University of Canterbury Fire Engineering Conference
A. Abu, M. Spearpoint (Eds.)
Christchurch, New Zealand, April 21, 2015

VISIBILITY OF PHOTO LUMINESCENT EGRESS SIGNAGE THROUGH SMOKE

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Keywords: Visibility, Photo Luminescent, Egress, Signs, Smoke, Fire.

Abstract. *Assessing visibility as a mode of tenability is an important part of the fire engineering design of many building. Visibility through smoke is often predicted based on the visibility of the egress signage through smoke, as it is this signage which helps people to navigate to a place of safety. The visibility of internally illuminated and reflective egress signage has been previously characterized by defining the obscuration coefficient of the signs. The aim of this investigation is to quantify the visibility of photo luminescent egress signs through smoke, and determine how they compare to reflective and internally illuminated signage. This study recommends that photo luminescent egress signage should be treated as equivalent to reflective signage when estimating the visibility of egress signs through smoke. Internally illuminated signs have a greater visibility through smoke than reflective or photo luminescent signs.*

1 INTRODUCTION

1.1 Background

In the event of a fire, loss of human tenability can occur as a result of exposure to heat, smoke inhalation, and loss of visibility. Whilst the latter is not physically incapacitating, loss of visibility reduces a person's ability to navigate to a place of safety, leading to further exposure to heat and smoke inhalation [1]. One method of improving a person's ability to navigate to a place of safety is by providing egress signage.

Modelling software such as B-RISK [2] or Fire Dynamics Simulator [3] can be used to estimate the level of visibility through smoke people will have in a building in the event of a fire. This estimation is based on whether or not people will be able to see the buildings egress signs. These software programs allow the user to specify whether the egress signs in the building are illuminated or reflective. Both programs leave some ambiguity as to whether photo luminescent egress signs should be treated as equal to illuminated or reflective signs.

1.2 Theory

Visibility is defined as the maximum distance at which an object of defined size, brightness and contrast can be seen and recognized [4]. A number of factors affect the visibility of an egress sign. The signs properties, including its size, colour, content and level of illumination can make it easier to detect and read at a distance. Environmental conditions such as ambient lighting and smoke can affect visibility. Ambient lighting reflecting in smoke can have a effect much like car headlights in fog, resulting in reduced visibility [5]. Smoke can obscure the sign, refracting and reflecting light from the sign.

The density of smoke can be calculated as the transmittance or optical density. The transmittance (T) is the fraction of light (of a given wavelength) which passes through on abject or substance. It is defined in Equation 1, where I_o is the incident light intensity, and I is the intensity of light received.

$$T = \frac{I}{I_o} \tag{1}$$

The optical density, is calculated as the log of the inverse of the transmittance, as shown in Equation 2.

$$OD = \log_{10}\frac{1}{T} \tag{2}$$

The extinction coefficient is calculated from the incident (I_o) and received (I) light intensities of an obscuration meter, and the length of the light beam of the obscuration meter (l), as shown in Equation 3.

$$C_s = \frac{1}{l}\ln\left({}^{I_o}\!/\!{}_{I} \right) \tag{3}$$

The visibility (V) of signs through smoke can be expressed as a relationship between the obscuration threshold of the sign (k) and the smoke optical density or extinction coefficient (C_s) [1], [6], as presented in Equation 4.

$$V = \frac{k}{C_s} \tag{4}$$

The obscuration threshold (sometimes referred to as the k-factor) is an empirical constant which relates the visibility of a sign to the extinction coefficient of the smoke and is expressed in Equation 4 [6].This relationship can be rearranged as a function of the obscuration threshold, as illustrated in Equation 5.

$$k = V \cdot C_s = \frac{V}{1/C_s} \tag{5}$$

Where visibility is plotted against the inverse of the smoke extinction coefficient, the obscuration threshold can be found as the slope of a trend line passing through zero.

1.3 New Zealand Building Code

Historically the New Zealand Building Code (NZBC) [7] has only permitted the use of two types of egress signs; illuminated signs and reflective signs. Illuminated signs require an inbuilt light with an uninterruptable power supply which incurs installation and maintenance costs. In many situations reflective signs must also be provided with external illumination of no less than 200 lux on the face of the sign and an uninterruptable power supply to comply with the requirements of the NZBC.

In 2012 the NZBC [8] was amended to permit the use of photo luminescent (PLM) egress signs. PLM egress signage must be maintained in a charged state, with illumination of no less than 100 lux on the sign to charge it. They must have a minimum brightness of 0.03 cd/m^2 for the duration prescribed by the NZBC [7] (typically 30 or 60 minutes). An uninterruptable power supply is not required. PLM egress signs are often considered as a cheaper method of satisfying the NZBC than illuminated or reflective signs. They are easier to install than illuminated or reflective signs, and require almost no maintenance.

Signs complying with the NZBC can use ‘EXIT’ lettering or a running man pictorial to identify an escape route, and may use a directional arrow to indicate the direction of escape. Pictorial type signs can use the ISO 7010 E001 or E002 running man, with an ISO7010 E005 or E006 direction arrow. Figure 1 shows a photo of one of the signs used in this experiment. The luminance of the sign will be discussed later in the paper.

Figure 1: Photograph of illuminated sign tested with luminance measurements

Signs have a maximum rated viewing distance, dependent on their size and type [8]. The pictogram height of the illuminated and reflective signs rated for 24 m viewing must be no less than 150 mm. PLM signs must be 30 % larger than illuminated and reflective signs.

1.4 Previous works

Numerous studies have assessed the visibility of egress signage. The original work in the field was carried out by Jin [9] who proposed that the obscuration coefficient is between 5 and 10 for illuminated signs and between 2 and 4 for reflective signs. Obscuration thresholds of 8 and 3 respectively are commonly accepted and used in building design as a result of Jin's work [2], [3].

Jin's work defined these obscuration thresholds by placing people in a corridor containing non-irritant smoke. The corridor was lit to 80 lux for the visibility experiments with illuminated signs, and 40 lux for experiments with reflective signs.

Yamada et al. [6] measured the visibility of illuminated egress signs in a 24 m long corridor filled with theatrical smoke to analyse the effects of sign size and brightness. People were asked to walk along the corridor and indicate; when the sign became visible, when the sign was legible, and the visibility (in metres) could be recorded. These experiments were carried out in a dark environment, where the only light source was the illuminated signs.

Wong and Lo [10] investigated the visibility of different sizes and styles of illuminated exit signs, with English and Chinese text and running-man pictorials. An 18 m long corridor was constructed with a viewing window on one end and a sign on the other end. The signs were replaced with increasingly larger signs until the observer could detect, identify, and confidently read the signs at the end of the corridor. This was repeated for normal and emergency lighting conditions, without smoke.

Ouellette [5] studied the effect of colour and brightness of signs on visibility through theatrical smoke. A 1.5 m long box was constructed with a viewing window on one end and a sign on the other. Observers were asked to look through the viewing window as the brightness of the sign was increased until the sign was 'just readable'.

Tonikian et al. [11] identified a number of studies which have considered the performance of PLMs as part of a way-finding system, incorporating PLM strips at low levels in corridors and around doors, on handrails and stairs in stairwells, in combination with emergency egress signs. PLM way-finding systems have been found to perform similarly to, and sometimes better than conventional electrical powered lighting and way-finding systems. However the visibility of PLM egress signage as a standalone system has not previously been studied.

The performance of externally illuminated reflective egress signs through smoke does not appear to have been studied.

2 OBJECTIVE

The aim of this investigation is to quantify the visibility of photo luminescent egress signs through smoke in order to estimate the visibility of these signs as a means of defining tenable limits. This is achieved by defining the obscuration coefficient of PLM signs. This can now be incorporated into computer models such as B-RISK [2], and used as part of a specific fire engineering design of a building incorporating photo luminescent signs.

3 METHODOLOGY

3.1 Corridor

Experiments in a 12 m long corridor were used to measure the visibility of egress signs through theatrical smoke. Surfaces inside the box were unfinished plywood with no paint or wallpaper. Participants looked through an observation window at one end of the corridor. A curtain was hung behind the observation window to block out external light and prevent reflections on the glazing. The signs were mounted on a rail in the centre of the corridor ceiling. The sign was manually pulled towards the observer using a rope and pulley system. The dimensions and layout of the corridor are shown in Figure 2.

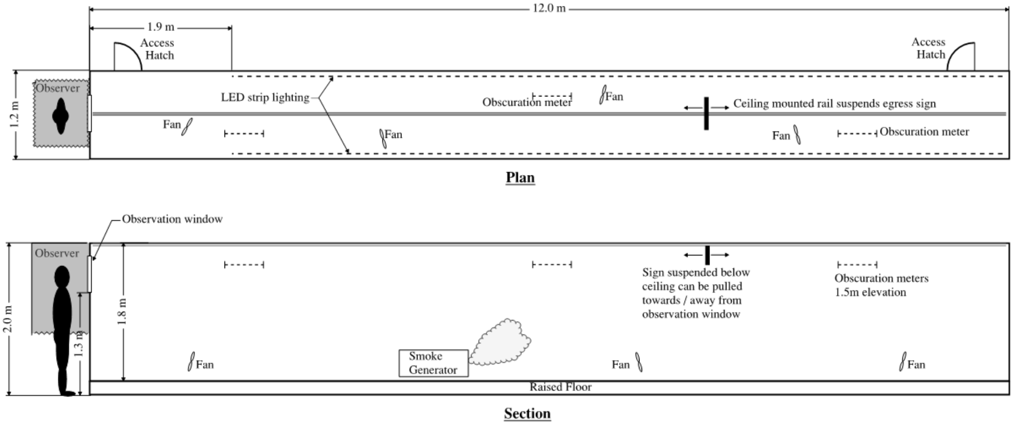

Figure 1: Dimensions and layout of the test corridor

Similar to previous studies [5], [6] a commercial theatrical smoke generator was used to fill the corridor with smoke. The smoke generator was placed inside the corridor with fans to stir the smoke and provide well-mixed conditions. The amount of smoke in the corridor was varied between experiments. Obscuration densities varied from 0.06 to 0.7.

Three laser obscuration meters where suspended from the ceiling on either side of the signs path to measure the density of the smoke. These were 1.5 m above the floor of the corridor, at approximately the same height as the sign. The path length of the obscuration meters was 525 mm. The obscuration meters were periodically calibrated using obscuration filters of known optical density.

Ceiling mounted LED strip lighting ran the length of the corridor to provide even lighting between 85 lux and 120 lux on the floor of the corridor. The light levels measured at different heights and locations in the corridor are displayed in Figure 3.

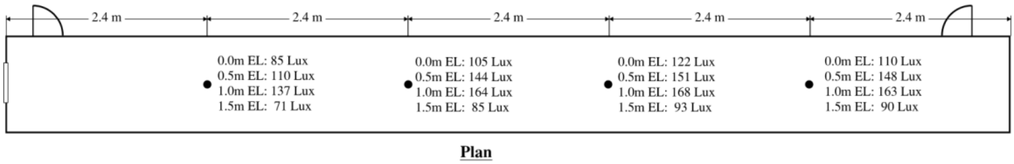

Figure 3: Light levels in the corridor

3.2 Signs

Three types of signs were studied in the experiment; photo luminescent, reflective and internally illuminated. The signs tested were commercially available and complied with the NZBC. They were rated for a viewing distance of 24 m, double to length of the corridor, to minimize the effect of size on the visibility of the signs.

The internally illuminated sign was a wall mounted / bulkhead type egress sign, with a 10 W fluorescent tube bulb, and was powered on a battery power supply. The brightness of the sign did not appear to dim or fade as the battery ran out. The luminance of the sign was between 90 cd/m^2 and 270 cd/m^2 on the pictogram, and between 13 cd/m^2 and 30 cd/m^2 on the background. The sign luminance measurements are shown in Figure 1.

The reflective signs were green and white signs made from PVC. External lighting on the face of the sign was not provided in dark conditions, and therefore the sign installation did not comply with the NZBC.

The PLM signs were placed in a charging light of between 120 lux and 190 lux, with a mixture of natural light and light from fluorescent tubes. When fully charged, the pictogram of sign had a measured luminance of between 1.5 cd/m^2 and 2.5 cd/m^2, with background luminance of approximately 0.02 cd/m^2. This was significantly brighter than the minimum 0.03 cd/m^2 required for compliance with the NZBC [8].

3.3 Volunteers

Visibility of objects differs from person to person. Some people may have better clarity of vision or contrast sensitivity than others, and may be able to see a sign in lighting conditions where others cannot see it. 42 people took part in the study, aged from 18 to 65 years old, with 10 females and 32 males to try and get a representative sample of differences in eyesight.

All participants were given the same briefing before the test began. They were shown one of the egress signs, and told that they sign could be upside down, and that the arrow on the sign point either left or right. They stood behind a curtain and look through the observation window. They were asked to state when they could see the egress sign with three levels of identification as the sign was pulled towards them:

1. Can detect the sign – can see that there is something in the smoke, but cant make out the features.
2. Can read the sign – can see which way the arrow points, and if the sign is upside down.
3. Can clearly read the sign – can make out the foot/shadow of the running man, shown on Figure 1.

At each stage of identification the distance to the sign and the average smoke extinction coefficient were recorded. This was repeated for each of the three types of signs, both with the corridor lights on, and in the dark.

The reflective sign was not visible in dark condition, until it was within 0.5 m of the observation window. If a participant stated that they could identify the sign when it was more than 0.5 m from the window, it would be an apparent mistaken identification, and the validity of measurements for that participant would be questionable. There were no mistaken identifications in this study.

4 RESULTS

The shape, colour and sometimes position of egress signage in buildings is relatively standardized. People may only need to be able to ‘read’ the sign, to determine identify the sign and see which way the arrow is pointing to be able to follow the signs directions. It is not enough simply to ‘detect’ that there is a sign, as there may be a number of other signs in an escape route. Therefore the performance of egress signs has been assessed based on when people can ‘read’ the signs.

A fire may not affect the power supply of lighting a building in its early stages, during evacuation. However, even where power fails, the NZBC requires emergency lighting with back-up power supply in most escape routes [12]. Although emergency lighting may only be required to provide 1 lux at floor level, it can be reasonably be assumed that there will be some level of ambient lighting in an escape route at any given time. Therefore, the performance of egress signs has been characterised primarily in light conditions.

The results are plotted below in Figure 4 and Figure 5 for the three types of signs in both light and dark conditions. Using Equation 5, the slope of the lines of best-fit provides the obscuration threshold for that sign. The R^2 value indicates the coefficient of determination for the line of best fit.

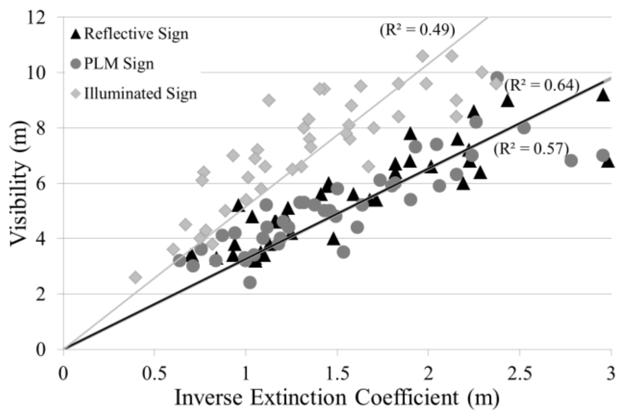

Figure 4: Visibility of signs in light conditions

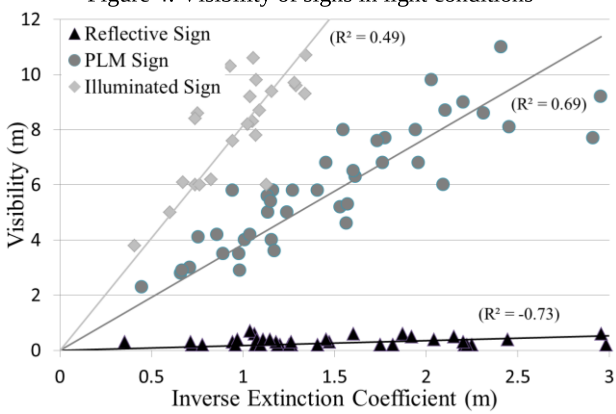

Figure 5: Visibility of signs in dark conditions

The obscuration thresholds for the three sign types in light and dark conditions are presented in Table 1 below. In both light and dark conditions, the illuminated sign performed significantly better than the reflective and PLM signs.

Table 1: Obscuration threshold for different sign types in light and dark conditions

	Light conditions	Dark conditions
Illuminated Sign	5.2 ± 1.1	8.2 ± 1.6
PLM Sign	3.3 ± 0.6	3.8 ± 0.7
Reflective Sign	3.3 ± 0.7	0.2 ± 0.1

5 DISCUSSION

5.1 Illuminated Signs

The illuminated sign tested had an obscuration threshold of 5.2, which is at the low end of the range from 5 to 10 proposed by Jin [9]. This may be linked to the performance of the signs tested. The sign tested had a measured brightness of between 90 cd/m^2 and 270 cd/m^2, where work by Jin was based on signs with a brightness of between 500 cd/m^2 and 2000 cd/m^2 [9]. Increasing the brightness of a sign has been found to increase the sign's obscuration coefficient [9]. The brightness of ambient lighting may also have impacted on the performance of the sign. Jin used an ambient light level of 80 lux, compared to a measured luminance 80 lux to 170 lux in the corridor.

The illuminated sign performed better in dark conditions than in light conditions. Table 1 shows that the obscuration coefficient for the illuminated sign was higher in dark conditions than in light conditions. In a smoke filled environment light refracts and reflects in the smoke, with a similar effect to car headlights in fog. With lighting in the tunnel illuminating the smoke, the relative brightness of a sign and its visibility are reduced.

5.2 Reflective Signs

Jin [9] also examined the visibility of reflective egress signage through smoke with 40 lux background lighting and proposed that the obscuration threshold for reflective signs should be between 2 and 4. An obscuration threshold of 3.3 was measured for the reflected signs used in this experiment, which aligns approximately with the middle of the range proposed by Jin.

When tested in a dark environment, the reflective signs unsurprisingly performed poorly as there was no light in the corridor to reflect. The signs only became visible close to the observation window where lighting leaking around the curtain illuminated them. The reflective signs were not provided with external lighting, as is generally required by the NZBC. Therefore the measured performance of the reflective signs is indicative only of the non-compliant installations, or where the external lighting or uninterruptable power supply fails.

As stated above, the performance of externally illuminated reflective signs has not previously been documented. However some inferences can be made. If an externally illuminated reflective sign was the only illuminated item in an otherwise dark environment, the visibility of the sign through smoke may increase in the same way that the obscuration coefficient of an illuminated sign is higher in dark conditions than in light conditions. Properly installed reflective signs, with dedicated external lighting complying with the NZBC, may perform well in dark conditions.

5.3 PLM Signs

Comparison of the measured obscuration coefficients of reflective and illuminated signs with previous work demonstrates shows that the results are comparable. This corroborates the results of the study, providing a level of confidence in the measurements taken for the visibility of PLM signs through smoke.

In light conditions, it is it hard to distinguish between the performance of the reflective and PLM signs. Both reflective and PLM signs have an obscuration coefficient of 3.3. This is despite the PLM sign being 30% larger that the reflective sign, as required by the NZBC [8]. Like the illuminated sign, the visibility of the PLM sign improves when background lights are turned off, with an obscuration coefficient of 3.8 in dark conditions.

Based on the results of this experiment, it is recommended that the visibility of PLM egress signs through smoke should be considered as approximately equal to that of reflective signage. An obscuration coefficient of 3 should be used for PLM signs.

5.4 Effects of lighting on visibility

Strip lighting was used on either side of the corridor to provide an even distribution of light throughout the corridor and no light source directly between the observer and the signs. In typical building design, luminaires and egress signage are both aligned down the centre of the ceiling in a corridor or escape path. Lighting designers may also choose to place lights immediately above the sign to provide ‘emphasis lighting’ of the egress signage [13]. The light intensity immediately beneath these luminaries is likely to be higher than for strip lighting to achieve the same distributed brightness. It’s expected that this would exaggerate the ‘car headlight effect’, with columns of brightly lit smoke obscuring the view of the sign.

5.5 Effects of smoke on sign legibility

Smoke appears to have only a minor impact on the legibility of signs, once the sign has been detected. The point at which at which a person could ‘detect’ an illuminated sign in the dark often coincided with them being able to ‘read’ the sign. Figure 6 differentiates between when participants in the experiment could ‘detect’, ‘read’, and ‘clearly read’ an illuminated sign. Refraction of the light through the smoke does not appear to impact significantly on a person’s ability to read a sign. However, smoke does have a noticeable effect on whether or not a person can ‘clearly read’ a sign. This effect may be significant in situations where people are unfamiliar with the style of egress signs, or where the signs are not common and recognisable.

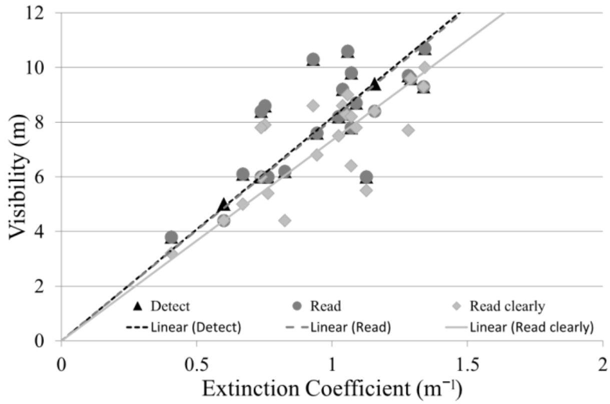

Figure 6: Identification of illuminated sign through smoke in the dark

5.6 Limitations

This study was subject to a number of limitations and further work is required to properly understand the visibility of egress signs.

The PLM signs used in this study where charged using a brighter charging light than the minimum required of 100 lux, and the signs were tested in their ‘fully charged’ state. The visibility of partially charged PLM signs through smoke, or signs which have be charged with a less bright charging light has not been studied.

The effects of dedicated external lighting on the face of a reflective sign in dark conditions has not been studied.

The effect of lighting between an observer and a sign in smoke logged conditions is not understood.

There are a significant number of different illuminated, reflective and PLM signs available on the market. This study used only individual samples of the three types of signs available, and has not considered the range of different styles and brands of signs available.

Irritation of the eyes caused by smoke on the eyes has not been considered.

The reliability of emergency lighting systems for illuminated signs has not been considered when evaluating the relative merits of illuminated and PLM egress signs.

6 CONCLUSIONS

This study has sought to characterise the visibility of photo luminescent egress signs. The results have been corroborated by testing the visibility of illuminated and reflected signs and comparing the results with published works. The visibility of internally illuminated signs is significantly better than the reflective and photo luminescent signs in both light and dark conditions. In light conditions the visibility of photo luminescent and reflective signs is approximately equal. Whilst the visibility of externally illuminated reflective signs through smoke in dark conditions has not been studied, it can be inferred that they would perform similarly to photo luminescent signs in dark conditions. It is recommended that photo luminescent signs are treated as equal to reflective signs when predicting visibility in smoke logged conditions. Photo luminescent should be treated as having an obscuration coefficient of 3 when viewed through smoke.

7 ACKNOWLEDGEMENTS

This study has been made possible through support from a number of firms and individuals. Notably, the support of Beca Ltd, and assistance from Michael Spearpoint and Grant Dunlop from the University of Canterbury have been invaluable.

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