# IMPACT OF 222 NM UV-C RADIATION ON COLOR ACCURACY OF VIDEO DISPLAYS IN PUBLIC BUSES

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**Abstract**

*The purpose of this study is to investigate the effects of 222 nm UV-C radiation on the color accuracy of bus interior materials, specifically video displays. The research examines the effects of exposing bus interior displays to UV-C radiation and measuring the resulting changes in monitor color accuracy over time. This wavelength of UV-C radiation is commonly used for disinfection purposes and can be used against COVID-19. The results show that UV-C radiation has a significant negative effect on display color and other parameters. The results may be useful in ensuring optimal color accuracy and durability under UV-C exposure, while providing a safe and effective method of disinfection against COVID-19.*

**Keywords:** *UV-C radiation, video display, public bus, color difference, correlated color temperature, gamma*

## 1. INTRODUCTION

The use of ultraviolet (UV) radiation for disinfection has been a well-established practice for many years and has become particularly relevant in the wake of the COVID-19 pandemic. Among the different types of UV radiation, UV-C has been shown to be particularly effective in inactivating a wide range of microorganisms, including SARS-CoV-2, the virus that causes COVID-19 (Buonanno et al., 2020). This is due to its ability to disrupt the genetic material of micro-organisms, preventing them from replicating and causing them to die. The use of UV-C radiation for disinfection has been implemented in various settings, including public transport, to reduce the spread of infectious diseases.

However, the use of UV-C radiation for disinfection also raises concerns about the potential negative effects on the materials and equipment used in these environments. UV-C radiation can cause photodegradation of materials, leading to changes in their physical and chemical properties (Yates et al., 2021). This can affect their performance and lifetime, causing problems such as discoloration, fading and cracking. Therefore, in this work we will investigate the potential negative effects of UV-C radiation on video displays used by bus drivers and passengers to detect changes in displayed image quality. The main objective of this study is to find out whether 222 nm UV-C radiation affects the color accuracy of video displays in buses and what are the potential problems associated with the use of UV-C radiation for disinfection in bus interiors. The results of the study will be used to guide the design of bus interiors and video displays to maintain high levels of color accuracy and longevity in the presence of UV-C radiation, while ensuring a safe and efficient method of disinfecting buses against COVID-19.

## 2. RELATED WORKS

In recent years, many studies have analysed the quality of different display devices. Many authors have investigated the effects of indoor lighting on the image quality of display screens, suggesting that ambient light not only affects the perceived color on a screen, but also affects the diagnosis of radiological images (Xu et al., 2020). Other researchers have found that display ageing is an important factor in the performance and image quality of various display devices, including mobile displays and LCDs. For example, Al-Murshedi et al. highlighted the importance of considering the effects of aging in applications such as radiological imaging, where display performance plays a critical role in diagnostic accuracy (Hogg, 2018). Walz-Flaningan et al. discuss the aging and quality control of color liquid crystal displays (LCDs) used in radiological imaging. The authors examine the effects of aging on the color accuracy and image quality of LCDs, and propose methods for monitoring and maintaining the performance of these displays over time. The article concludes that regular monitoring and calibration of LCDs is essential to ensure that they continue to provide accurate and reliable images for radiological imaging (Walz-Flannigan et al., 2011). Hellen-Halme et al. discuss the effect of ageing on the luminance of standard liquid crystal display (LCD) monitors. The authors examine the changes in luminance that occur over time as LCD monitors age and the impact of these changes on image quality. The study found that luminance decreased over time in all 180 monitor models tested. There was no difference in the rate of luminance decline between the monitor models. Different luminance values were found for different areas of the monitors, but no area deteriorated faster than another (Hellén-Halme et al., 2011). Krupinski et al. conducted a study to investigate whether the age of liquid crystal displays (LCDs) has any effect on the diagnostic accuracy and visual search efficiency of radiologists interpreting clinical images. Three LCDs with different levels of simulated ageing were used: new, 1 year old and 2.5 years old. The results of the study showed that there was no statistically significant difference in the diagnostic accuracy or visual search efficiency of radiologists using LCDs up to 2.5 years old. The shift of the white point towards yellow as LCDs age does not have a significant effect on the diagnostic accuracy or visual search efficiency of radiologists, at least up to 2.5 years of age (Krupinski et al., 2007).

The accuracy of color measurement and display evaluation technology has also been extensively addressed by researchers. The authors focus on the accuracy of color measurement technology and devices, such as handheld print-art spectrophotometers, smartphones, and various types of spectrophotometers. They examine factors that can affect the accuracy of these devices, such as time dependence and device independence, through the use of different colorimetric models, color spaces and color reproduction algorithms. Studies such as Tarasov and Milder (Tarasov and Milder, 2020) have highlighted the device dependence of color measurements and the change in color measurements over time as important factors to consider when using these devices. They also address the issue of measuring instruments, including their calibration, using different standards and methods to ensure the precision and accuracy of the measurements. Studies such as Zwinkels (Zwinkels, 1996) have examined the use of different standards and methods to ensure the precision and accuracy of measurements. This is critical in many areas such as the graphic arts, textile and paint industries where color consistency is a key factor in product quality.

Another important aspect is how to evaluate and optimise display performance. Authors have investigated factors that may affect the performance of these displays, including luminance inhomogeneity, viewing angle, resolution, magnification, and window settings (Kawamoto et al., 2017). Others (Hatanaka et al., 2009) have investigated the effect of viewing angle on observer performance and compared the performance of different types of displays. This is crucial in applications such as radiological imaging, where display performance plays a critical role in diagnostic accuracy. Elze and Tanner (Elze and Tanner, 2012) have investigated the temporal characteristics of LCDs and their impact on the user experience. They also include the evaluation of image quality for medical LCDs, using different metrics and methods to assess the diagnostic performance of the display and the influence on the observer's interpretation of the medical images.

Despite the fact that many studies have been carried out to analyse the quality of display devices, including the effects of ageing, interior lighting and color measurement accuracy, there has been no research into the 222 nm UV-C radiation on the color accuracy of LCD video displays used to display information to passengers in bus interiors. This wavelength of UV-C radiation is commonly used for disinfection purposes, particularly against COVID-19.

## 3. MATERIALS AND METHODS

### *3.1. Materials*

The AOC E970SWN monitor is a video display that was chosen to measure color accuracy in this study. It is an 18.5-inch monitor with a resolution of 1366x768 pixels and an aspect ratio of 16:9. It has LED backlighting and a viewing angle of 90 degrees. The AOC E970SWN has a contrast ratio of 600:1 and a brightness of 200 cd/m². It has a response time of 5 ms. It also supports 16.7 million colors. This monitor was chosen to measure color accuracy in this study because it is a common type of video display used in buses.

*3.2. 222 nm UV-C radiation on video display*

The specialized UV-C exposition chamber has been designed and developed to simulate the effects of prolonged exposure to UV-C light on various materials. It consists of two Quantadose B-Series DF28B-B3 20 watt filtered 222nm UV-C excimer lamp modules fitted with 222nm bandpass filters and a special housing to cool and protect the lamps from damage. The lamps are powered by a special 40W input high voltage excimer lamp electronic power supply. This specific wavelength of UV light has been shown to be highly effective in killing bacteria and other micro-organisms, while being less harmful to human cells, making it a safe and effective option for research (Buonanno et al, 2013). The use of bandpass filters in the lamp modules ensures that only the desired wavelength of UV light is emitted, further enhancing the precision and accuracy of the UV-C exposition chamber. These modules are installed in a specially designed box which helps to minimize the amount of ambient light entering the chamber, further enhancing the accuracy of the UV-C exposure process. The specially designed housing for the lamp modules and the use of a dedicated power supply ensure that the UV-C exposition chamber is safe and easy to use. The photos of the developed UV-C exposition chamber are shown in Figure 1 with the specified equipment and components.

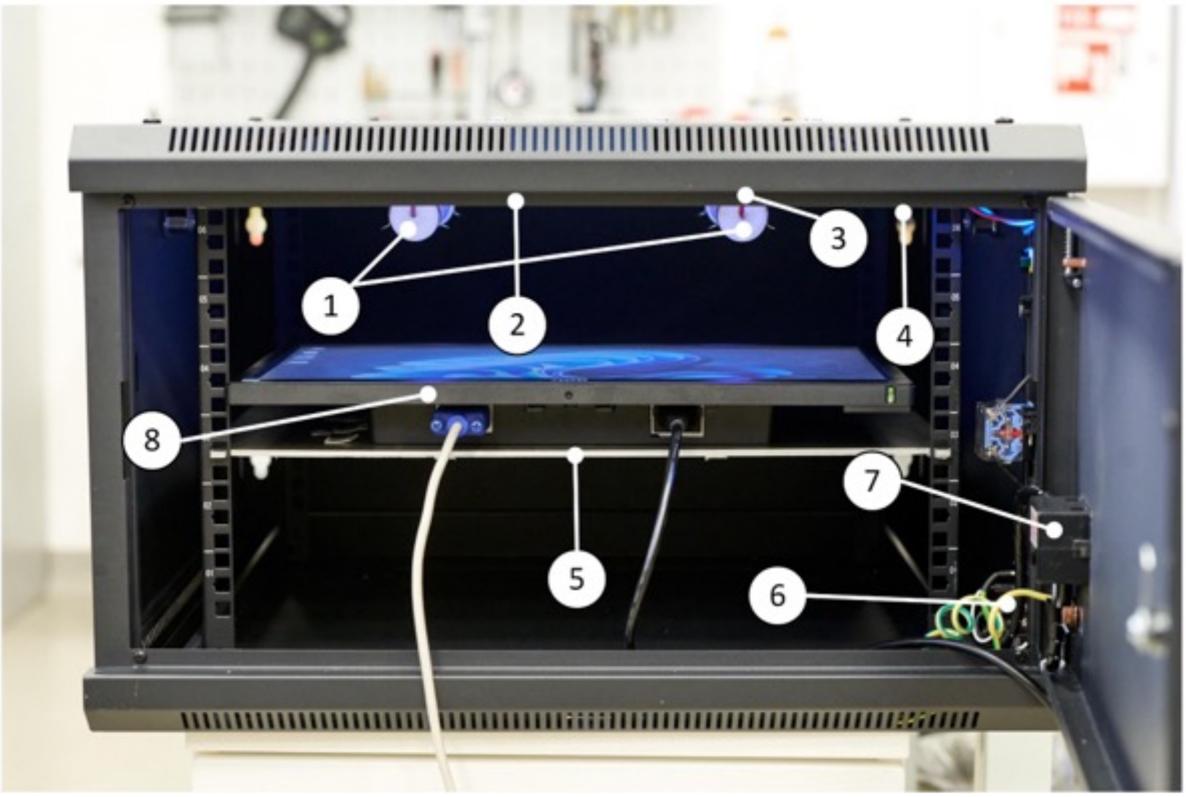


**Fig. 1.** Developed 222 nm UV-C exposition chamber: 1 – 2X 222 nm Bulbs; 2 – 2 x 24 V coolers for temperature control; 3 – Bulb blaster; 4 – power supply; 5 – exposition plate; 6 – safety switch (Thumb); 7 – irradiation controller (timer), 8 – tested video display

The intensity of the UV-C radiation in the UV-C exposition chamber can be varied by adjusting the exposure distance from the light source. The irradiance step can be varied in 13 mm increments, from

18 mm to 330 mm. The ability to adjust the irradiance distance in 13mm increments allows for a wide range of irradiance levels to be tested, from low to high intensity UV-C radiance. This allows for a detailed study of the effects of different UV-C irradiance levels on the materials being tested. This feature also allows for the simulation of different UV-C exposure and disinfection scenarios, for public transport environments.

The spectra of the lamps used in the UV-C exposition chamber were measured using an Avantes AvaSpec ULS2048 CL spectroscope. To ensure accurate measurements, the spectra of the lamps were taken at a distance of between 5 cm and 10 cm from the light sources. This distance was chosen to ensure that the spectra were not affected by any scattering or absorption of light within the UV-C exposition chamber. The spectroscope was also used to measure the far UV-C disinfection spectrograms. The spectrogram of the direct light from the lamps is shown in Figure 2. As can be seen from the graph, the lamps emit light mainly at a wavelength of 222nm. The graph also shows that the lamps emit very little light at other wavelengths, minimising the potential for harmful UV exposure to humans.

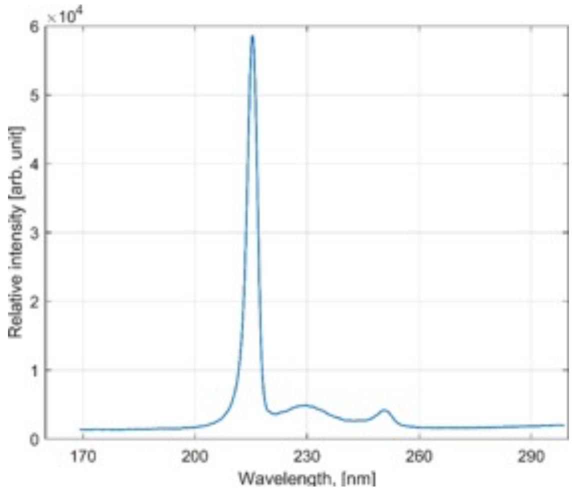


**Fig. 2.** Spectrogram of the light of UV-C lamps used in this research

Radiation intensity and exposure time are critical factors in determining the effects of 222 nm UV-C radiation on materials. Irradiation refers to the amount of energy per unit area delivered to the material, while irradiation time refers to the duration of exposure. The combination of irradiation intensity and time determines the total energy delivered to the material and can have a significant effect on the color and mechanical properties of the material.

Taking into account previous studies (Su et al., 2022, Matsuura et al., 2022, Kitagawa et al., 2021, Moreno et al., 2021, Naveen and Gurtoo, 2022) that have determined UV-C radiation doses for effective disinfection and longevity of use of public buses, the following radiant exposure iterations for displays were selected in this study: 96.714 J/cm2, 193.428 J/cm2 and 290.142 J/cm2.

*3.3. Measurement of display color accuracy before and after UV-C exposure*

The X-Rite i1Display Pro instrument was used to initially calibrate the selected display (Fig. 3). This is a color calibrator widely used in the industry for measuring and adjusting the color accuracy of displays. It is a hand-held instrument that contains a spectrophotometer, a device that measures the color accuracy of a display by analysing the light emitted by the display in different areas and comparing it to the ideal color accuracy.

The instrument has a measurement range of 0.1 to 200 cd/m² and it can measure up to a maximum of 2048 color patches per display. It also has a measurement uncertainty of ≤ΔEab 0.3 at 50% white and a measurement repeatability of ≤ΔEab 0.15.

In this study, the X-Rite i1Display Pro was used to measure the display color parameters before any UV-C irradiation and after each iteration UV-C radiant exposure. The device was used to take multiple color accuracy measurements at different points on the display and the results were analysed using color measurement software, which provided a detailed report of the color accuracy of the video displays, including Delta E values, a standard measure of color difference. Using the X-Rite i1Display Pro ensured that the color accuracy measurements were accurate and comparable, providing an objective and reliable assessment of the effect of UV-C radiation on the color accuracy of the video displays in the buses.


**Fig. 3.** Measurement of the display color parameters using X-Rite i1Display Pro

The measurements of color accuracy before and after UV-C exposure were analysed using specially developed Matlab scripts to determine the effect of UV-C radiation on the video displays.

The main metric that has been used to assess the quality of a monitor before and after UV-C irradiation is the color difference ΔE00 (CIEDE2000) (CIE, 2001). It quantifies the difference between two colors. It's calculated as the difference between two sets of color values (such as RGB or LAB) and gives a single number that represents the perceived difference between the two colors. The comparison of two colors measured in the CIELAB color space is done using the following formula:

$$\Delta E00 = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)}$$

The full derivation of this formula is given in (Sharma et al., 2005)

ΔE00 is widely used in color science and technology, as it allows for objective color comparisons and helps ensure color consistency across different materials and devices. According to (Electronics for Imaging, Inc., n.d.) this metric can be interpreted as follows:

- 0 - 1 – a normally invisible difference
- 1 - 2 – very small difference, only obvious to a trained eye
- 2 - 3.5 – medium difference, also obvious to an untrained eye
- 3.5 - 5 – an obvious difference
- >5 – a very obvious difference

## 4. RESULTS AND DISCUSSION

This study evaluates the effect of UV-C radiance exposure on video displays in terms of pixel color differences, correlated color temperature and gamma parameters. The first measurement of the following parameters was made before any UV-C exposure and measurements 2, 3 and 4 were made iteratively after 96.714 J/cm2, 193.428 J/cm2 and 290.142 J/cm2 UV-C exposures respectively. As can be seen in Figure 4, even after 96.714 J/cm2 of irradiance, there is a very small difference that is only apparent to the trained eye on average in the colors displayed, and when the irradiance is increased, these color differences, although fluctuating, remain significant. And in Figure 4 we can see that the maximum difference of individual colors increases even to an obvious difference after 290.142 J/cm2 UV-C radiance exposure.

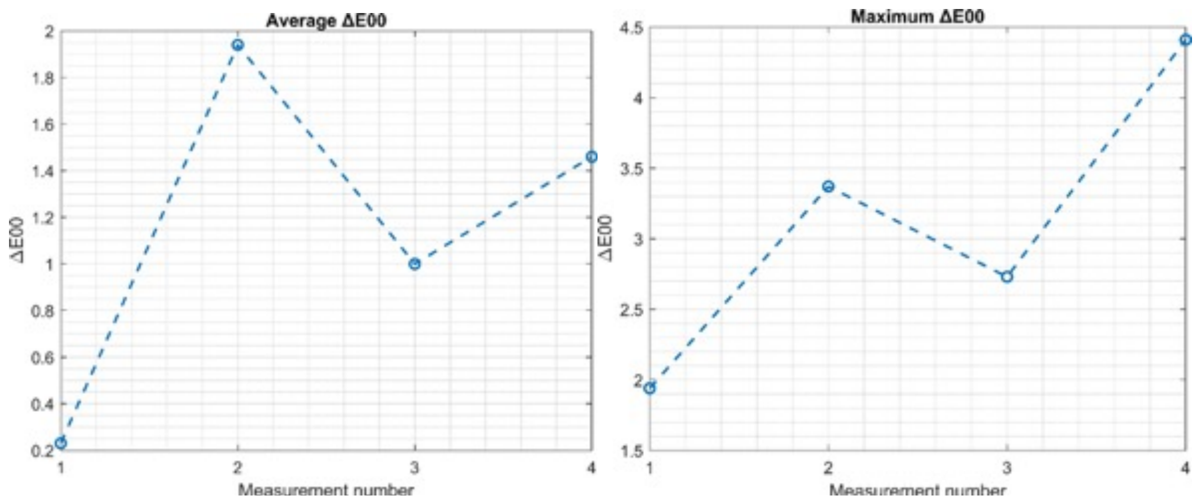


**Fig. 4.** Average (left) and maximum (right) color difference ΔE00 measured for the respective UV-C radiant exposure iterations

Figure 5 shows the difference in the corresponding colors after each measurement iteration taken after the application of UV-C radiation. It can be seen that there is a clear color difference in certain color groups, especially in the black and dark grey color groups.

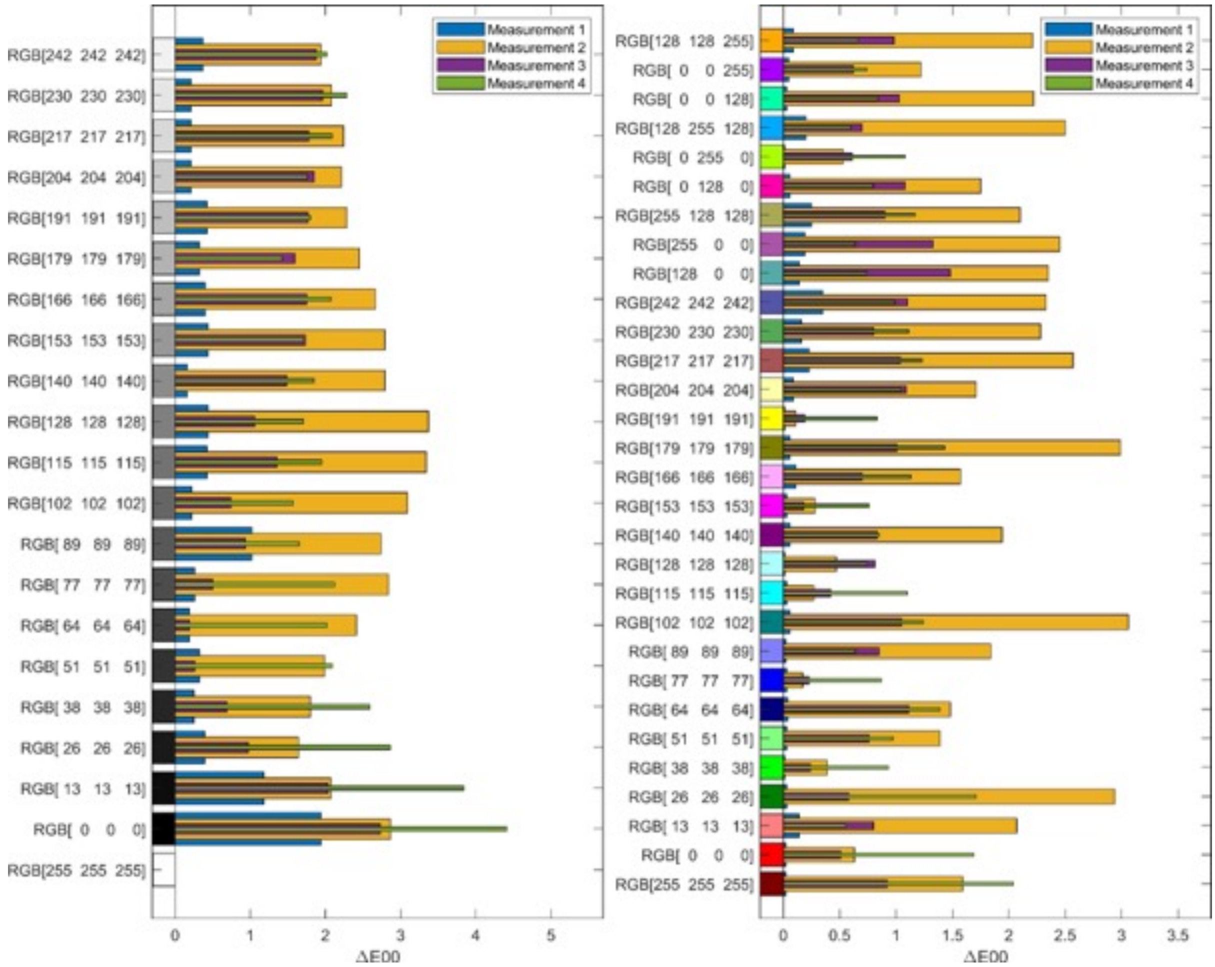


**Fig. 5.** ΔE00 of the corresponding pixel colors measured for the respective UV-C radiant exposure iterations

The correlated color temperature and gamma were also compared after each level of exposure (Fig. 6). As can be seen from the graph, the greatest effect of radiation exposure is observed at the lowest and highest display luminance percentages, where the greatest deviations from the nominal values are observed. Even greater differences between nominal and measured values can be seen when comparing the gamma parameters, with particularly large deviations occurring at the highest display luminance percentages.

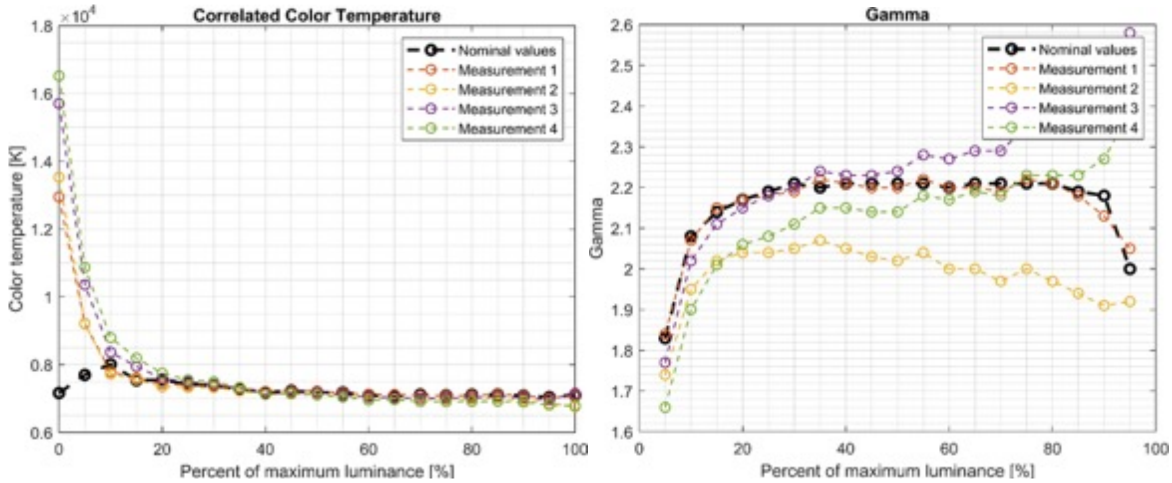


**Fig. 6.** Correlated color temperature (left) and gamma (right) measured for the respective UV-C radiant exposure iterations

In summary, 222nm UV-C radiant has a significant negative effect on all display parameters: pixel color differences, correlated color temperature and gamma. We can also see that at 96.714 J/cm2 exposure, significant changes in all these parameters are observed. As the irradiance increases, the correlated color temperature and gamma deviations only increase, as does the maximum pixel color difference.

## 5. CONCLUSIONS

Based on the results of the study, it can be concluded that UV-C radiance exposure has a negative impact on the quality of displays used in public transport. Exposure to UV-C radiation causes noticeable color differences, particularly in the black and dark grey color groups, and affects the correlated color temperature and gamma parameters of the display. It is important to consider the effects of UV-C radiation on displays in public transport as it may affect the readability and visibility of information presented on the displays. Therefore, measures should be taken to reduce the exposure of public transport displays to UV-C radiance, such as the use of protective screens or limiting the exposure time, in order to maintain the quality of the displayed image and ensure that passengers receive accurate and clear information.

## ACKNOWLEDGMENTS

This research has received funding from European Regional Development Fund (project No 13.1.1-LMT-K-718-05-0002) under grant agreement with the Research Council of Lithuania (LMTLT). Funded as European Union's measure in response to Cov-19 pandemic.

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