Investigation of the Potential Use of Blue Light in Forward Scattering Optical Smoke Chambers to Detect all UL217 Fires in the New Standard

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Abstract

In this study we investigate the response of blue (470 nm) light and infra-red IR (870 nm) in different types of smouldering and flaming fires to investigate their potential to detect all UL217 fires in the new standard. We show that correlation between the European EN smoke tunnel and the American UL smoke box does not exist for both blue and IR optical chambers. In the study we show that blue light responds better in flaming fires than IR light, including the new flaming polyurethane test. We also show that during the nuisance broiling hamburger test, the blue response is possibly larger than that of any of the actual flaming fires. However, though there is potential to pass the new UL217 standard, this is just an initial study and a wide range of comprehensive testing is still required.

Keywords: UL217, fire detection, forward scattering, optical chamber, blue light

Introduction

With the recent adoption of ANSI/UL 217-2015 [1], smoke alarms must undergo a variety of new fire tests in order to pass the standard. Smouldering and flaming polyurethane, along with a nuisance test, broiling hamburgers, will prove the most challenging to pass due to the similarities of the test obscuration and ionisation profiles. Recently, the National Institute of Standards and Technology, conducted a study in which 45 commercially available smoke alarm models from 7 different manufacturers were fire tested to the new standard. This study found that no alarms currently on the market could meet the new standard [2].

Therefore, it is clear that either a major overhaul of current technology, or an introduction of new technology is required to pass the new fire tests. It has been shown that flaming polyurethane fires produce smoke particles with an average particle diameter of less than 0.05 μm, as compared with 0.1 μm for smouldering ponderosa pine [3]. Theory suggests that smaller incident wavelengths such as blue light instead of current infra-red (IR) light, will have an increased scattering signal for smaller particle sizes [4]. Therefore, optical smoke sensors incorporating blue LEDs with smaller wavelengths may have the potential to better detect the new UL217 flaming polyurethane test fire.

The use of blue LEDs to detect smoke is not a new technology and the concept of its use has been described previously [5]. There are a number of smoke detection units currently on market combining blue and IR LEDs. One such company, Nest have published a white paper in which they show that their response time is improved in flaming fires with the use of split-spectrum blue and IR LED sensor [6]. However, as shown in the white paper, eliminating false alarms during the nuisance hamburger test has remained elusive. While previous studies have discussed the response of blue LEDs, the raw data has not been included. In this study, the data from both blue and IR LEDs in a range of test fires will be presented. Using this data the potential for the use of blue LEDs to pass the UL217 standard will be discussed.

Experimental

A blue LED, λ = 470 nm and an IR LED, λ = 870 nm, were mounted within standard Ei Electronics optical chambers. Both sets of LEDs had the same viewing angle and luminous intensity. Initial testing and calibration was carried out in an AW Technologies 1000 series smoke tunnel, with a Topas Aerosol Generator ATM 225 and a UL smoke box. The smoke tunnel utilises paraffin aerosol, and is used to conform to the European EN standard, while the UL smoke box utilises cotton wick and is used to conform to the North American UL standards. Further testing was carried in a custom built Ei Electronics smoke test box, while official testing was carried out in an EN fire test room in ANPI, Belgium.

Theory

Light scattering by small sub-micron sized particles is governed by Mie scattering theory. The general solution for Mie scattering is found through the application of Maxwell's equations. However, a simplified approximation of Mie scattering is given in Eq. 1 [7].

$$Q = 2 - \frac{4}{p}\sin p + \frac{4}{p^2}(1 - \cos p) \qquad \text{(Eq. 1)}$$

Where, $p = \frac{4\pi a(n-1)}{\lambda}$

Q = efficiency factor of scattering

n = refractive index of the particle

a = diameter of the particle

Λ = wavelength of incident light

Taking the refractive index of smoke particles as 1.5 [8], the theoretical scattering Q factor for blue and IR light is shown in Fig. 1. This theory indicates that for particles below 0.1 µm blue light will scatter 3 times more efficiently than IR light, while for particles close to 1 µm both blue and IR light should scatter a similar amount. Utilizing this knowledge, we will investigate if the ratio of blue to IR light scattering can be used to determine the fire type to potentially pass the new UL217 standard.

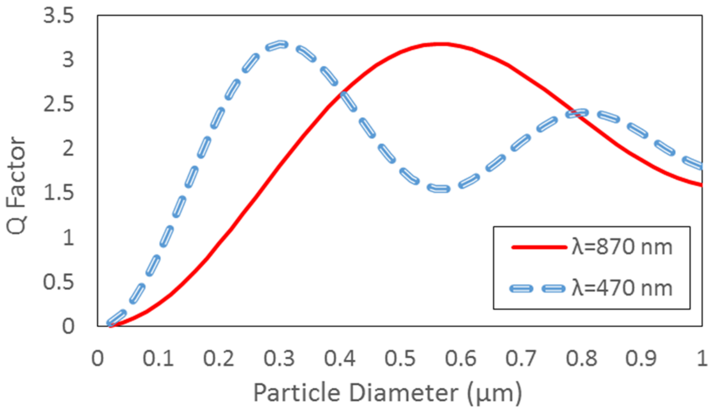

Fig. 1. Theoretical scattering strength of blue light (λ = 470 nm) and IR light (λ = 870 nm) according to the van de Hulst approximation for Mie Scattering [7] taking the refractive index of smoke to be 1.5.

Results

Initial calibration of the blue and IR optical chambers was carried out in the European EN standard smoke tunnel. This tunnel utilizes atomised aerosol paraffin oil which has an approximate particle diameter of less than 1 µm [9]. The gain factors both blue and red optical chambers were calibrated to give the same output during a test ramp within the EN smoke tunnel as shown in Fig. 2. This is the same test that is carried out during testing for the European EN Standards.

Although the blue and IR optical units are calibrated together in the EN smoke tunnel, the results of the UL smoke box with smouldering wick are remarkably different. As shown in Fig. 3 the blue LED response is approximately 5 times larger than the IR LED response. The average particle diameter of smouldering cotton wick is 0.09 µm [3]. Due to the small size of these smoke particles theory states that blue light will scatter more than red light. However, an increase by a factor of 5 is more than expected. There is no simple explanation for this, but factors such as the smoke particle shape, particle colour or clumping of smoke particles is not taken into account in the theory and can affect the scattering intensity.

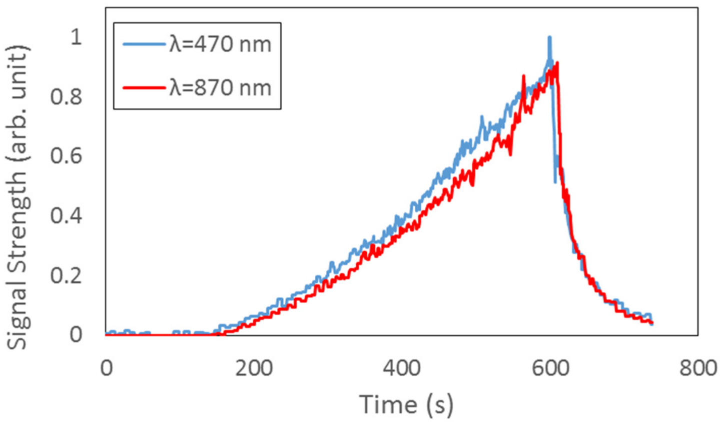

Fig. 2. Comparison of the signal strength response of blue LED (λ = 470 nm) and IR LED (λ = 870 nm) to aerosol paraffin in the EN smoke tunnell.

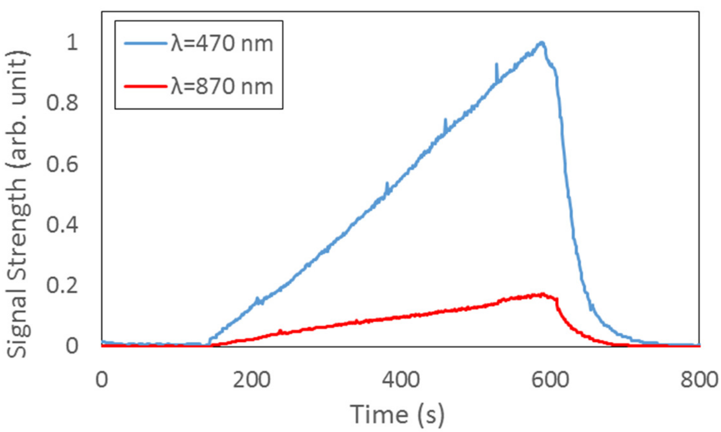

Fig. 3. Comparison of the signal strength response of blue LED (λ = 470 nm) and IR LED (λ = 870 nm) to smouldering cotton wick in the UL smoke box.

These initial results are promising as blue light is scattered more in small particles than IR light. However, it is clear that calibration of the blue and red optical chambers is not comparable between the UL and EN smoke tests. As testing is carried out in actual fires with real smoke, the units were both calibrated to the same sensitivity in the UL 217 box for all further tests in this study.

Theoretically flaming fires produce smaller smoke particles than smouldering fires. A simple check of this was carried out in the Ei smoke chamber testing both smouldering and flaming paper fires. The results of the smouldering and flaming fires are shown in Fig. 4 and 5 respectively.

For the smouldering paper the response of the IR and blue LEDs are similar and no clear distinction between their responses can be made. This is expected as the mean particle diameter for smouldering paper is approximately 0.1 µm, similar to that of smouldering cotton wick, with a particle diameter of 0.09 µm [3].

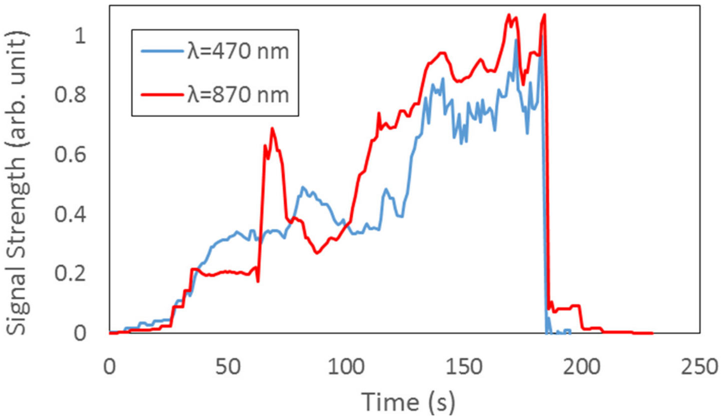

Fig. 4. Comparison of the signal strength response of blue LED (λ = 470 nm) and IR LED (λ = 870 nm) to smouldering paper in a custom built smoke chamber.

However, during the flaming paper combustion the blue LED response is up to a factor of 4 times stronger than the IR LED response. The mean particle diameter for flaming paper combustion is 0.04 µm [3], just under half that of smouldering combustion. This decrease in mean particle size results in an increased scattering ratio between IR and blue light.

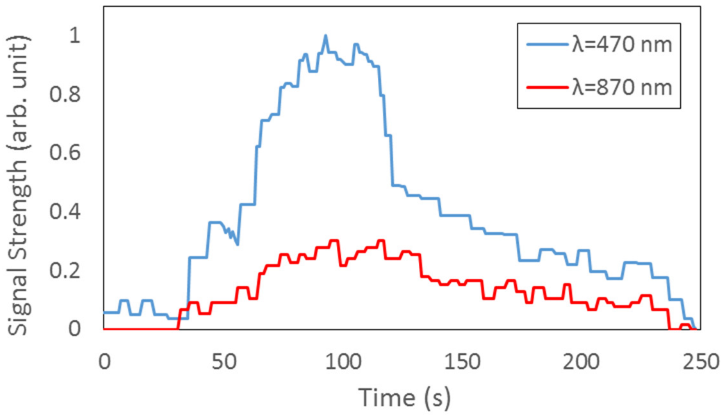

Fig. 5. Comparison of the signal strength response of blue LED (λ = 470 nm) and IR LED (λ = 870 nm) to flaming paper in a custom built smoke chamber.

Similar results were also found for flaming wood with a blue LED response between 2 and 3 times larger than that of the IR LED. Flaming wood has a larger particle diameter than flaming paper, 0.06 µm [3], so the small decrease in the observed response may be attributed to Mie scattering theory, though other effects such as particle shape and colour may also affect the scattering ratio. These results prove that blue light has the potential to distinguish between smouldering and flaming fires.

However, it is the response to flaming polyurethane that is of most interest to this study. The response of the blue and IR LEDs to flaming polyurethane in the Ei test box are shown in Fig. 6. The blue signal recorded is approximately twice as strong as the IR signal. Polyurethane foam has a particle diameter of approximately 0.05 µm, so an increased signal from the blue LED is expected. However, the ratio of blue to IR signal is not as strong as that observed for flaming paper and flaming wood. The cause is not clear, but again may be due to particle colour or refractive index which can also influence the scattering intensity.

Although this internal testing shows promising results, fire tests in an accredited lab are required to confirm the initial findings. Large scale testing was carried out in ANPI, Belgium which has a fire test room built to the European EN standard. Here a range of fire tests were carried out to investigate the response of blue and IR optical chambers.

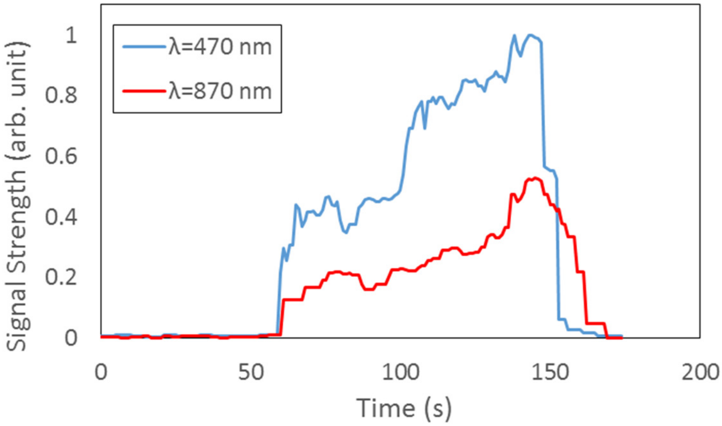

Fig. 6. Comparison of the signal strength response of blue LED (λ = 470 nm) and IR LED (λ = 870 nm) to flaming polyurethane in a custom built smoke chamber.

The first test carried out was TF2, which is a smouldering wood test. The response of the IR and blue optical units were similar as shown in Fig. 7. The quickness of the blue response can be attributed to the slow air flow and the unpredictability of smoke particle density during TF2. It is highly possible that randomness in the smoke pattern reached the blue chamber before the IR chamber so the authors do not consider this initial blue response a notable finding. Overall, the blue LED has a slightly stronger overall response than the IR LED in this test by up to 50 %.

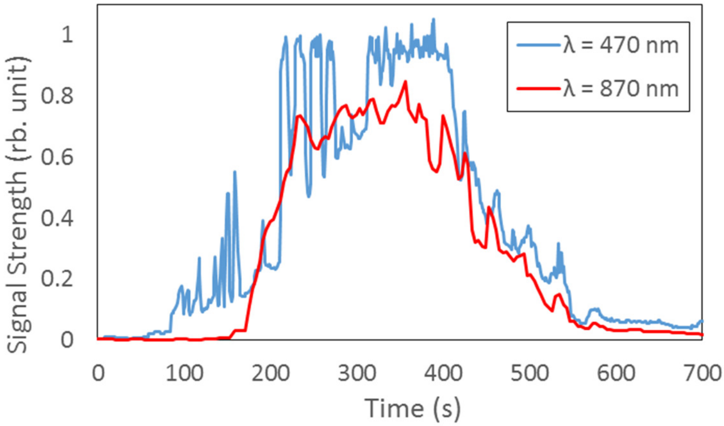

Fig. 7. Comparison of the signal strength response of blue LED (λ = 470 nm) and IR LED (λ = 870 nm) during TF2, smouldering wood in the ANPI fire test room.

TF4 is a flaming polyurethane test as part of the EN standard. Although similar, it is not identical to the new UL 217 flaming polyurethane test. The recorded blue and IR LED data for the EN TF4 is shown in Fig. 8. Again, the blue signal is double that of the IR signal. Although this is a promising result, it is not clear that this difference between blue and IR LED response will be enough to pass the UL217 test. The increased signal strength of blue light over IR light is observed for all flaming fires including TF1 (flaming Wood) and TF5 (flaming Heptane).

During this study it was found that on many occasions it was possible to differentiate smouldering from flaming fires using the blue LED as a secondary indicator. However, to pass UL217 the units must not alarm during the nuisance test which is proving a challenge for current optical units on the market.

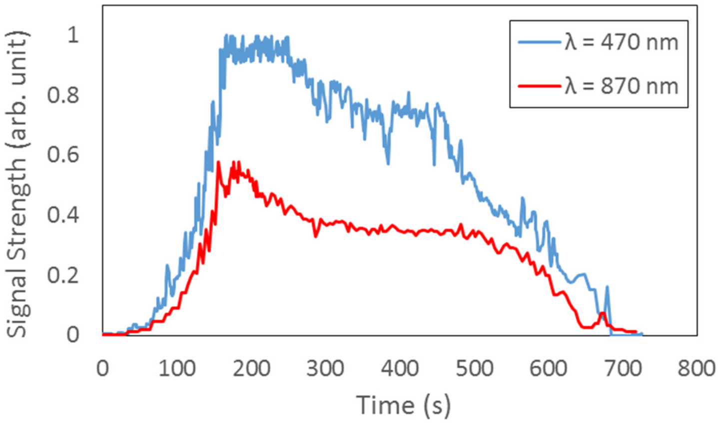

Fig. 8. Comparison of the signal strength response of blue LED (λ = 470 nm) and IR LED (λ = 870 nm) during TF4, flaming polyurethane in the ANPI fire test room.

Provisional results for the nuisance broiling hamburger test from internal testing are shown in Fig.9. The response of the blue LED is between 5 and 6 times that of the IR LED. This ratio is larger than that seen previously for any of the flaming fire tests. Therefore, theoretically it may be possible to distinguish between the UL fire tests and the nuisance hamburger tests. However, in a life-saving application, dependence on an increased signal to distinguish a nuisance source is a potentially dangerous situation. While these preliminary results show potential, the authors advise caution and that a comprehensive range of fires must be tested to ensure customer safety.

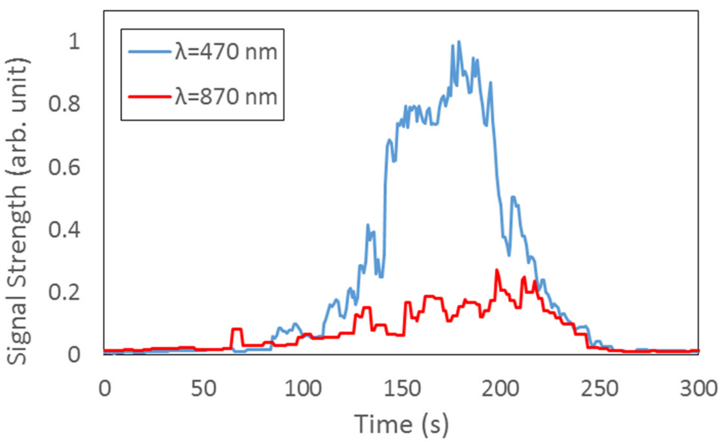

Fig. 9. Comparison of the signal strength response of blue LED (λ = 470 nm) and IR LED (λ = 870 nm) for broiling hamburger test.

Conclusions

Although this study is still in its infancy, the results show that there is potential for a combination of blue and IR forward scattering optical chambers to be used to pass the new UL217 test. We have shown that blue light has a larger response to flaming fires than smouldering fires. Therefore, it should be possible to detect all fire tests including flaming polyurethane. The nuisance hamburger test will remain difficult to distinguish. Initial testing has shown that the blue LED response is larger for the nuisance test. Therefore, it may be possible to distinguish the nuisance test from one of the actual fire tests. However, this is a potentially dangerous situation in a real world setting as it could lead to a delayed alarm response in the presence of an actual fire. At the time of publication testing has not been conducted in the UL test lab and this must be completed to confirm the initial findings of this study. Another issue that must be considered is the accuracy of unit calibration and repeatability of smoke chamber. We have found issues with consistent readings in the UL smoke box with variances of up to 30 %. This may prove an issue when attempting to remain within the upper and lower smoke limits of the broiling hamburger and flaming polyurethane tests.

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