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A FIELD STUDY ON PHOTOLUMINESCENT SIGNAGE USED TO GUIDE BUILDING OCCUPANTS TO EXIT IN COMPLETE DARKNESS

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A field study was conducted in an office building to assess the effectiveness of photoluminescent material to facilitate occupant evacuation. The office building's four identical stairwells were set with different conditions; one had full lighting, one had reduced lighting, another one had reduced lighting with photoluminescent wayguidance signs and one had photoluminescent wayguidance signs with no other lighting output. Non-informed occupants evacuated through the 4 stairwells. Speed of movement recorded using video cameras showed a similar speed of movement when considering the different density of the 4 stairwells.

INTRODUCTION

Interviews with victims after large fires have demonstrated that occupants could benefit from additional wayguidance information to efficiently move to safety, especially when evacuating during a power failure or in smoke conditions (Proulx, 1998; Fahy and Proulx, 1995). Installing a Photoluminescent Material (PLM) wayguidance system along evacuation routes appears to be a potential means of improving occupants' fire safety. A PLM system consists of signage elements that can be installed in the form of signs, paint, strips or fabric on any surface. The particularity of this non-radioactive material is that it contains pigments which have the capacity to store, in a few minutes, the energy from normal lighting. The material will restore this energy as a yellowish-green glow when all lights are extinguished. The initial bright glow emitted by the material will gradually diminish in brightness, but will remain visible for 3 to 40 hours, depending upon the type of material used.

If properly installed, some of the benefits of using a PLM wayguidance system are that it can provide orientation and confidence to evacuating occupants. Also, if installed as a continuous strip, PLM can assist orderly and speedy evacuations in blackout conditions and in heavy smoke. PLM is totally reliable, provided it has been exposed to proper lighting to become fully charged. Further, PLM can be set up in new or existing buildings, is simple and economical to install and requires a minimum of maintenance.

Disadvantages of using a PLM system are: it does not provide as much brightness as lamps or luminaires; and the material decreases in intensity as the stored energy is emitted. Also, for PLM to work properly, it is necessary to illuminate the evacuation routes to charge the material. Finally, a person passing from a fully-lit space to an area with PLM only, will need a few seconds to adapt to this new lighting.

LITERATURE REVIEW

In the UK, Webber and his colleagues have completed several laboratory studies on the usefulness of PLM as a wayguidance system (Webber et al, 1988). They concluded that the performance of the subjects under the PLM conditions was similar to that under emergency lighting. Based on subjects' ratings, they concluded that PLM could provide a viable alternative to emergency lighting. They have also conducted studies on the visibility of wayfinding systems and lighting systems in smoke. The results of these studies showed that electrically-powered wayfinding components have a higher visibility performance in smoke than PLM components. However, with no other lights on, the PLM was better perceived in smoke (Webber 1997; Webber and Aizlewood, 1994).

Jensen, in Norway (1993) tested 84 subjects in dense smoke with seven different wayguidance systems. His results on visual guidance are contradictory to popular belief: he found that the level of luminance alone is not important in smoke! Results show that a PLM strip, 25 mm wide, built into a directional rail, performed the best among other systems at high smoke densities.

Heskestad and Pedersen (1998) pointed out in their review of experiments on PLM and electrical powered wayfinding systems, that it is our ability to perceive details that takes the longest to adapt in darkness but we are able to follow continuous lines without perceiving the detailed directional information. Therefore, with respect to speed of movement in a smoke environment, there are no significant differences between systems as long as they are continuous.

It should be noted that these studies were usually performed along short paths, with few subjects moving along routes one at a time and in laboratory environments. No field studies to assess the performance of the material, with actual occupants, have been carried out. To enable this material to be used, results from field studies are needed. The results of such studies will demonstrate the impact of PLM on actual occupants' movement during evacuations.

STUDY OBJECTIVE

The objective of this study was to assess the potential use of PLM as a safety communication system to support office occupant evacuation. The study was also aimed at measuring the occupant time to start, move and evacuate the building. The field study allowed us to measure the speed of movement of occupants in a natural setting and to obtain an assessment of the system from non-informed occupants.

METHODOLOGY

To gather data, an unannounced evacuation drill was conducted in an office building. The building selected was a 13-storey concrete structure built in 1979. Four identical windowless stairwells leading to the outside were located at each corner of the square-shaped building. Each floor area of 3700 m^2 had an open plan concept divided into 4 quadrants. Work stations were divided with partition walls, 1.7 m in height. In the centre of the building was the core area, with elevators and washrooms. There were approximately 150 office workers on each floor doing research and clerical activities. It was decided to study Floors 9, 10 and 11 in the building which presented similar partition wall configurations.

The building's four identical stairwells were set up with different conditions, as shown in Table 1. It is important to mention that, in this building, the stairwells' emergency lighting was the full lighting with an average output of 245 lux. For the study, the lighting conditions in three of the stairwells were modified while Stairwell B received no treatment; it acted as the control stairwell. Lighting in Stairwells A and D was modified to obtain a reduced output of not less than 3.3 lux, which is a code requirement. To reduce the lighting, 2 out of 3 double-tube luminaires were switched off, providing Stairwell A with an average lighting of 57 lux and Stairwell D with a slightly higher average output of 74 lux. Also, Stairwell D had PLM signs and a wayguidance system installed. Stairwell C also had PLM signs and a wayguidance system and had all lights switched off a few minutes before the evacuation, as presented in Figure 1. During the evacuation drill, the regular lighting was turned off on the 3 studied floors, leaving only the building emergency lighting.

Table 1: Stairwell Experimental Design

Stairwell	Condition
A	Emergency lighting reduced to 57 lux
B	Control stairwell - Full lighting 245 lux
C	PLM without any other lighting
D	PLM with emergency lighting reduced to 74 lux

Stairwells C and D were equipped with PLM from the top floor of the building down to the bottom. The installation of the material was according to the Photoluminescent

Safety Products Association Standard 002 Part 1 (PSPA, 1997). The stairwell was equipped with two continuous wayguidance lines, 10 cm in width; one line at skirting board and the other 1 m from the floor. Directional signs were enclosed within these continuous lines. A 2 cm strip was fixed on the tread of each step and a 10 cm piece was positioned on the riser of each step. A sign identifying the floor number was installed on each door as well as a sign identifying the "Transfer Floors". Directional signs were positioned on each door and at mid-landing. In accordance with Canadian practice, signs were positioned at the top of each exit door, identifying them as a final exit. The material and installation costs for the stairwells were estimated at $2,000 CDN/floor.

Figure 1: Stairwell C with PLM and lights off

Twenty video cameras were used to gather data. Cameras were placed at the entrance to each stairwell on Floors 9, 10 and 11, in the stairwells on the landing between the fifth and sixth floors and at ground level at each exit door. At each exit, questionnaires were handed out to evacuees.

The evacuation procedure for the building was detailed in a manual availabsTD 3ts off
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Table 2: Mean Speed of Movement in the Four Stairwells

Stairwell	Mean Speed m/s	Std Dev.	Number of Evacuees	Density p/m^2	Calculated Speed m/s
A (54 lux)	0.70	0.1556	82	1.25	0.72
B (fully-lit)	0.61	0.1016	101	1.30	0.70
C (PLM only)	0.57	0.1202	144	2.05	0.49
D (PLM + 74 lux)	0.72	0.0854	65	1.00	0.79

analyzed. A total of 457 occupants were observed in the recordings. Data was coded for each individual regarding gender, the time of arrival at the exit door, the time each entered the stairwell, the time each passed the 5th floor and the final time of exiting. General behaviour of the evacuees was noted.

Before the evacuation message was issued, the fire alarm rang for 2 min. During that time, the evacuees on all floors gathered around the nearest exit door to the stairwell to listen to the voice communication messages. The average time for occupants to start their evacuation was 1 min 12 s.

The exact speed of movement for each evacuee was noted from the video and the average speed of movement in each stairwell was calculated, which is presented in Table 2. The slowest mean speed of movement was in Stairwell C, at 0.57 m/s. Stairwell A had a mean speed of 0.70 m/s and Stairwell B had a mean speed of 0.61 m/s. Finally, Stairwell D had a mean speed of 0.72 m/s.

An Analysis of Variance shows a significant difference between the four stairwells ($F = 36.73$, $df = 3, 388$, $p < 0.001$). A multiple comparison procedure, the Bonferroni test, was used to identify pairs of groups having significantly different means. The results show that the mean speed of movement for evacuees in Stairwell C (PLM only) is significantly slower ($\overline{X} = 0.57$, $p < 0.05$) compared to Stairwell A (57 lux) ($\overline{X} = 0.70$, $p < 0.05$), Stairwell B (fully-lit) ($\overline{X} = 0.61$, $p < 0.05$), and Stairwell D (PLM and 74 lux) ($\overline{X} = 0.72$, $p < 0.05$). There is also a significant difference between Stairwell B (fully lit) ($\overline{X} = 0.61$, $p < 0.05$) and the two stairwells with emergency lighting reduced to 57 lux, (Stairwell A) ($\overline{X} = 0.70$, $p < 0.05$) and, PLM and 74 lux (Stairwell D) ($\overline{X} = 0.72$, $p < 0.05$). There is no significant difference in the mean speed of movement for Stairwells A (57 lux) and D (PLM and 74 lux).

These results indicate that the speed of movement was faster in the two stairwells that had the emergency lighting reduced compared to the stairwell that had the PLM only and the stairwell with full lighting! The latter finding appears incongruous; how to explain that occupants move faster in stairwells with reduced lighting compared to a fully-lit stairwell? After examining the data closely, an explanation for these results appeared. Stairwell C had the slowest speed of movement, but it also had the largest crowd in the stairwell with 144 people. In that stairwell, there was also the upward movement of 3 firefighters which slowed down all the descending occupants. Stairwell B, with full lighting, was second slowest and was also the second most crowded of the stairwells with 101 evacuees. Stairwell A was the second fastest and least crowded with 82 evacuees. Finally, Stairwell D had the fastest overall speed and also the least amount of people with

65 evacuees. Therefore, the more plausible explanation for the decrease in speed in the different stairwells is related to the increase in crowding and not to the lighting conditions in each stairwell.

The density of occupants descending varied for each stairwell. Density of evacuees was calculated for the three busiest minutes of the evacuation. As shown in Table 2, Stairwell C had the highest density with an average of 2.05 p/m^2, which is almost 3 people for every 5 steps. Stairwells A and B were similar with, respectively, 1.25 p/m^2 and 1.30 p/m^2. Finally, Stairwell D had the lowest density, with an average of 1.0 p/m^2. Pauls (1995) has developed, from 21 case studies of highrise office evacuations, an equation to calculate the expected speed of movement of occupants going down stairwells under normal conditions. This equation is $s = 1.08 - 0.29d$, where s is the speed of movement in m/s and d is the density. For Stairwells A, B, and D the calculated speed of movement is slightly higher than the observed speed of movement, while for Stairwell C, the calculated speed is lower than the observed speed. This result confirms that the observed speed of movement was faster than what could be expected for Stairwell C.

DISCUSSION AND CONCLUSIONS

This study shows that occupants are prepared to travel in a stairwell with PLM signs and wayguidance system without any other illumination source even though, for a majority of the participants, it was their first encounter with PLM signage. A majority of the evacuees (93%) assessed the quality of the lighting in the 3 stairwells with emergency lighting or full lighting as "very good" or "acceptable". There is no difference in their assessment of the stairwell with full lighting or reduced emergency lighting. This means that stairwell lighting reduced to an average of 57 or 74 lux appears to be acceptable to the evacuees as full lighting.

Through the questionnaire, the lighting quality of Stairwell C, with PLM signs and wayguidance system only, was assessed by 30% of the evacuees who used that stairwell, as "poor" or "dangerous". However, this question was badly worded, so respondents might have been inclined to give a negative answer. Nevertheless, this result raises a few concerns. Three areas for PLM wayguidance improvement are identified:

1) The occupants were completely naive and were probably experiencing PLM wayguidance systems for the first time; education and training would remove the normal reaction to the unknown.
2) The luminance of the PLM components should be increased. It should be pointed out that the luminance properties of the PLM material used in this study were not the highest that may be currently achieved.
3) The amount of material installed may be increased. In an attempt to maintain the amount of material to the minimum required under European standards, it is possible that the quantity of material used was too little for the location. An immediate improvement would be expected from wayguidance lines on both sides of the stairs and some marking on the handrail.

Clearly, 70% of the evacuees in the PLM stairwell found the lighting quality very good or acceptable, which is a very positive assessment of the system. This result allows us to conclude that most people consider it perfectly acceptable to evacuate down a stairwell with the only lighting being provided by a PLM wayguidance system meeting specific standards.

One of the most important findings of this study is the speed of movement of a natural crowd descending four stairwells under different lighting conditions. Findings show that, irrespective of the lighting conditions tested, speeds of movement are comparable to speeds obtained in previous studies in stairwells with full lighting (Bryan, 1995; Proulx and Pineau, 1996). The mean speed of movement obtained for the stairwell with PLM only, is deemed very good, considering that this stairwell had the largest crowd, a high density of users and that firefighters ascended the stairwell. It was not expected to obtain such a disproportionate crowd in that stairwell compared to the other three. Such outcomes, however, are to be expected in field studies, since occupants are not controlled and are left to go where they want. It was also not expected that firefighters would climb part of that stairwell while occupants were still evacuating. However, this is a conceivable situation, if a real fire emergency had been suspected on the 10^{th} floor.

This study shows the interesting potential of PLM signage to support occupant evacuation. Such signage, properly installed, can address deficiencies in the traditional approach to emergency lighting associated with power failure or smoke-logging of high-mounted luminaires. To obtain the expected outcome, though, it is essential to install the material as a continuous strip with markings on steps and handrails, as well as identification and directional signs. The installation of a PLM wayfinding system appears to be a cost-effective addition or even a potential replacement for traditional electrical emergency lighting, since it does not consume energy, requires no wiring, needs minimum maintenance and is totally reliable, provided it is installed in locations where permanent full lighting is provided. The occupants' behaviour, their speed of movement and their subjective appraisal of the material are all in agreement to conclude that PLM signs and wayguidance systems could be a worthwhile addition improving occupant fire safety in buildings.

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