Long-term Colour Stability of Navigation Buoys

Customer:

SeaHow® by MeriTaito

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Target:

7 pcs of plastic material samples of navigation buoys in four different colours. The sample pieces were taken from finished products.

Table 1. List of samples under test.

Diameter [mm]	Colour		Type
400	RAL 9017	Black	Multi-layer
400	RAL 3028	Red	Multi-layer
400	RAL 6037	Green	Multi-layer
400	RAL 1023	Yellow	Multi-layer
800	RAL 9017	Black	Through-coloured
800	RAL 3028	Red	Through-coloured
800	RAL 6037	Green	Through-coloured

D400

D800

Fig. 1. *Plastic material samples of navigation buoys.*

Testing Time:

The start of the test: 31st March, 2016
The end of the test: 7th November, 2016

Purpose of the Test:

To test the long-term colour stability of the navigation buoys when exposed to solar radiation. The solar radiation consists of UV, visible and thermal IR radiation.

To verify how the colours match to the allowed chromaticity regions according to IALA Recommendation E-108 – Surface colours used as visual signals on aids to navigation, Edition 3, 2013.

Test Method:

The exposure in this test consists of two parts.

Exposure 1

Solar radiation exposure (UV+vis+IR)

Intensity: 1120 W/m^2
T(Amb): ~40°C
Cycle: 22 h solar irradiation / 2 h water spray or high RH (salt mist spray weekly)
Duration: 56 days

Test conditions based on ISO 4892-1 and MIL-STD-810G METHOD 505.5

Exposure 2

High-intensity solar radiation exposure (UV+Vis+IR)

Intensity: Continuous high-intensity radiation (3500 W/m^2 with sample cooling)
T(Amb): ~30°C
Duration: until reaching an UV-energy dose that corresponds to at least of 15 years in natural conditions on vertical surfaces

Measurements

Chromaticity coordinate zone analysis
Colour CIELAB1976 and DE (colour change)

Feasibility of the Test Method:

Solar radiation, especially the radiation in the UV range, is the main reason for colour changes of plastic materials. In addition to sunlight, the navigation buoys are exposed to moisture and salt water in their actual use environment.

The intensity of solar radiation is increased up to 3500 W/m^2 and solar lamps with pronounced intensity in the UV spectral range are used in order to highly accelerate the effects of solar UV radiation. Cooling air is used to prevent excessive heating of the samples and the resulting effects.

Chromaticity coordinate zone analysis can be used to verify whether the colour of the products is within the limits set by the requirements. Measurement of CIELAB colour coordinates and the colour change takes into account the lightness of the colour in addition to the chromaticity, and thus corresponds to the actual visual appearance of the product surface.

Performed Actions:

Solar radiation

The light from the solar simulator has effectively similar spectrum as the natural sun. The properties of the simulated solar radiation used in this test, and those of natural sunlight, are described in Table 2. Table 2 shows the spectral distribution of the standard solar spectrum for natural sunlight (CIE 85-1989 AM 1.5) and the spectrum of the simulated radiation used in this test in the ranges of ultraviolet (UV), visible, and thermal radiation (IR). The main part of the test, Exposure 2, was run with a solar lamp that produces an excess amount of UV radiation when compared to natural sunlight. In addition, the intensity of radiation during Exposure 2 was increased to 3500 W/m^2. In this way, the test could be highly accelerated.

Table 2. Spectral distribution of natural sunlight (as defined in CIE 85-1989 AM 1.5) and radiation from solar simulator used in this test (Exposure 1 and Exposure 2) in the ranges of ultraviolet (UV), visible (Vis), and thermal radiation (IR).

Spectral region		Exposure 1		Exposure 2		Sunlight	
	[nm]	[%]	[%]	[%]	[%]	[%]	[%]
UV	280-320	0.5	4.7	7.9	25.6	0.2	5.8
	320-360	1.5		6.1		2.3	
	360-400	2.7		11.6		3.3	
Vis	400-520	13.7	52.9	20.1	44.0	18.6	56.4
	520-640	26.7		16.0		18.6	
	640-800	12.5		7.9		19.3	
IR	800-3000	42.4	42.4	30.4	30.4	37.8	37.8

The total intensity of radiation was measured with a precision pyranometer from the sample area. The measured intensity and duration of exposure for Exposure 1 and Exposure 2 are shown in Table 3. The energy doses in units of kWh/m^2 and kLy are given in details in Table 4.

Table 3. Total intensity of radiation and duration of the exposure.

	Intensity	Exposure time
	[W/m^2]	[h]
Exposure 1	1090 ± 82	1232
Exposure 2	3500 ± 100	1700

Table 4. Solar radiation energy received by the samples during the test.

Spectral region	Exposure 1		Exposure 2		Total	
	[kWh/m^2]	[kLy]	[kWh/m^2]	[kLy]	[kWh/m^2]	[kLy]
UV	63	5	1523	131	**1586**	**136**
Vis	710	61	2618	225	3328	286
IR	570	49	1809	156	2379	205
Total	1343	115	5950	512	**7293**	**627**

Test conditions
Ambient air temperature during the solar radiation was in the range of 30 – 40℃. During the high-intensity solar radiation, Exposure 2, cooling air was used to prevent overheating of the samples. Maximum surface temperature of the samples was ≤ 70℃ (black samples).

The first part of the test, Exposure 1, i.e., 1232 h of solar radiation, was carried out in cycles. The 24-hour test cycle consisted of 22 h solar radiation and 2 h spraying. The spraying was done using purified water. Once a week the water spray was replaced with salt spray. Details can be found in Ref. 1.

Figure 2 shows the samples under solar irradiation.

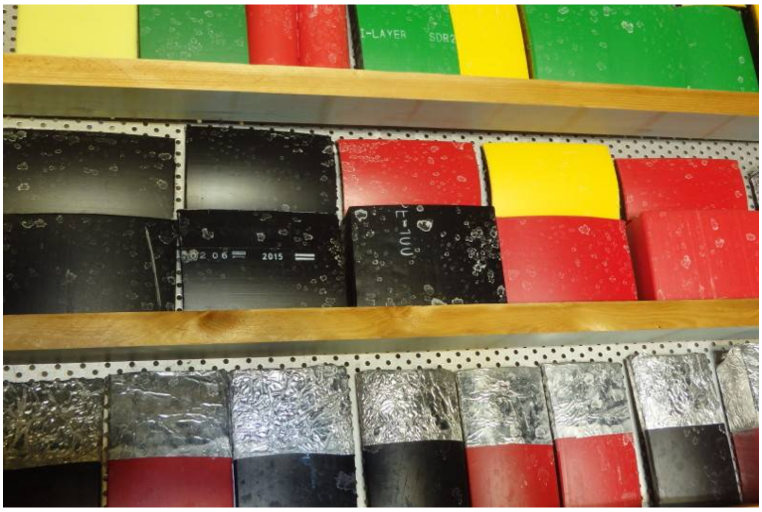

Fig. 2. *Test arrangement showing the samples under solar irradiation during Exposure 1. Note: A larger set of samples was involved in the first part of the test (Exposure 1).*

Measurements
Colour measurement was performed a few times during the test. A chromaticity coordinate zone analysis was carried out in connection with the colour measurements. The samples were wiped with a soft cloth which had been soaked in tap water before each colour measurement.

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Visual observations

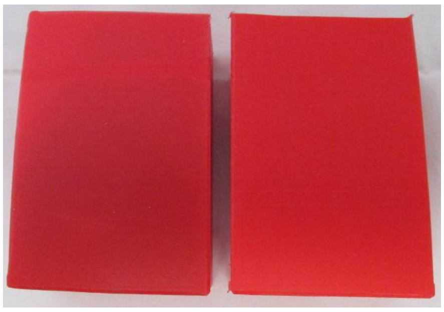
The samples were visually investigated and photographed with non-irradiated reference samples. The photographs are shown in Fig. 3. The non-irradiated reference sample is on the right in each photograph.

D400

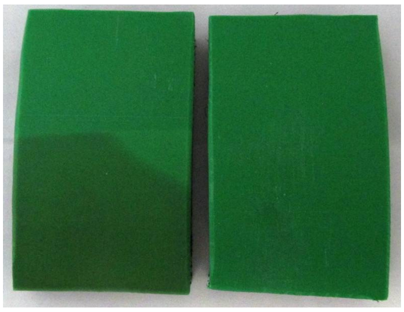
D800

D400

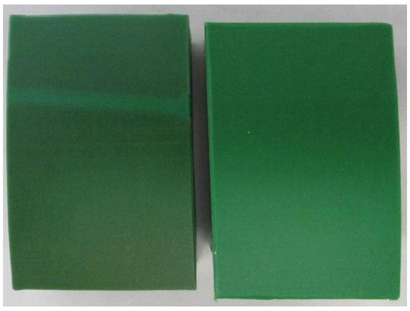
D800



D400



D800



D400

Fig. 3. *Samples photographed after the test. The sample exposed to solar radiation is on the left, and a non-irradiated reference sample is on the right.*

Used Equipment:
Solar simulator, No. 20
Solar test chamber, No. 42 / Ch3
Radiation intensity: Pyranometer No. 25, calibrated 28th April, 2015. Calibration is valid.
Multimeter No. 6, calibrated 12th May, 2016. Calibration is valid.
Temperature: IR Camera No. 58, calibrated 29th January, 2016. Calibration is valid.
No. 42 / Ch3_1, calibrated 27th January, 2016. Calibration is valid.
Colour: Spectrophotometer No. 70, calibration is made before every measurement session. Calibration is valid.

Analysis:

Optical Analysis

The *L*a*b** colour coordinate values of the samples were measured with a spectrophotometer. The reflected specular component from the samples is included in the *L*a*b** values. Colour difference ΔE represents the Euclidean distance between two colours according to Eq. 1.

$$\Delta E=\sqrt{\Delta L^{*2}+\Delta a^{*2}+\Delta b^{*2}} \tag{1}$$

*L**-coordinate indicates the lightness of the sample. The bigger the value the lighter the sample.
+*a**-coordinate indicates the red direction and -*a** indicates the green direction.
+*b**-coordinate indicates the yellow direction and -*b** indicates the blue direction.
The colour coordinates are shown schematically in Fig. 4.

Under ideal viewing conditions a ΔE value of 1 represents a just perceptible colour difference to the human eye. However, the human eye sees differently colour differences in different colours. The differences in darker colours are more perceptible to the eye.

A colour can be characterized by two parameters: luminance and chromaticity. In the CIE system, a luminance parameter *Y* describes the brightness of the colour, and two colour coordinates *x* and *y* specify the point on the chromaticity diagram. The CIE 1931 chromaticity diagram is shown in Fig. 5.

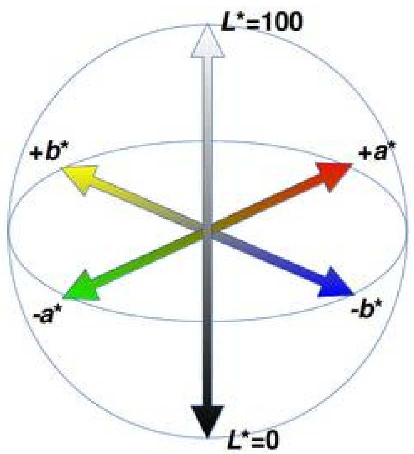


Fig. 4. *CIE L*a*b* colour coordinate system.*

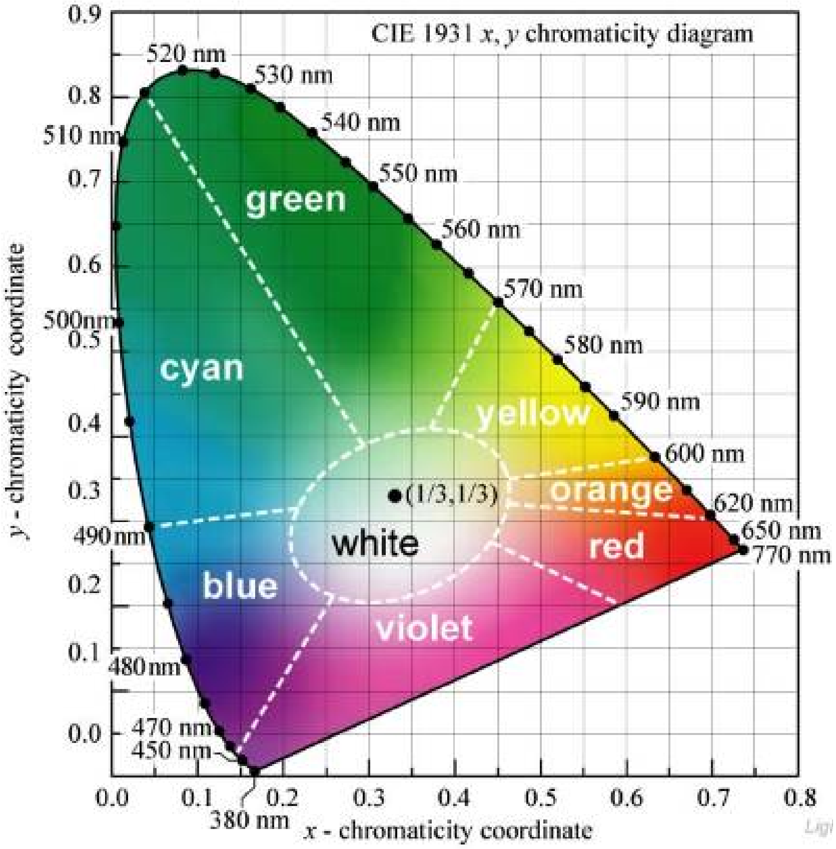


***Fig. 5.** CIE 1931 x, y chromaticity diagram.*

Colour change ΔE
Colour change ΔE (SCI, specular component included) as function of UV energy is shown in Fig. 6. The shape of the curves indicates that the rate of the colour change has been either slowed down or fully stopped at the end of the exposure. Each value is an average of five measurement points that cover the surface area uniformly.

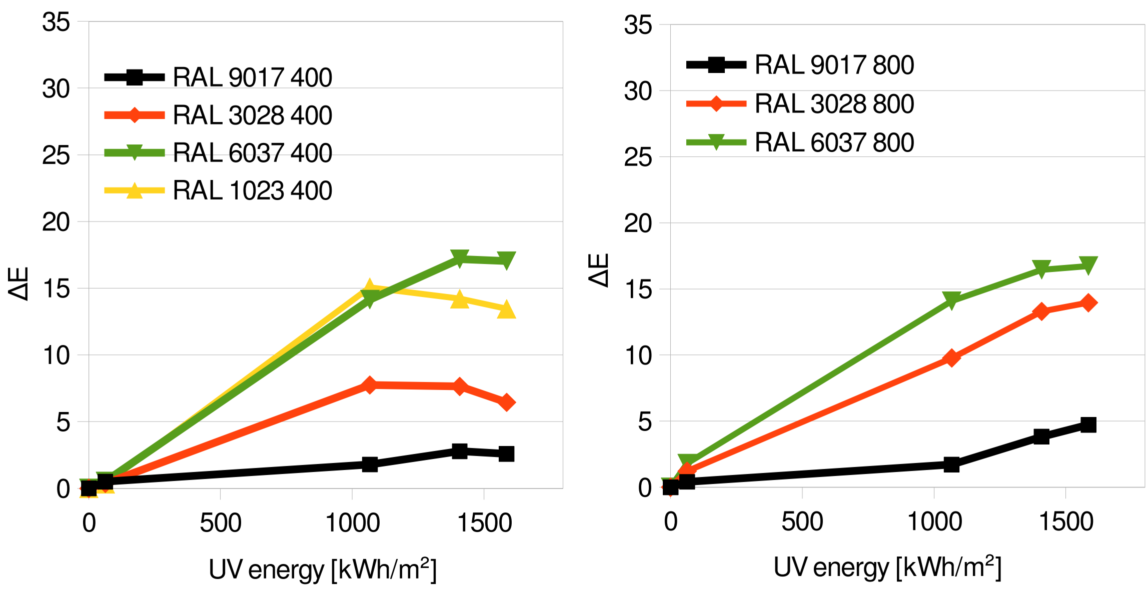


***Fig. 6.** Colour change ΔE as a function of UV energy.*

Chromaticity zone analysis

Chromaticity diagrams of the samples are shown in Figs. 7 – 11. The colour coordinates *x* and *y* were taken from a reflection spectrum measured from each sample with a spectrophotometer. The allowed chromaticity regions according to IALA Recommendation E-108 – Surface colours used as visual signals on aids to navigation, Edition 3, 2013, are shown in the diagrams. For the red colour, an extended chromaticity region for matt or semi-matt surface finishes was used.

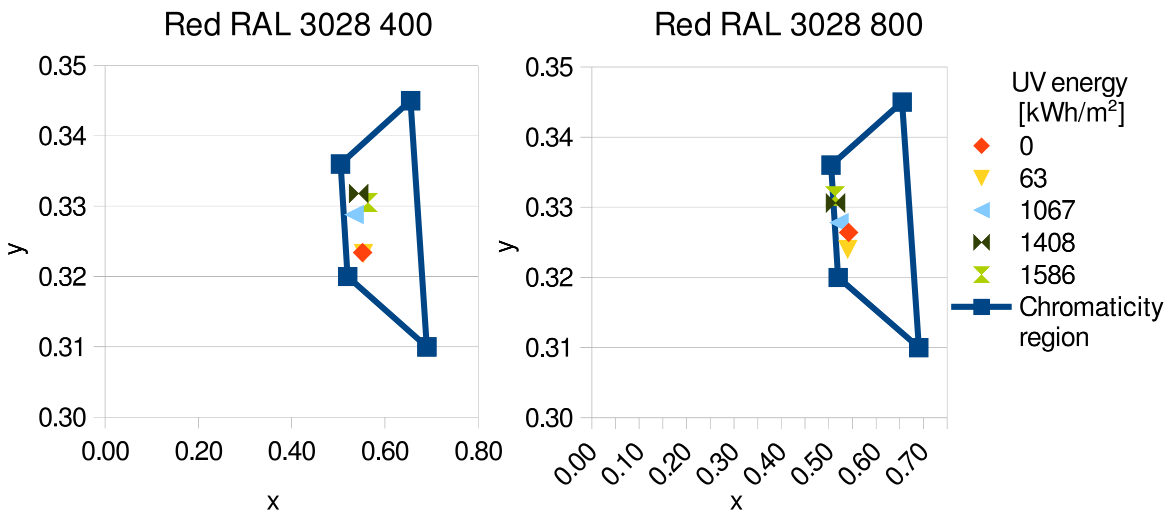


Fig. 7. *Chromaticity diagrams for red samples. The chromaticity region is according to IALA Recommendation E-108; extended Red for matt or semi-matt finishes.*

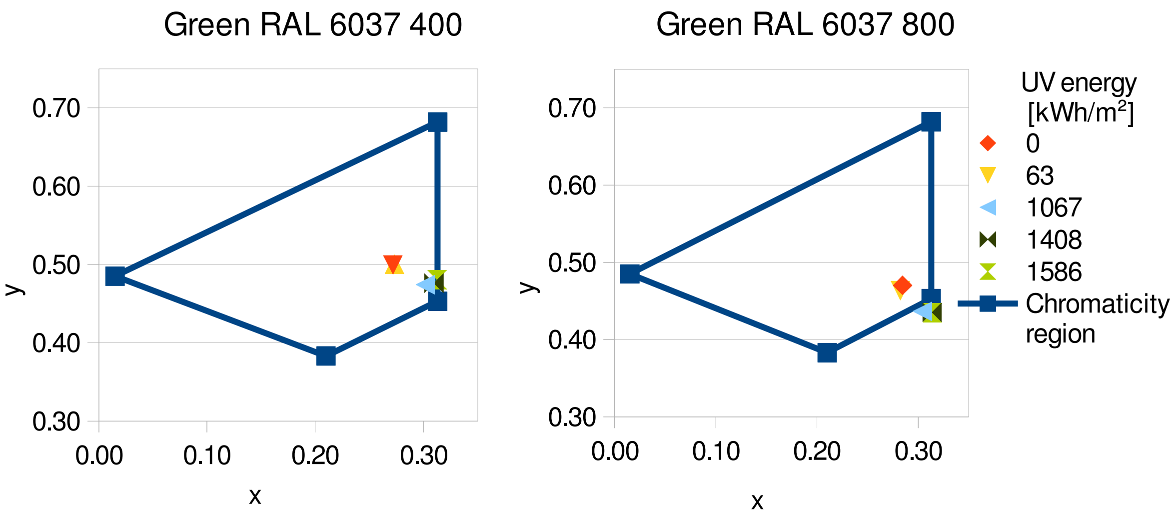


Fig. 8. *Chromaticity diagrams for green samples. The chromaticity region is according to IALA Recommendation E-108.*

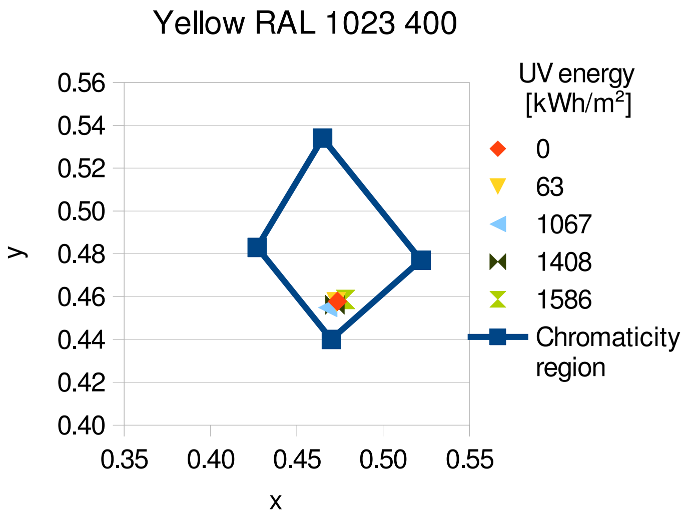


Fig. 9. *Chromaticity diagrams for the yellow sample. The chromaticity region is according to IALA Recommendation E-108.*

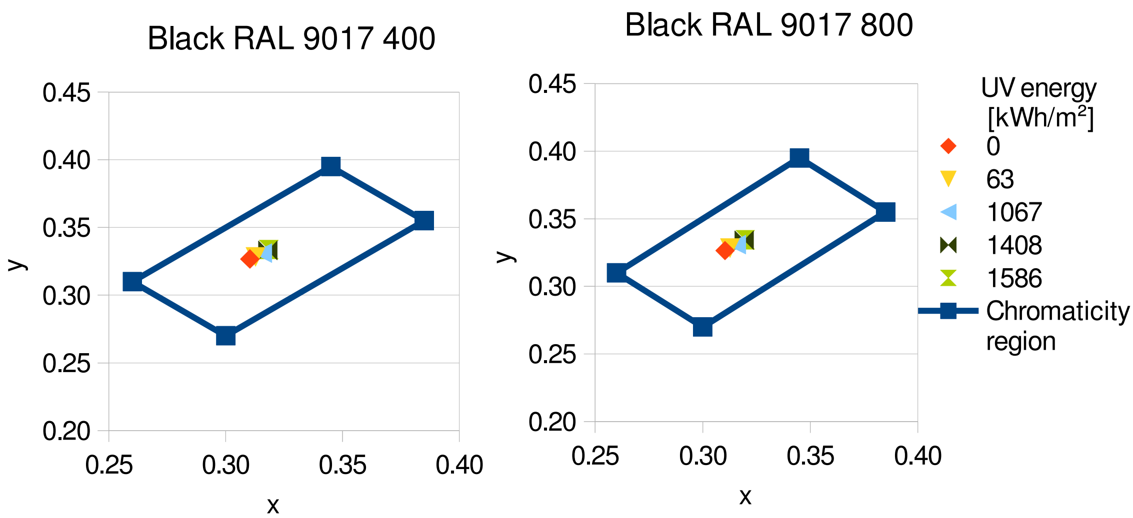


Fig. 10. *Chromaticity diagrams for black samples. The chromaticity region is according to IALA Recommendation E-108.*

Radiation Correspondence:
The mean solar radiation energy per year onto a horizontal surface as a function of latitude is shown schematically in Fig. 11 and the corresponding solar energies are given in units of kWh/m^2 and kLy in Table 5. The mean solar energy is an average of existing solar radiation data, e.g. Meteonorm Global Meteorological Database. It is presented as a function of latitude. Meteonorm Global Meteorological Database utilizes long-term measurement data of global solar radiation and scientific models.

An approximation of the correspondence of the solar energy load of this test to the natural solar energies in years is given in section Conclusions in Table 5. This estimate of the correspondence of the solar energy load of this test to the natural solar energies is based on the total UV energy dose and does not take into account the differences in the spectra of the simulated and natural radiation.

Since the surface of the buoys is in vertical position, the energy correspondence to vertical surface is also presented in Table 5. The maximum solar energy load to the vertical surface is received when the buoy is orientated to the equator, i.e., when it faces north in the Southern Hemisphere and south in the Northern Hemisphere. However, the buoys are not fixed and may change their orientation because of waves, ocean currents and tides and thus face to any direction. Therefore, a range between the worst case and random orientation is estimated and given in Table 5.

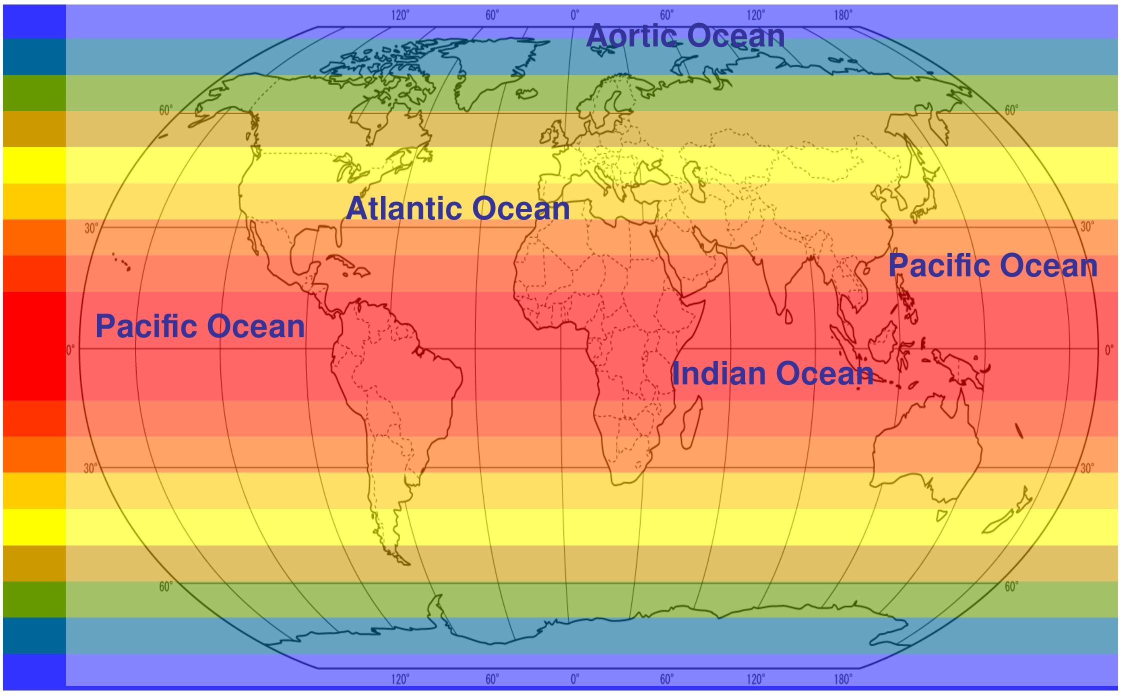


Fig. 11. *Mean solar radiation energy per year onto a horizontal surface as a function of latitude. The colour scale is explained in Table 5.*

Table 5. Mean solar energy per year as a function of latitude and an approximation of the correspondence of the solar UV energy load of this test (1586 kWh/m^2 / 136 kLy) to the natural solar energies in years. The colour scale used in Fig. 11 is shown in the left column.

		Solar energy per year		Correspondence in years	
		Horizontal		Horizontal	Vertical
	Latitude	[kWh/m²]	[kLy]	Years	Years
	90°N	0			
	80°N	850	73	32	
	70°N	950	82	28	
	60°N	1000	86	27	**28 – 37**
	50°N	1200	103	22	**26 – 34**
	40°N	1500	129	18	**23 – 29**
	30°N	1800	155	15	**23 – 27**
	20°N	2000	172	13	**24 – 29**
	10°N	2150	185	13	**25 – 28**
	0	2300	198	12	**23 – 27**
	10°S	2150	185	13	**25 – 28**
	20°S	2000	172	13	**24 – 29**
	30°S	1800	155	15	**23 – 27**
	40°S	1500	129	18	**23 – 29**
	50°S	1200	103	22	**26 – 34**
	60°S	1000	86	27	**28 – 37**
	70°S	950	82	28	
	80°S	850	73	32	
	90°S	0			

Recommendations:

N/A

Conclusions:

The test specimens, plastic material samples of navigation buoys, in colours black, red, green and yellow, were exposed to solar radiation until an UV-energy dose, which corresponds to at least 23 years in natural conditions on vertical surfaces, was reached.

The black, red, green and yellow colours of the navigation buoys remained in chromaticity regions according to IALA Recommendation E-108 – Surface colours used as visual signals on aids to navigation, Edition 3, 2013. Green RAL 6037 (sample D800) was just at the border of the green chromaticity region after the exposure.

The visual appearance of the colours was however changed due to changes in gloss and/or lightness of the colour that are not taken into account in the IALA Recommendation for chromaticity regions.

Remarks:

This Executive Summary Report is derived from a comprehensive test report MeritaitoVirtanen__tr091116RP.pdf [2].

The presentation “Colour Stability of Navigation Buoys, Seahow - Youtube” [3] has been created on the basis of this test report.

Actions, operations and reporting are in accordance with IEC/ISO 17025 'General requirements for the competence of testing laboratories'.

References

[1] Test Report: MeritaitoVirtanen__ex290616HS.pdf
[2] Test Report: MeritaitoVirtanen__tr091116RP.pdf
[3] Colour Stability of Navigation Buoys, Seahow – Youtube
https://www.youtube.com/watch?v=Ub0nNdSZ5Q8

Signatures:

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Littoinen, 8th December, 2016
Solar Simulator Finland

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