www.bregroup.com

Briefing Paper

An investigation into factors that influence the effectiveness of Visual Alarm Devices

Raman Chagger and Gemma Sambells

Acknowledgements

The authors would like to thank the sponsors, namely the following, for providing the funding and for contributing time and resource to support this collaborative research work.

- Jeff Cutler, Apollo Fire Detectors Limited
- Bernard Laluvein, BEH Laluvein Consulting
- Daniel Foster, C-TEC
- Neil Young, Cranford Controls Limited
- Steve Martin/ Philip Williams, Eaton Electrical Products Limited
- Colin Todd, Fire Industry Association
- Skaria Abraham, Fike Safety Technology
- Steve Cox, Hochiki Europe (UK) Limited
- Mike Barson, Honeywell
- Faruk Meah, Johnson Controls
- Jens Wizner, Pfannenberg
- Aleksandar Duric, Don Scott, Siemens
- Adrian Mealing, Klaxon Signals Limited
- James Jones, Vimpex

A special thanks also to Colin Todd and Bernard Laluvein for supporting this work with their experience, technical knowledge and independence.

Any third-party URLs are given for information and reference purposes only and BRE. does not control or warrant the accuracy, relevance, availability, timeliness or completeness of the information contained on any third-party website. Inclusion of any third-party details or website is not intended to reflect their importance, nor is it intended to endorse any views expressed, products or services offered, nor the companies or organisations in question. Any views expressed in this publication are not necessarily those of BRE. BRE has made every effort to ensure that the information and guidance in this publication were accurate when published, but can take no responsibility for the subsequent use of this information, nor for any errors or omissions it may contain. To the extent permitted by law, BRE shall not be liable for any loss, damage or expense incurred by reliance on the information or any statement contained herein.

Contents

Summary

Visual alarm devices (VADs) are used to create a visual warning to draw attention in the event of a fire alarm. These devices, mounted on walls or the ceiling, typically use Xenon tubes or LEDs to create the visual flash which is usually red or white in colour. The properties of the VADs and many external factors will influence their attention drawing effectiveness.

Over three phases this study investigated five factors: wall surfaces, direct or indirect presentations to people, VAD colours, background light levels and pulse durations. Red and white VADs were used (either Xenon or LED) for this study and sometimes these devices were modified, when required.

Phase 1 of this study was to identify the effects of wall surfaces to determine the external room conditions under which VAD performance is most effective. This was performed by measuring the reflected signals from VADs 1m from different surfaces. It was observed that white and light surfaces yielded the most effective response for both red and white VADs and the least reflected light was received from surfaces dark in colour or textured. LED VADs were generally most effective across the range of different surfaces used in this study with white ones being most effective.

Phase 2 of this study focussed on investigating the direct and indirect viewing of red and white signals from ceiling and wall mounted VADs. The tests were performed under two ambient light level conditions with 48 participants facing either away or towards the device. It was observed that direct view was always more effective than indirect view and that wall devices were more effective than ceiling devices. In terms of colours, it was observed that the red VADs were about 20% more effective than white ones however the response variations for the red VADs were significantly greater than the white ones.

Phase 3 of this study investigated the attention drawing effectiveness of VADs with varying pulse durations and VAD colours under different ambient light conditions. Eight VADs (7 LED and 1 Xenon) were matched in terms of the on-axis effective luminous intensity levels and the effective illumination distributions. The flashing signals were presented under four different ambient light levels to 36 subjects individually seated at a table in front of a screen and occupied in a multiple-choice question task, until the subjects responded to each of the presentations.

Phase 3 confirmed previous work in this area that as the pulse widths of LED devices shorten the attention drawing effectiveness increases. It also showed that a red and an equivalent cool white LED device resulted in similar subject responses. In all four ambient light levels the Xenon device was more effective at drawing attention than the LED devices of different pulse durations (5 - 200ms). The Light Research Center have reported that the use of the constant a=0.01s in the Blondel-Rey formula gives more comparative performance for flashing devices. This was not confirmed for the LED pulse durations used for this study. Savage's claim that the shorter the pulse duration, the smaller the participant response variations, was not supported by the data.

Abbreviations and glossary of terms

The abbreviations list and glossary are compiled from terms used in this publication. The descriptions in the glossary are not intended to be comprehensive, but to help the reader understand the meaning of terms as they are used in this Briefing Paper.

Abbreviations

LED = Light Emitting Diode

LRC = Light Research Center

MDF = Medium-Density Fibreboard

VADER = Visual Alarm Device Evaluation Rig

VADs = Visual Alarm Devices

Glossary

Coverage volume – a 3D volume within which the required illumination is achieved.

Direct viewing – when a person in a protected space is facing towards the VAD.

Effective Luminous Intensity - the light output of the visual alarm device measured using the equipment and method detailed in Annex A of EN 54-23.

Indirect viewing – when a person in a protected space is facing away from the VAD.

VADs – devices that are either mounted on the ceiling or wall which, in the event of a fire, emit pulses of flashing light to provide a visual warning to people in the vicinity.

Introduction

Visual alarm devices (VADs) are used to provide a visual alarm when required, such as for the deaf and hard of hearing, in areas of high ambient noise (e.g. factory) or where silent warnings are required (e.g. broadcasting studio). Most VADs are Xenon or LED flashing light devices and their effectiveness in drawing the attention of people in the vicinity is critical to providing reliable warnings.

The test standard to which all VADs in Europe must comply is EN 54-23:2010 [1]. This standard calls up the Blondel-Rey [2] formula to calculate the effective luminous intensity (Ieff), expressed in candela (cd), of pulses generated from Xenon and LED devices. Measurements taken of Ieff at different angles can be used to identify a “coverage volume” which is effectively a volume within which a minimum illumination is achieved (see Visual alarm devices for fire [3]). The Blondel-Rey formula is:

$$I_{eff} = \frac{\int_{t_1}^{t_2} I(t)dt}{a + (t_2 - t_1)}$$

(Formula 1)

where: I(t) is the instantaneous value in candela (cd),

a = 0.2 s,

t_2 - t_1 is the pulse duration between the 10% of peak amplitude for the pulse.

The formula was generated based on a study of direct viewing of point sources in a dark environment. However, visual warnings are most often detected though indirect viewing, i.e. seeing the light in the peripheral vision in an illuminated space. This has led many to question the suitability of this formula to be used for devices primarily intended to alert people. A number of studies have previously been performed most notably by the Light Research Center (LRC) [4] and by Savage [5]. Both studies identified key issues regarding the use of the Blondel-Rey formula for visually alerting people under indirect viewing conditions.

The effectiveness of a VAD installed in a typical service environment will be dependent on many factors such as the space itself, the properties of the VAD as well as the position of persons. In terms of the space, factors like the size of the space in which the VAD is installed, the illumination of that space (which may change due to sunlight) and the types and finishes of surfaces in that space will all contribute collectively to effective warning. In terms of the VAD, it can be ceiling or wall mounted, red or white in colour and it can be an LED (with varying pulse durations) or Xenon. Persons in the space could be facing towards (but not necessarily looking at) the VAD, hereafter referred to as direct viewing or they could be facing away (say facing a wall in a space where the VAD is centrally installed on the ceiling), hereafter referred to as indirect viewing. Some of these factors were investigated over three phases of work to assess VAD effectiveness, namely:

- **Phase 1** measured the reflected light from red and white Xenon/ LED VADs from various coloured and textured surfaces expected in typical service environments,
- **Phase 2** investigated the effects of indirect and directly presented light from wall and ceiling red/white LED VADs to a group of participants,
- **Phase 3** reviewed the comparative response of people to red and white coloured VADs, varying ambient light levels (from 50 lux to 1000 lux) and the effects of pulse durations (from 5ms to 200ms).

The findings from this work are intended to provide evidence to support the revision of the LPCB Code of Practice Code of Practice CoP 0001 [6] and EN 54-23 [1], if required.

Details of the VAD manufacturers and models used during this study are not disclosed, however general performance specifications details are provided, where required.

Phase 1: Surface effects

Overview

The types of surfaces that may be present in a space and contribute towards effective warning were investigated by measuring the reflected signals from red and white Xenon and LED VADs from a number of internal walls and coloured surfaces, present in typical service environments. The Visual Alarm Device Evaluation Rig (VADER) was used to measure the reflected effective luminous intensities from different red/white and Xenon/LED VADs on 34 walls and MDF painted surfaces.

MDF board was painted using 9 different colours and finishes (silk or matt), and 25 walls and surfaces, typically found in commercial buildings, were used. The MDF boards were painted with two coats of Wood Primer in white and two coats of the designated paint colour. The 25 walls used were from the BRE site and encapsulated a range of colours, materials, textures and finishes grouped into the following five categories, with the number of surfaces of those groups shown in brackets, paint (9), wood (3), brickwork (4) - example shown in Figure 1, wallpaper (3) and textured (6) finishes (e.g. wooden panels).

Figure 1: Example of internal wall (brick) used for gathering measurements

Instrumentation

Measurements of the VADs effective luminous intensity as well as the reflectivity and gloss levels from the different surfaces were recorded.

The VADER and associated software have been developed, by BRE and Product Technology Partners, for measuring the effective luminous intensity from Visual Alarm Devices (VADs), according to the method described in sections 5.3.1, 5.3.2, 5.3.5 and Annex A of the EN 54-23 [1] product test standard.

The luminance meter (Minolta LS-100) was used to take measurements of reflectivity from walls and the MDF/wood panels. The glossmeter (Zehntner ZGM 1020 glossmeter) was used to measure the specular reflection measured in gloss units (GU). Both were measured to determine if there was any correlation with or effect on VAD performance.

How the VADs were used

One manufacturer provided two LED devices (of similar pulse durations) that both contained clear lens covers with the colour being produced by red and white LEDs. Another provided two Xenon devices of similar specification, with the required colour being produced using red or clear covers.

The four VADs (red and white as shown) were mounted with the VADER sensor located centrally in the board, as shown in Figure 2.

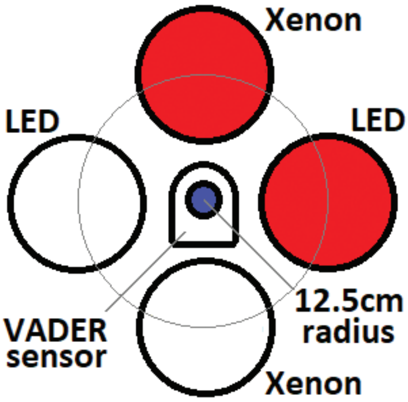


Figure 2: Location of four VADs and the VADER sensor (centre)

The board containing the VADs and sensor was always positioned 1m (±5mm in the corners) from the surface being tested (about 1m x 1m of clear area) which was free from obstructions (such as power sockets).

As the VADER required low ambient light levels to perform measurements the 9 MDF screens were measured in a dark room. When measuring surfaces around the BRE site, when the ambient light levels were too high a black sheet of cloth was draped over a temporary frame to locally reduce the light. Factors were applied for the four VADs to normalise the responses from the different surfaces. These factors took into account the acceptance angle of the sensor and compensated for cos θ losses at both the surface being tested and incident light returning to the sensor.

Once the light from the VAD was reflected from the surface and received by the VADER this result was compared with the original data from that VAD to determine a response ratio. If the surface was a perfect mirror the ratio would be 1, indicating no loss of light.

Results

For the MDF screens it was observed that white surfaces produced the greatest response ratio for both red and white VADs. For red VADs surfaces similar in colour such as red and orange yield a greater ratio response than coloured surfaces such as green and cyan. From the measurements of gloss and reflectance, it was noted that silk finish surfaces were generally better irrespective of colour.

It was observed using the walls that the LED devices were generally most effective across the range of different wall types with the white LED VAD being most effective. For all the wall types the Xenon red device outperformed the Xenon white device. Walls that displayed the greatest loss from the different VADs were those dark in colour and textured surfaces whereas the highest outputs were observed from (in decreasing order) tiled wall, white painted walls, off white walls (i.e. dull, cream), lightly coloured walls (i.e. mint green, lilac, light blue, duck egg).

No clear correlation between ratio of output of devices and gloss was observed however a general correlation between output of devices and the amount of reflectance was observed. The results show that glossy surfaces (such as tiled walls and painted doors) exhibited the highest gloss readings. The brickwork exhibited the least gloss and the painted walls were generally in a similar range to the painted MDF boards. The walls which were white or lighter in colour exhibited the highest measured surface reflectance.

Analysis

The results of the mean and standard deviation ratio responses of the VADs from all of the 34 MDF and wall surfaces are shown in Table 1 below.

The LED devices were marginally more effective with the mean of the white LED device being 2.5% higher than the corresponding red device. The mean from both LED devices is 38.2% higher than the Xenon mean, demonstrating that the light reflects more effectively from LED VADs.

Whilst a comparison of red devices against white devices reveals that the red ones on average were 8.1% higher, this is misleading as the red Xenon has a significantly better performance than the white Xenon (whereas red and white LED VADs were similar). This may have been due to the particular lens used as part of this study and it would be worth repeating this test with other Xenon VADs with similar specification to confirm the observations made.

There was no clear correlation between the gloss measurements and the performance of VADs. For the reflectance measurements there was a general correlation as a greater reflectivity led to a greater ratio response of the VADs. However, some textured or highly coloured surfaces showed less correlated results. This could be because some of those surfaces may have dispersed the light at wider angles or absorbed it.

	Walls		MDF		Combined Average	Combined SD
	MEAN	SD	MEAN	SD		
Red Xenon	0.244	0.116	0.189	0.121	0.229	0.118
White LED	0.322	0.181	0.197	0.137	0.289	0.178
Red LED	0.313	0.162	0.196	0.138	0.282	0.163
White Xenon	0.192	0.100	0.162	0.109	0.184	0.101

Table 1: Mean and standard deviation responses of the VADs from all MDF and wall surfaces

Phase 2: Direct and indirect viewing

Overview

Whether people are facing a device (direct viewing) or away from the device (indirect viewing) can determine whether people respond to the visual warning signal. Similarly, the colour of the device (red or white) contrasting with the walls can also influence how they respond. The ambient illumination levels can also influence whether the signals are seen, as in bright spaces a brighter warning signal would be required.

The aim of this phase of work was to assess the response of 48 participants over four tests (12 people per test) to these conditions and variables. All participants were subjected to the eight conditions shown in Table 2 and the codes in Column 1 are used in the results (Figure 5).

Code	Ambient Level	VAD type	ORIENTATION
HCD	High	Ceiling	Direct
HCI	High	Ceiling	Indirect
HWD	High	Wall	Direct
HWI	High	Wall	Indirect
LCD	Low	Ceiling	Direct
LCI	Low	Ceiling	Indirect
LWD	Low	Wall	Direct
LWI	Low	Wall	Indirect

Table 2: The eight light test configurations varying ambient light, VAD type and orientation

A room with the squarish footprint was used (6.41m x 5.96m x 2.88m high) to perform the tests and the VADER was used to measure the coverage volumes of the following four VADs used:

- white LED ceiling mounted,
- white LED wall mounted,
- red LED ceiling mounted,
- red LED wall mounted.

Additional lighting, on a separate circuit, was installed in this room to permit low and high ambient light level conditions (see Figure 3).

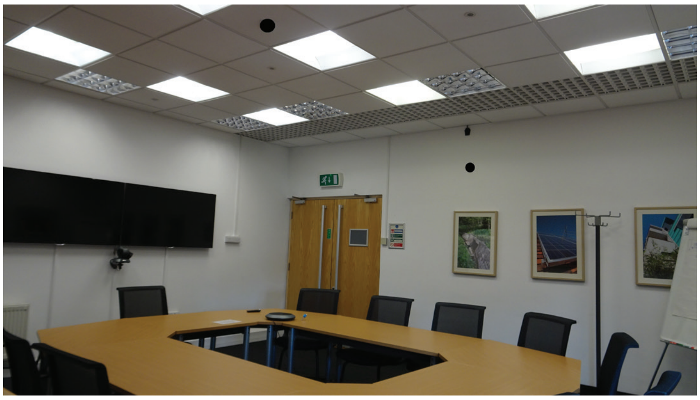


Figure 3: Room with high ambient light level condition

From 36 measurements taken from the walls the mean and standard deviations of the illumination for the low ambient light level was 260±70 lux and 600±190 lux for the high ambient light level.

VAD ratings

Using the dimensions of the room the target specifications, to illuminate the room, of the Ceiling mounted device was C-3-8.9 and for the Wall mounted device was W-2.4-6.5.

A coverage volume test was performed on all VADs (which all had clear lenses) using the VADER and the ratings were determined. The pulse durations of all VADs used were 50ms ± 40%. A number of white and red VADs were supplied and those most appropriate were selected as shown below:

- Ceiling Device 1 rating C-3-9.6 (white),
- Ceiling Device 2 rating C-3-10.1 (red),
- Wall Device 1 rating W-2.4-6.9 (red),
- Wall Device 2 rating W-2.4-6.7 (white).

Participant instructions

Participants were not explained the reasons for the tests but were informed that they would be exposed to 8 different flashing light test conditions. During the tests they would rate how effective they considered the warning from the visual signals to be in terms of drawing their attention.

They were given an envelope with a number from 1 to 12 that corresponded to the location in the room where they would be sat as shown below. The double doors (light red), providing entry to the room, are shown as well as the location of the windows (thick red) that were covered during the tests and all reflective objects on the walls were removed.

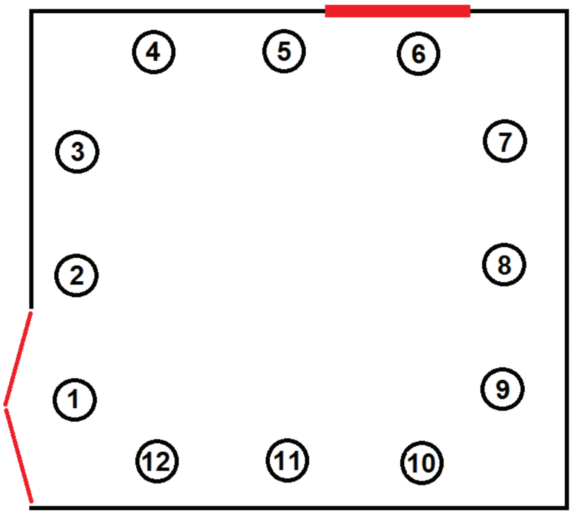


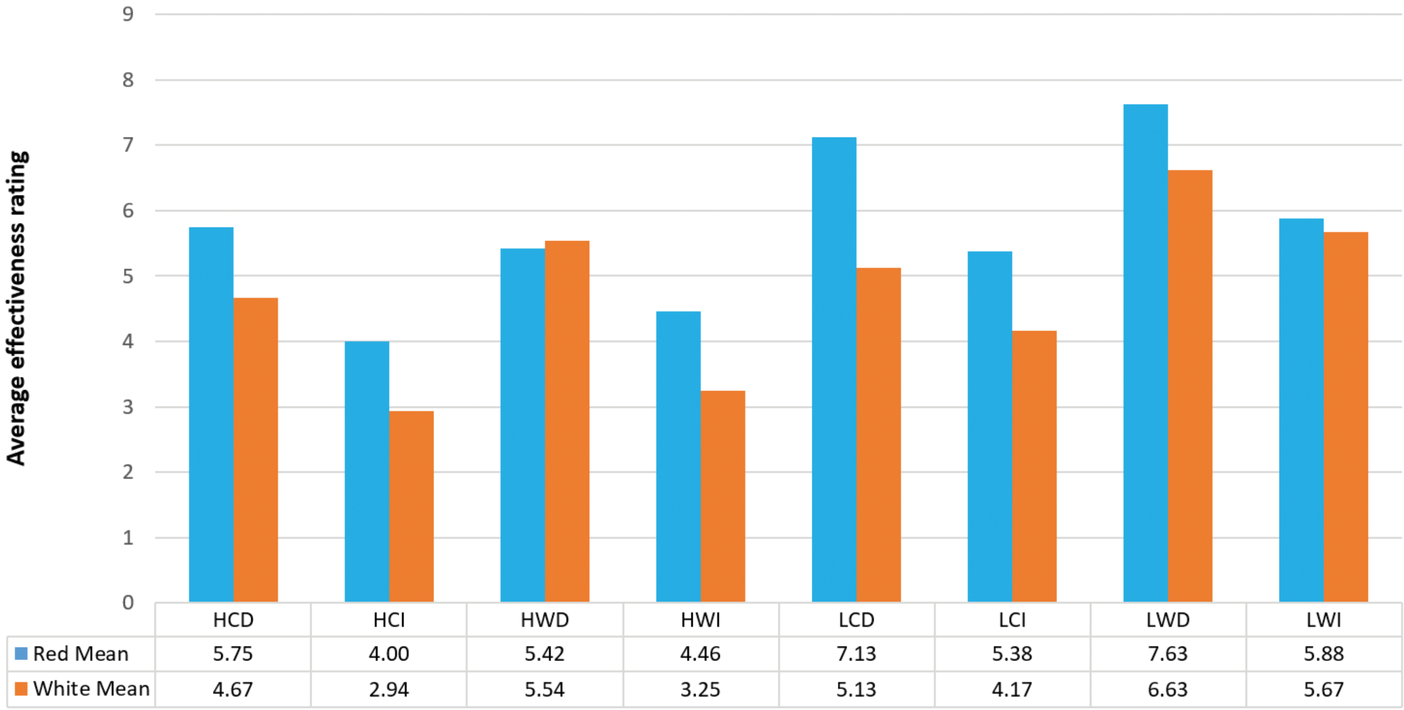
Figure 4: Participants positions within the room

By having 3 people equally spaced along the walls and then averaging the results from all 12 measurements, permitted an overall average performance rating of the VADs to be generated under the different test conditions. The various weightings given to each of the ratings were based on those used previously in FIA Fact File 57 [7] with highly, moderately, acceptably, not really effective and absolutely ineffective ratings scoring 9, 7, 5, 3 and 1 respectively.

Participants were first tested with white VADs and then on another day with the red ones.

Results

The average effectiveness rating from the red and white VADs for the 8 different light conditions (summarised in Table 2) are shown in Figure 5 (higher values indicate greater perceived effectiveness).



	HCD	HCI	HWD	HWI	LCD	LCI	LWD	LWI
🟦 Red Mean	5.75	4.00	5.42	4.46	7.13	5.38	7.63	5.88
🟧 White Mean	4.67	2.94	5.54	3.25	5.13	4.17	6.63	5.67

Figure 5: Average effectiveness ratings of subjects to 8 light conditions with red/white VADs

Analysis

The following observations were made:

- Direct view was always more effective than indirect under the same conditions.
- The responses under low ambient conditions were always higher than high ambient under the same conditions.
- Wall devices were generally more effective than ceiling devices under the same conditions.
- Overall, the red VADs were perceived to be 20.1% more effective than the white ones.
- The standard deviations for all 8 conditions were between 1.80 and 2.20 for the white devices and between 1.66 and 2.61 for the red VADs demonstrating their greater variability.

Phase 3: VAD colours, background light and pulse durations

Overview

From previous work, detailed in the VAD briefing paper titled "The attention drawing effectiveness of light pulses generated from Xenon and LED devices" [8] a method for testing and assessing the response of people to pulse durations and light levels was established. A video of this method, used previously, is available online [9]. Essentially a person is sat at a desk facing a wall and are presented with VAD signals with different characteristics and at different ambient light levels until they respond.

This method could be used to investigate the response of people to VAD colours by using red and cool white LED VADs both at 40ms pulse duration. It could also be used to assess the effects of background light by using four illumination levels (80, 200, 600 and 800lux) again at 40ms pulse duration, as well as the effect of pulse durations by using cool white LED VADs at 5, 20, 40, 100 and 200ms under four different light conditions of 80, 200, 600 and 800lux.

The findings from the pulse durations work would be used to evaluate the LRC claim that the constant a=0.01 sec was more accurate and Savage's claim [5] that the shorter the pulse width the smaller the detection variation.

As the test programme required eight samples with a range of pulse durations, colours and types (Xenon/LED) a number of samples were sourced, modified and used. The actual measured values of pulse durations and outputs of those samples are shown in Table 3 and the pulse profiles in the Appendices.

Test space

From the previous work [8] it was identified that to test the performance of VADs required a space at least 20m long x 5m wide with a screen at least 3m wide x 2m high and a space approximately 5.39m x 2.62m x 21m was identified with a screen 4.64m x 2.4m high (see Figure 6).

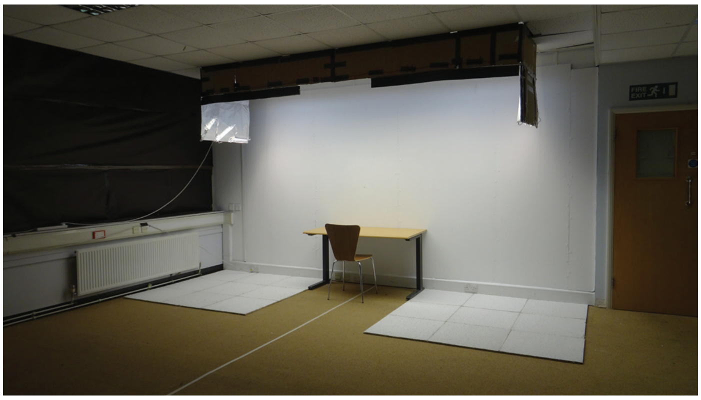


Figure 6 – The room and screen

To ensure that the light level of the room could be controlled, the windows in the room were blacked out and various lights and reflectors were used to achieve the required ambient light levels.

Ambient light levels

Using a lux meter the illuminance levels measured at the screen and the table were taken before and after the subject trials, at a number of positions as shown in Figure 7. These locations are within the expected peripheral vision of human subjects.

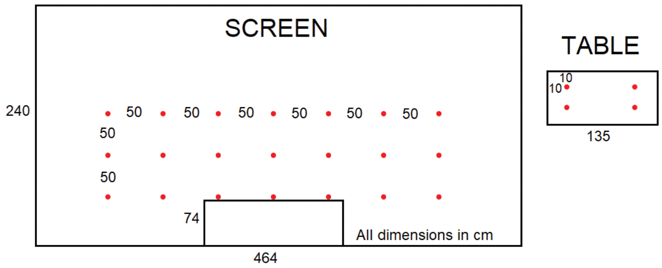


Figure 7 – Location of the measured positions

The four lights levels achieved were High (H) 776±272 lux, Medium (M) 608±203 lux, Low (L) 168±60 lux and Ultra-low (UL) 81±73 lux.

Measurement and comparison of VADs

VADs with different colours and with pulse durations were prepared then measured using the VADER.

The pulse widths and the effective luminous intensity levels (Ieff) achieved for the eight devices used are shown in Table 3 and the pulse profiles for all are shown in Appendix A. Note the device designation numbers shown in the first column are used throughout the rest of this report.

Device	Type	Colour	Pulse duration (ms)	Ieff at 90° α (cd)
#1	LED	Cool white	4.9	22.3
#2	LED	Cool white	19.9	45.8
#3	LED	Cool white	39.9	48.0
#4	LED	Cool white	99.9	47.5
#5	LED	Cool white	199.9	47.6
#6	LED	Red	39.9	22.0
#7	LED	Cool white	39.9	22.5
#8	Xenon	White	0.16	48.9

Table 3: VAD pulse durations and Ieff

For all the devices a colour chart was produced to give a visual representation on a wall opposite the device (at 3m) of the effective light contrast and effective illumination distribution. Two of these are shown in Figure 8 for the modified Xenon device (top) and the modified cool white 20ms LED device (bottom).

The distributions demonstrate that the peak effective illumination at (0,0), directly opposite the device, is comparative and the effective illumination distribution from the Xenon device, despite having a more uneven distribution was evened out using filters and various lenses applied to the outer casing, to match the LED device.

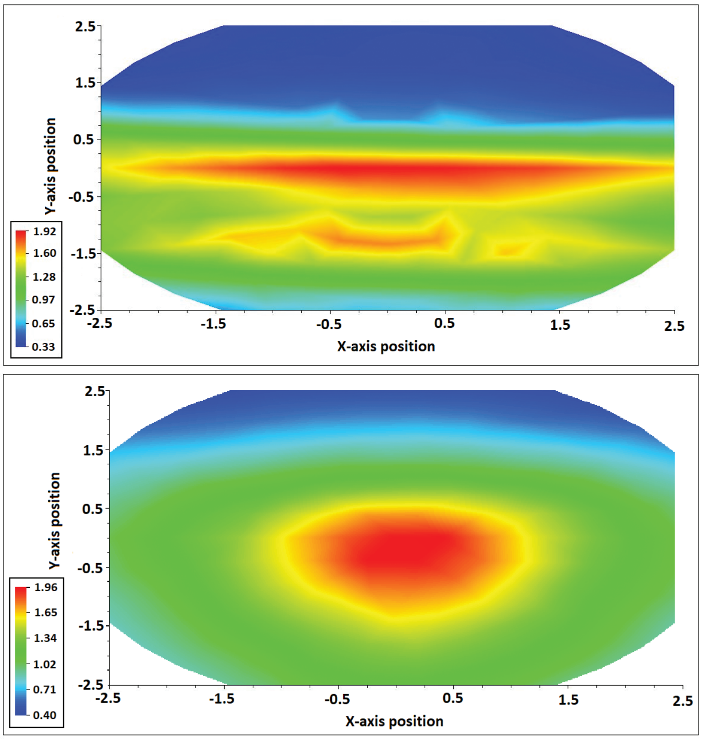


Figure 8: Effective illumination distribution (lx) for Xenon and an LED VAD

Test samples and configurations

For the tests the eight VAD samples were fixed to a wooden board so that they could be secured on a trolley at a height of approximately 2m above the ground, shown in Figure 9.

Figure 9 – Devices attached to trolley

With the 8 VADs, 2 colours and 4 ambient light levels achieved in the test room, fourteen configurations were identified for testing which are detailed in Table 4:

	Test Number	Device	Illumination level
VAD colours	1	White LED 40ms (#7)	200
	2	Red LED 40ms (#6)	200
Background light	3	White LED 40ms (#3)	80
	4	White LED 40ms (#3)	200
	5	White LED 40ms (#3)	600
	6	White LED 40ms (#3)	800
	7	White Xenon (#8)	80
	8	White Xenon (#8)	200
	9	White Xenon (#8)	600
	10	White Xenon (#8)	800
Pulse duration	11	White LED 5ms (#1)	200
	12	White LED 20ms (#2)	200
	13	White LED 100ms (#4)	200
	14	White LED 200ms (#5)	200

Table 4: Configuration for each VAD test

Whilst more tests could have been performed to get further data, the time it took to complete these 14 measurements was about 30 minutes from the moment the subject sat down. This was considered to be the top limit of people's attention for such a task before tiredness would be expected to reduce their alertness and delay their responses.

The exact method for performing the tests is detailed in [8] and are not reproduced.

Results

In total 36 subjects (with varying demographics of age, gender and glasses) were tested, and 100% of the subjects responded to all 14 tests before the VADs were 1m from the screen.

The mean (μ), standard deviation (SD), maximum, minimum and median response distances (in m) are shown in Table 5. The variation is also shown and was taken (SD/μ as a %) to check Savage's claim that the shorter pulse widths had smaller detection variations.

Light levels	**Ultra-low**		**Low**								**Medium**		**High**	
Device	**#3**	**#8**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#3**	**#8**	**#3**	**#8**
μ (m)	14.6	19.0	8.05	9.36	9.08	5.40	3.98	5.92	5.74	13.5	5.63	7.74	4.05	6.25
SD (m)	3.82	2.63	2.54	2.40	2.54	1.65	1.06	1.31	2.00	3.24	2.03	2.03	1.30	1.67
Min. (m)	5.75	12.8	2.09	5.04	4.09	2.93	1.72	2.76	1.97	6.73	2.25	3.89	2.04	2.28
Max (m)	20.9	20.9	15.7	16.2	15.0	9.24	6.90	8.39	12.2	20.2	10.7	11.8	7.30	11.7
Med (m)	14.4	20.8	8.06	9.32	9.31	5.23	3.92	6.02	5.61	14.2	4.89	7.50	3.88	6.30
Var. (%)	26.2	13.8	31.6	25.6	28.0	30.6	26.6	22.1	34.8	24.0	36.1	26.2	32.1	26.7

Table 5: The mean, max, min and median response distances (in m) for all presentations

Following the tests with the 36 subjects a "calibration" of the effective illumination levels was performed to enable the illumination level of the different VADs to be calculated using the distance at which the person responded. The calibration was performed by measuring the Eeff (lux) levels using the VADER at 18, 15, 12, 9, 6 and 3m from the VADER sensor. The Eeff (lux) levels and distance were plotted, resulting in a power formula that was used.

Phase 3: VAD colours, background light and pulse durations (Continued)

Pulse durations and colours

Using the average distance measurements shown in Table 5 together with identified power formulas the mean effective illumination levels for each device was calculated. These are plotted in Figure 10 for all devices in the low light level condition (200 lux). Low levels of effective illumination indicate that less light was required to alert subjects to the flashing lights (they were seen from a greater distance).

The following observations can be made using these results:

- The Xenon device is clearly the most effective, with the shortest pulse duration (4.9ms) being the closest to the Xenon.
- For the LED devices the Blondel-Rey formula does not lead to similar effective illumination levels for different pulse durations. If it had done, then all of the values would have had the same effective illumination.
- For the LED devices as the pulse widths shorten the attention drawing effectiveness increases for the same effective illumination. This can be seen with devices 2-5 that are all around 47Cd as well as devices 1 and 7 that are around 22Cd.
- For the red (#6) and white 40ms (#7) VADs they have comparable responses and are at similar levels. The cool white LED 40ms device had a 2.2% higher output that could account for the slight improvement in performance of this device. Note the % variation was 22% for the red VAD and 35% for the white indicating greater variability in subject responses to white light.

With 200ms pulse duration devices being highly ineffective, it is worth reviewing whether the upper limit in EN 54-23 should be reduced.

Ambient light levels

Figure 11 shows the performance of #3 (48Cd, 40msec, LED) and #8 (49Cd, 0.16ms, Xenon) for the ultra-low, low, medium and high ambient light level conditions.

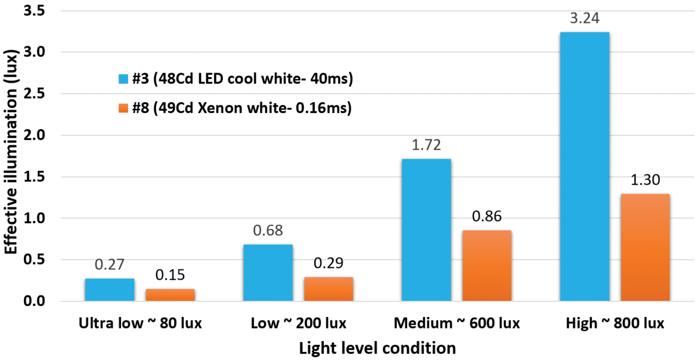


Figure 11: Responses of similar LED and Xenon VADs under different light levels

The following observations can be made using these results:

- The Xenon device outperforms the 40msec LED devices for all 4 light conditions, producing the same response, typically with around 46% of the effective illumination of the LED device, overall.
- As the ambient light level illumination increases the effective illumination required from the VAD to draw attention increases for both the Xenon and LED devices.

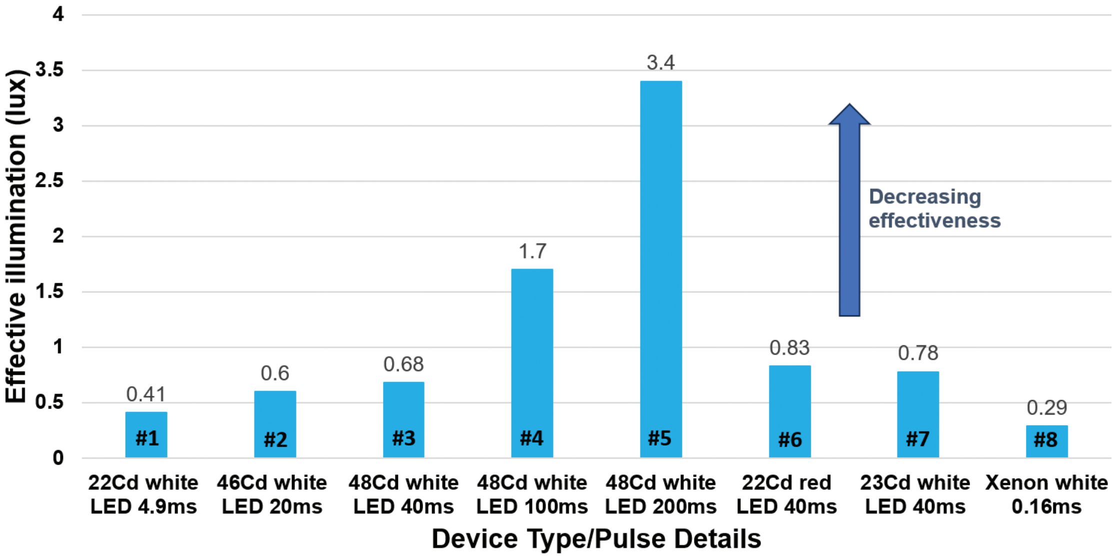


Figure 10: The mean responses for all devices under the low light level condition

Comparisons with previous work

LRC and Savage

The study by LRC had reported that using a constant value of 0.2s in the denominator of the Blondel-Rey formula was not a suitable value for predicting the performance of flashing lights viewed indirectly. LRC used a smaller value for the constant and proposed a=0.01s, stating that this equalised the flashes of light from LED VADs with different durations, so that the effective illumination was similar.

This claim was investigated by converting the results with the proposed new value of a giving the revised levels shown in Figure 12.

This data shows that the peak performance responses for the different devices are still quite varied, with the highest effective illumination value (at 200ms) being twice that of the lowest, the cool white 40ms device. Without use of the new constant the max:min ratio of effective illumination (see Figure 10) was 3.4/0.41= 8.3, so clearly the revised constant does bring responses from different pulse duration VADs closer together.

The use of the constant a=0.01s in the Blondel-Rey formula appears to be more suitable than the existing value of 0.2s for LED pulse durations between 5ms and 200ms with the optimum attention drawing effectiveness being between 20ms and 40ms. However, there may be a more suitable formula that could be determined by having more data at other pulse durations such as 10, 60, 80, 125, 150 and 175ms.

One of the findings from the study by Savage [5] was that the shorter the pulse durations the smaller the detection variations. During the previous study [8] this was validated for the low light level condition, but for the high light level condition there was no correlation. In this study, for the variations of LED devices 1 to 5 under low light conditions (shown in Table 5) demonstrates no correlation of variation with pulse duration.

Comparison of Phase 3 data with Phase 1

During Phase 1 it was demonstrated that the measured light received by the photopic light sensor is 38.2% higher for LED VADs, but this work has shown that Xenon devices appear to be more effective for warning subjects. However, note that for Phase 1 it was the measured reflectance of pulses off a surface and is difficult to correlate this with subjective experiences.

Comparison of Phase 3 data with Phase 2

The aim of Phase 2 was to identify the effects of indirect and directly presented light from wall and ceiling LED VADs (red and white) under two different ambient light conditions (low = 260 lux and high = 600 lux) to identify the conditions that produced the most effective warning.

It was observed in Phase 2 that responses under low ambient conditions were always higher than high ambient for the same device and position. This was validated in Phase 3 too, during which it was observed that as the ambient light level increased so does the effective illumination required to provide suitable warning (see Figure 12) which was observed for the Xenon and LED VADs.

During Phase 2, on average, the red devices demonstrated greater variability in subject responses than the white ones. From Table 5, the percentage variations for conditions L6 (red) and L7 (white) were 22.1% and 34.8% respectively which suggest that in Phase 3 white VADs had greater variability. The reasons for this may be due to the different test set-ups, room conditions and test methods. However, further work with a greater selection of VADs would be required to provide more reliable data in order to determine subject response variabilities to red and white LED VADs.

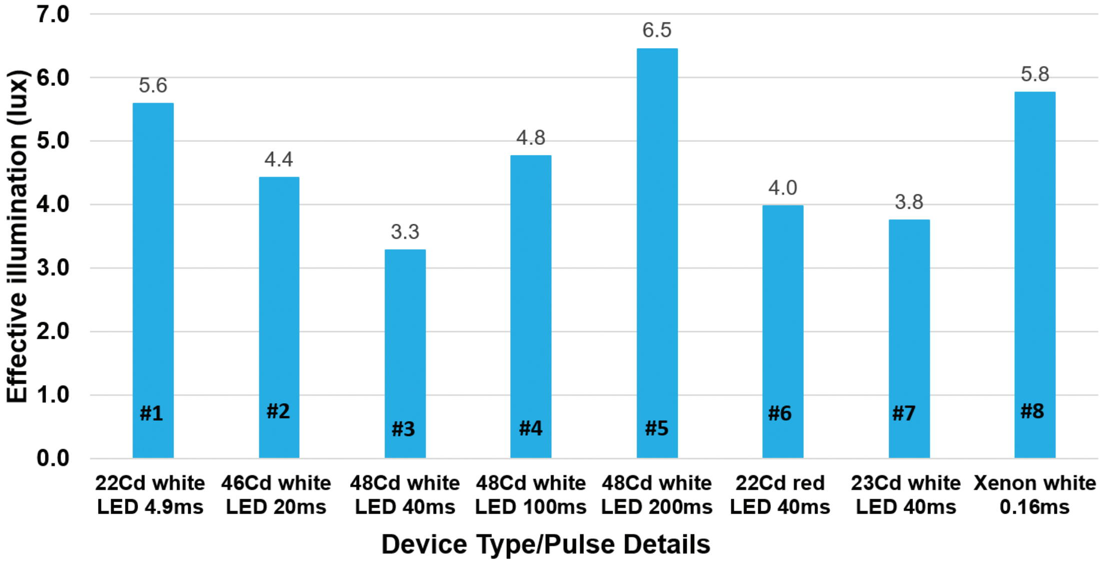


Figure 12: Adjusted effective illumination levels using the constant a = 0.01s

Conclusions

The aim of Phase 1 of this study was to identify the effects of wall surfaces to determine the conditions under which VAD performance is most effective.

For red VADs surfaces similar in colour such as red and orange yield a greater response than coloured surfaces such as green, cyan. However white surfaces yielded the greatest response for both red and white VADs.

Walls that displayed the greatest loss from the different VADs were those dark in colour and textured surfaces whereas the highest reflected outputs were observed from (in decreasing order) tiled wall, white painted walls, off white walls (i.e. dull, cream), lightly coloured walls (i.e. mint green, lilac, light blue, duck egg). White colours yielded the greatest response.

The LED VADs were generally most effective across the range of different wall types with the white LED VAD being most effective. Responses from red VADs were, on average, 8.1% higher than white ones. A repeat of this study with other manufacturers VADs is recommended to confirm the observations made in this study and ensure that the results observed are not specific to the VADs tested.

The aim of Phase 2 of this study was to identify the effects of indirect and directly presented light from wall and ceiling LED red and white VADs under two different ambient light levels to identify the conditions that produced the most effective warning. In a room with an approximately square footprint and using VADs rated for the particular dimensions of the room, 48 participants in 4 sets of 12 were presented with visual signals from red and white VADs.

Whether VADs were red or white the following were observed:

- Direct view was always more effective than indirect under the same conditions.
- Responses under low ambient conditions were always higher than high ambient for the same device and position.
- Wall devices were always more effective than ceiling devices under the same conditions.

When comparing red VADs with white ones the following were observed:

- Overall, the red VADs were perceived to be about 20% more effective than the white ones.
- The standard deviations for white devices were significantly less than red devices indicating a greater variability in subject responses to the red devices.

The aim of Phase 3 was to compare subject responses to flashing Xenon and LED VADs of varying pulse durations, colours and under various ambient light conditions. One Xenon and 7 cool white LED Vads were used. These were matched in terms of the on-axis effective luminous intensity and the effective illumination distribution.

The flashing signals were presented individually to 34 participants who were seated in front of a screen and occupied in a multiple-choice question task. The devices were turned on one at a time and, from a distance of 20.8m, were gradually brought closer to the screen until the subjects responded. Using calibration data, the distances were converted into the equivalent effective illumination required to produce a response.

Data from subject responses to the 5 pulse durations (5, 20, 40, 100 and 200ms) indicated that the Blondel-Rey formula does result in similar effective illumination levels. It was confirmed that as pulse widths of LED devices shorten the attention drawing effectiveness increases for the same effective illumination. Cool white and red devices with a 40ms pulse duration had similar performance. The Xenon device was found to be the most effective even outperforming the 5ms VAD.

The LRC have reported that the use of the constant a=0.01s in the Blondel-Rey equation gives more comparative performance for flashing VADs. This was assessed by using VADs with pulse durations between 5ms and 200ms and was found to be less accurate at the extremes with the optimum attention drawing effectiveness being in the 20ms - 40ms range. Savage’s claim that the shorter the pulse duration, the smaller the participant response variations, was found not to be true.

It was demonstrated during Phase 1 that the measured reflected light was higher for LED VADs, but Phase 3 work demonstrated that Xenon devices appear to be more effective for warning subjects. However, this may have been due to the fact that for Phase 1 it was the measured reflectance of pulses and for Phase 3 was subjective responses.

It was observed during Phase 2 that responses under low ambient light level conditions were always better than high ambient light level conditions, which was validated in Phase 3. During Phase 2, on average, the white devices demonstrated greater variability in subject responses than the red devices, and during Phase 3 the responses to white VADs were more variable. Further work, with a greater selection of VADs, would be required to provide more reliable data in order to determine subject response variabilities to red and white LED VADs.

The findings from this study will be used to support the revision of the LPCB Code of Practice CoP 0001. A review of the upper pulse duration limit in EN 54-23 and further work to better understand the differences between red and white LEDs is recommended.

References

[1] EN 54-23:2010. Fire detection and fire alarm systems – Visual Alarm Devices. London, BSI, 2010.

[2] The perception of lights of short duration at their range limits. Transactions of the illuminating Engineering Society 7(8): 625-662 by Blondel A, Rey J. 1912.

[3] Visual alarm devices for fire: An introduction to BS EN 54-23:2010 (IP 1/13) by Raman Chagger. BRE, Garston, Watford, WD25 9XX. January 2013.

[4] Parameters for Indirect Viewing of Visual Signals Used in Emergency Notification by John D. Bullough, Nicholas P. Skinner and Yiting Zhu. Lighting Research Center, Rensselaer Polytechnic Institute. September 2013.

[5] Flash Pulse Width Effectiveness in Notification Appliances by Ken Savage. Tyco Safety Products. SUPDET 2011 Conference. January 2011.

[6] Loss Prevention Code of Practice CoP 0001 Issue 1.0. Code of Practice for visual alarm devices used for fire warning. BRE, Garston, Watford, WD25 9XX. 2012.

[7] FIA Fact File 57 [8] Report on tests conducted to demonstrate the effectiveness of visual alarm devices (VAD) installed in different conditions. Fire Industry Association. August 2015

[8] The attention drawing effectiveness of light pulses generated from Xenon and LED devices by Raman Chagger, BRE, Garston, Watford, WD25 9XX. January 2015.

[9] Visual alarm devices – their effectiveness in warning of fire (Video). Available from (accessed June 2024): https://bregroup.com/FSR/VADs2

Appendices

This section details the pulse profiles of the VADs used in Phase 3.

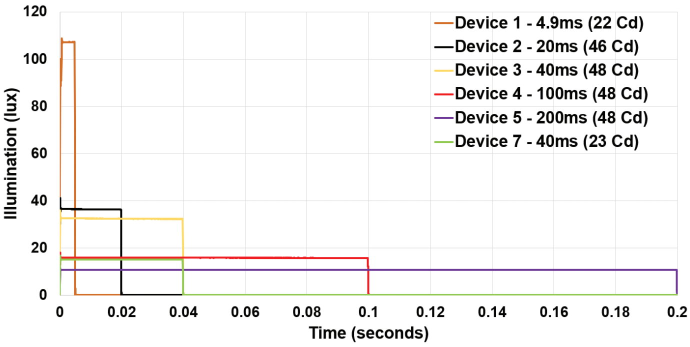


Figure A1: Pulse profiles of Cool white LED VADs (1-5 & 7)

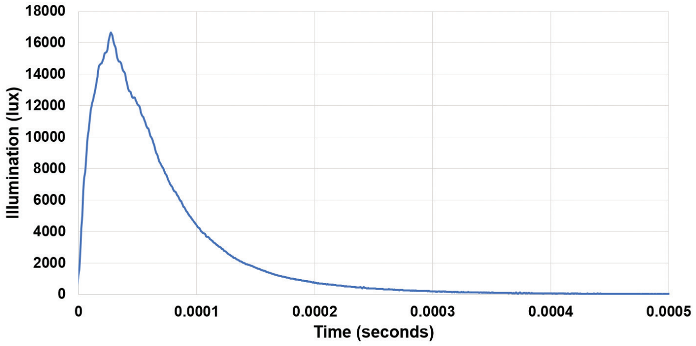


Figure A3: Pulse profiles of Xenon VAD (8)

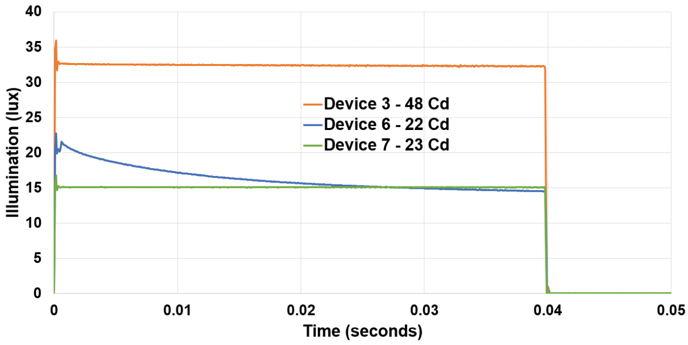


Figure A2: Pulse profiles of 40ms VADs (3, 6 and 7)

BRE Group
Watford, Herts
WD25 9XX

T +44 (0)333 321 8811
E enquiries@bregroup.com
W www.bregroup.com

126154 © Building Research Establishment 2024. Copyright attribution to BRE. July 2024.