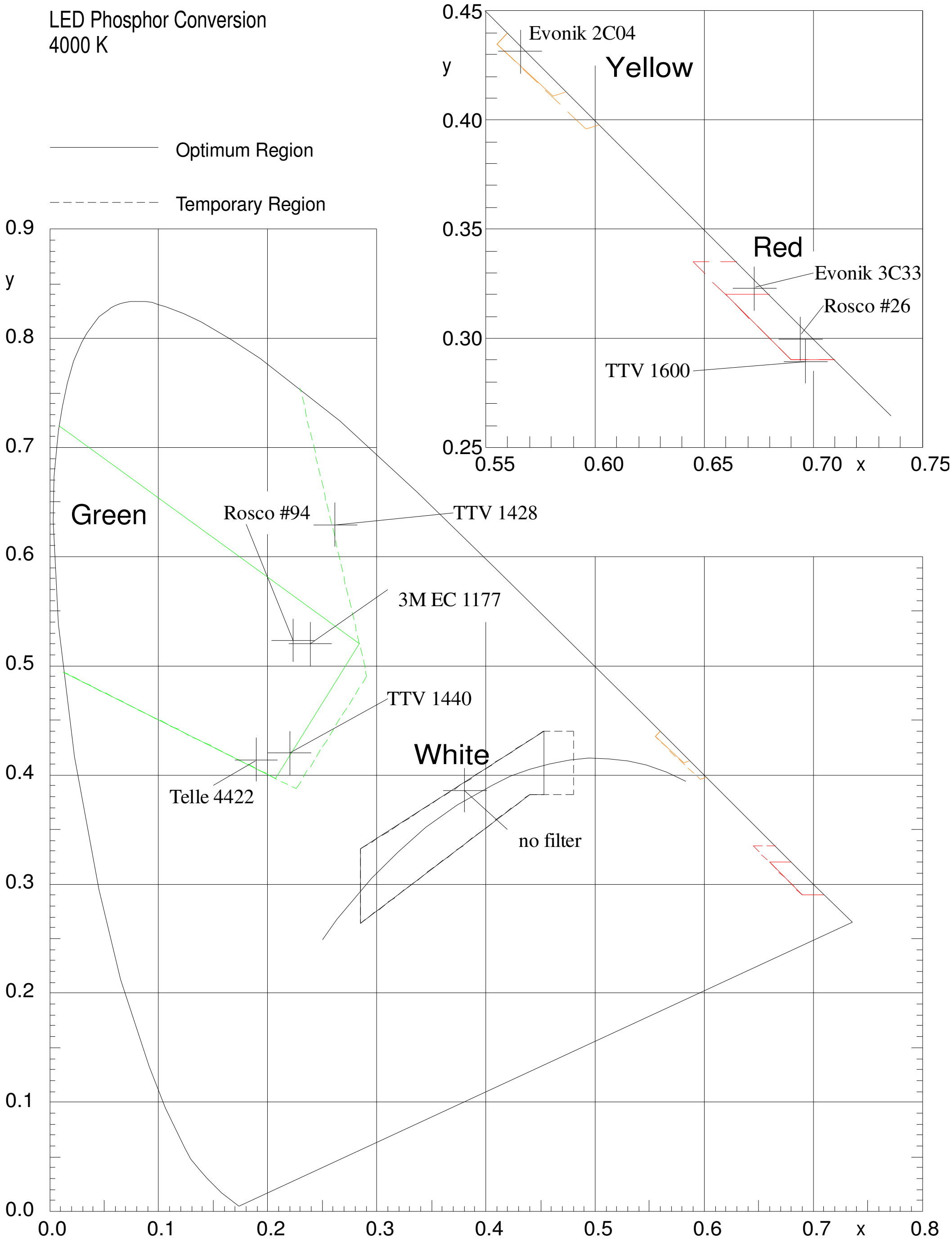

Figure 22: Resulting colours for PC LED 4000 K

9.3.5. PC LED 5500 K

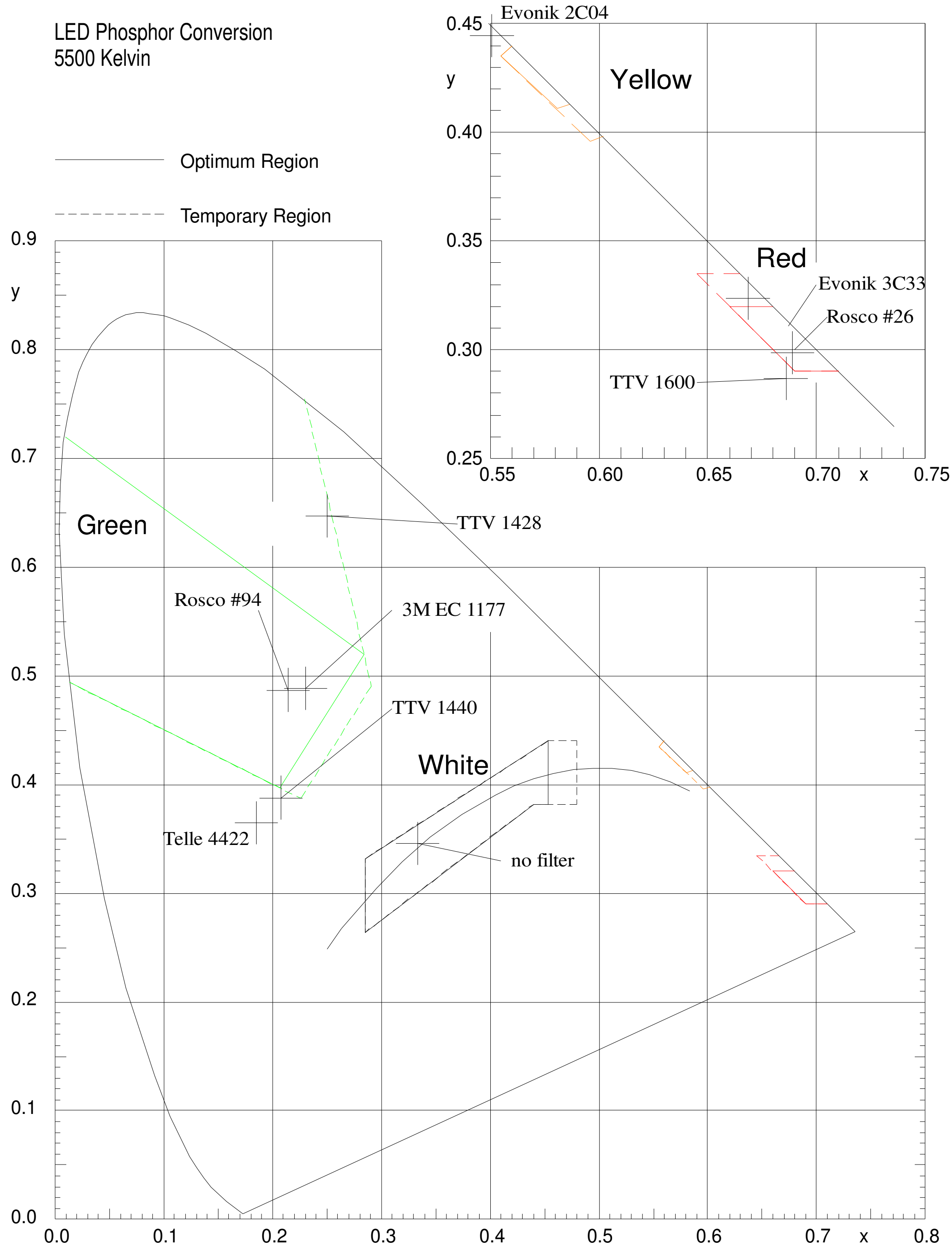

Figure 23: Resulting colours for PC LED 5500 K

9.3.6. PC LED 9000 K

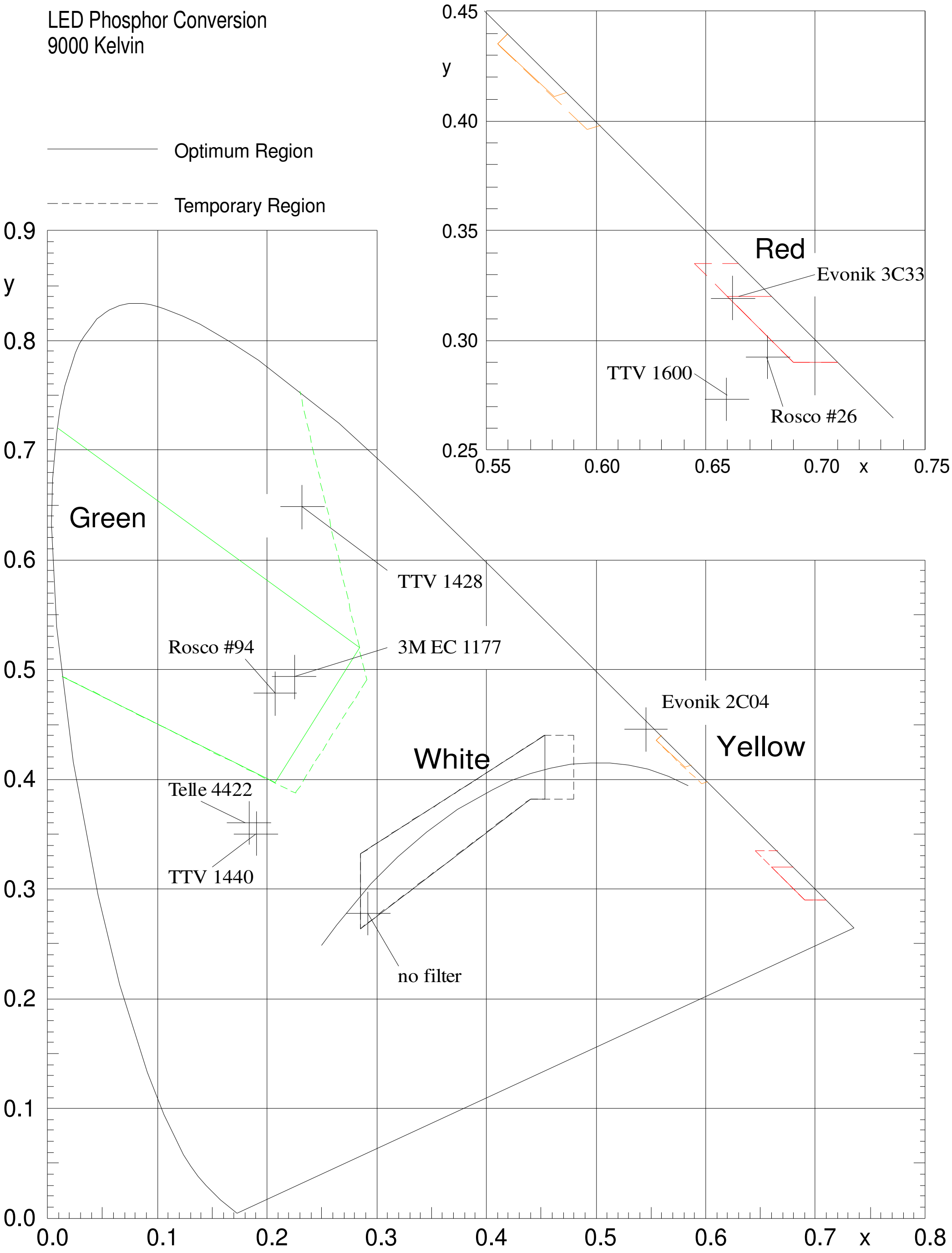

Figure 24: Resulting colours for PC LED 9000 K

9.3.7. Metal halide lamp 3900 K

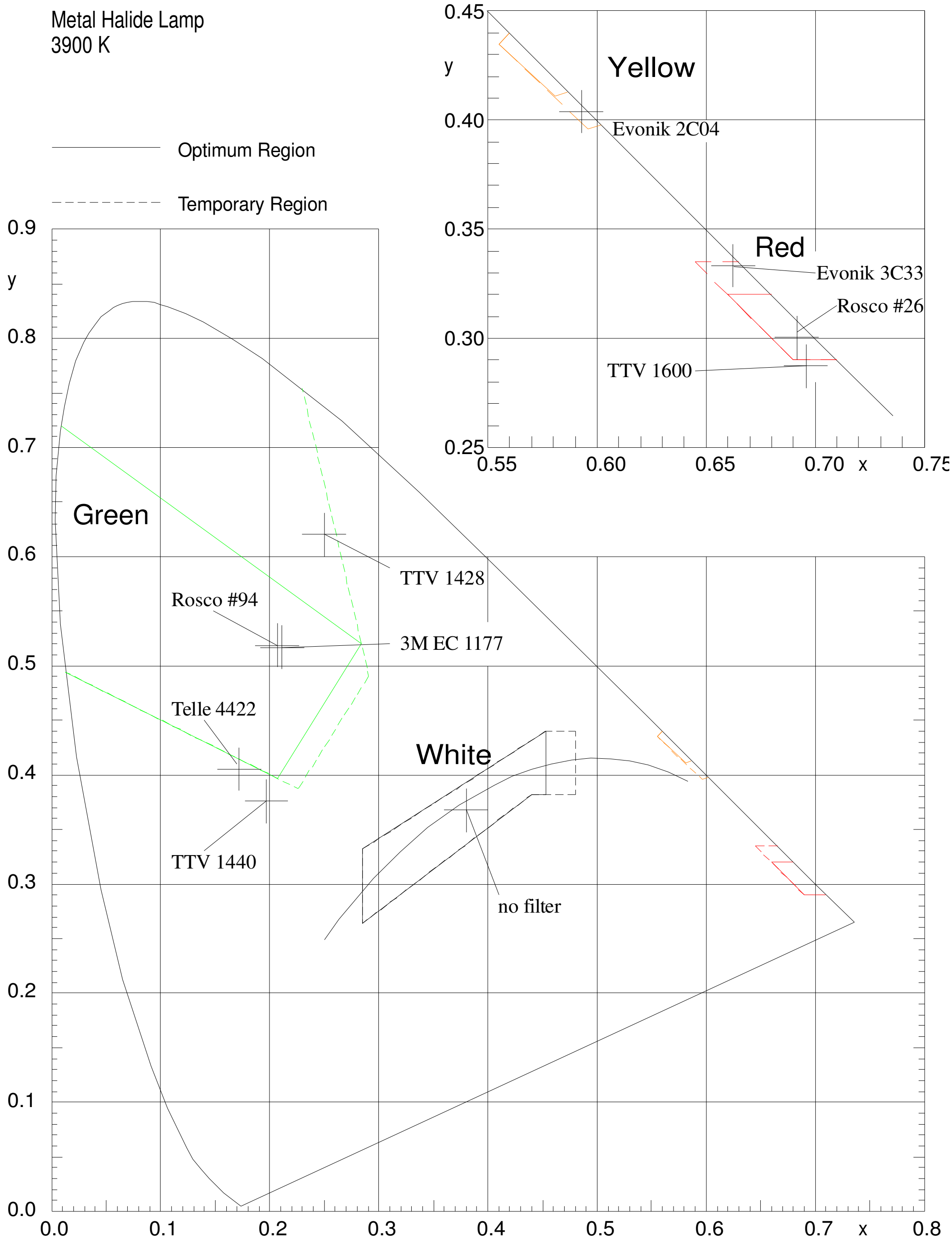

Figure 25: Resulting colours for metal halide lamp 3900 K

9.3.8. Metal halide lamp 5800 K

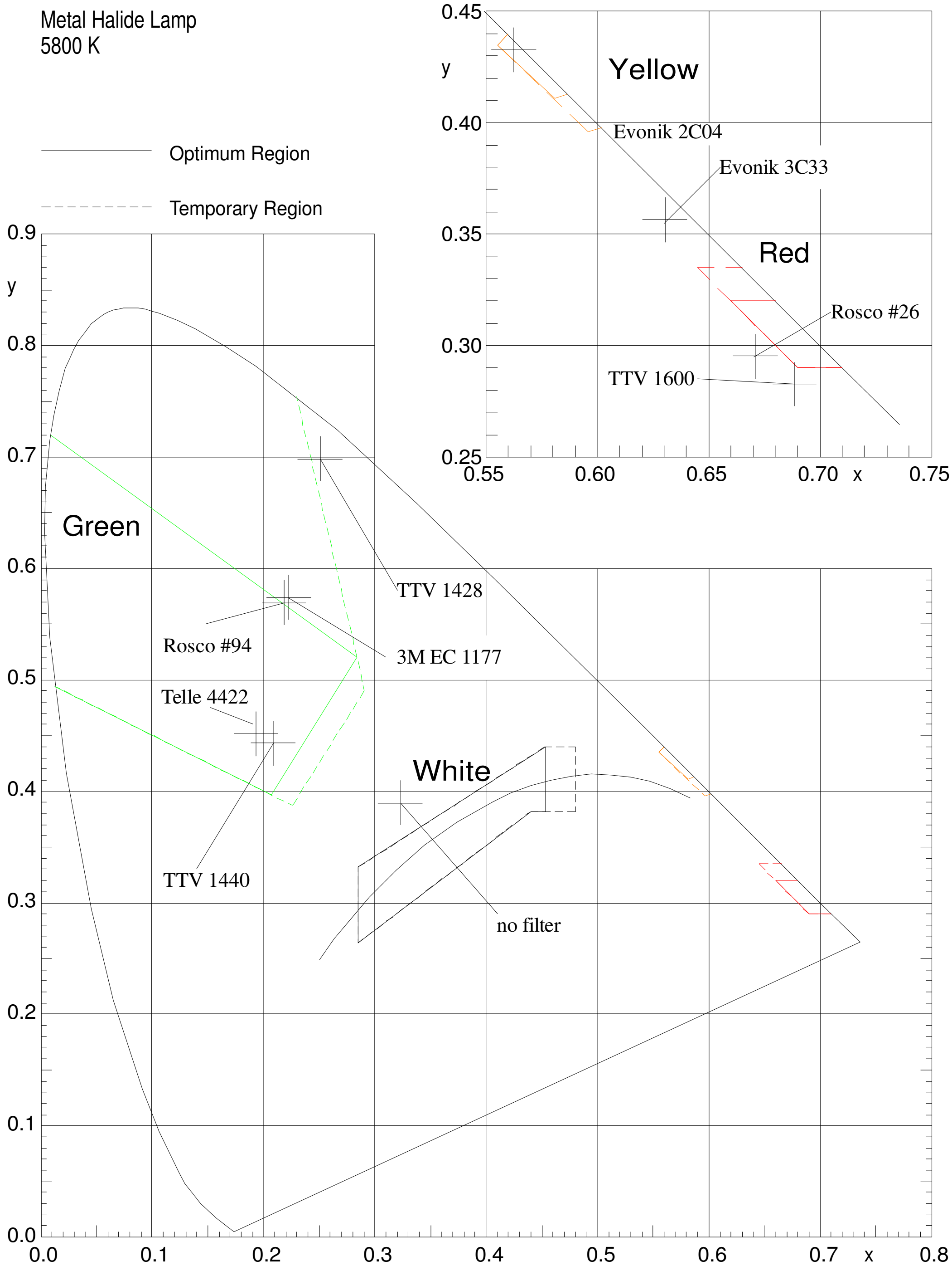

Figure 26: Resulting colours for metal halide lamp 5800 K

9.3.9. Metal halide lamp 6200 K

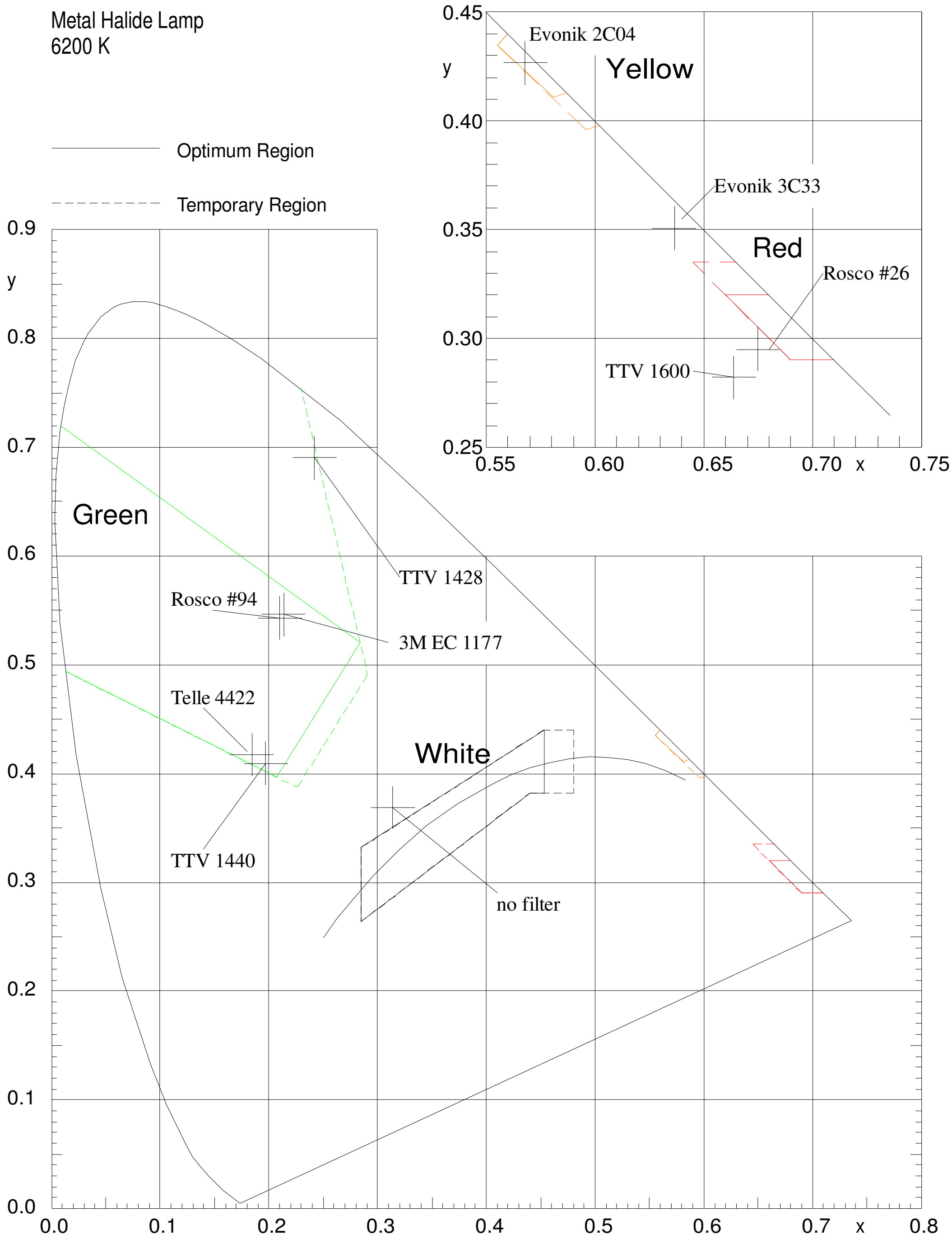

Figure 27: Resulting colours for metal halide lamp 6200 K

9.4. References

[1] IALA Guideline No. 1041 On Sector Lights

[2] IALA Wiki ENG Technical information, optical material

[3] IALA Recommendation E-200-1 On Marine Signal Lights Part 1 - Colours

[4] CIE S004/E2001 Colours of Light Signals