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Effectiveness of a Photoluminescent Wayguidance System

Guylène Proulx, Brian Kyle and John Creak

ABSTRACT

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 signs and wayguidance system and one had photoluminescent signs and wayguidance system with no other lighting. Non-informed occupants evacuated through the 4 stairwells. Speed of movement in the four stairwells, recorded using video cameras, showed a similar speed of movement when considering the different density of the 4 stairwells. Of the evacuees who descended the photoluminescent stairwell, with no other lighting, 70% gave a very positive assessment of the system. However, one-third of the evacuees of that stairwell, had some criticisms that could be alleviated by adding more material or increasing the brightness of the material.

KEYWORDS: photoluminescent, evacuation, emergency lighting, movement in stairs

INTRODUCTION

Interviews with victims after large fires have demonstrated that occupants could benefit from additional wayguidance information during their evacuation, especially when evacuating during a power failure or in smoke conditions. It is often found that power generators do not kick-in during power failures related to fire incidents, due to damage to the generator, over-charge or bad maintenance (Fahy and Proulx, 1995). Even when the emergency lighting is operational, or for that matter with full lighting, evacuees often complain that they had to evacuate in complete darkness (Proulx, 1998; Proulx, 1996). The absence of lighting in the means of egress, that characterise many fires, is usually due to smoke obscuration of the luminaires that are typically located at the ceiling or at the top of walls. Installing a Photoluminescent Material (PLM) wayguidance system along evacuation routes appears to be an effective way of improving occupants' evacuation movement during fires. A PLM system consists of high mounted signs, guidance lines incorporating directional signs and stair markings. The particularity of this non-radioactive material is that it contains pigments that have the capacity to store energy from normal lighting and will emit this energy as a yellowish-green glow when all lights are extinguished. Over time, the material will diminish in brightness, but will remain visible to the dark-adapted eye for a period of time depending on the type of material. Tests have shown that the light emitted from the luminous material may be visible to the dark-adapted eye for as long as 40 hours (Krokeide, 1988).

Over the years, PLM has been improved to such a degree that the material is now installed along evacuation paths in many settings such as hotels, hospitals, underground transport systems, ferries, aircraft and offshore platforms

(Creak, 1995; Webber and Shipp, 1996). A number of countries, including England, Norway, Sweden, Germany and Japan, have developed regulations, standards or codes of practice providing installation and illumination criteria. In North America, PLM could serve as a cost-effective supplement to emergency lighting or even as an alternative to installing emergency lighting in some areas of new or refurbished buildings.

If properly installed, some of the benefits of using a PLM wayguidance system may include the following:

- it provides orientation and confidence, thereby reducing anxiety in situations where evacuation is necessary;
- if installed as a continuous strip, PLM can assist orderly and speedy evacuations in blackout conditions;
- PLM will not fail provided it has been exposed to proper lighting to become fully charged;
- in heavy smoke, a continuous strip of PLM positioned at 1 m from the floor and at the skirting board is better as a directional guide than regular or emergency lighting that is ceiling or wall-mounted, since the latter is likely to become obscured;
- PLM is simple and economical to install;
- it can be set up in new or existing buildings;
- it requires a minimum of maintenance;

- it is inherently flame-retardant, it is also unaffected by cold, explosions and, to some degree, vandalism; and
- PLM is non-radioactive and non-toxic.

Some of the disadvantages of using a PLM system may include the following:

- it does not provide as much brightness as lamps or luminaires;
- the material decreases in brightness as the stored light is emitted;
- 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;
- it is necessary to illuminate the evacuation routes to charge the material; and
- the optical brightness (luminance) of the material will depend on the material selected, the level and type of the activating illumination and the time of illumination prior to the light failure.

LITERATURE REVIEW

In the UK, Webber and his colleagues have completed several laboratory studies on the usefulness of PLM as a wayfinding system. 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 (Webber et al, 1988; Webber and Aizlewood, 1992; Webber, 1987). 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 perceived in smoke after elapsed times of up to 5 min. In smoke, the presence of high-mounted luminaires reduced contrasts producing unhelpful scattered light. Webber concluded that electrically-powered wayfinding systems offered more effective visual guidance in smoke than traditional emergency luminaires (Webber 1997; Webber and Aizlewood 1994a, 1994b).

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 is not important in smoke! Results show that, "The photoluminescent strip built into the directional rail was 25 mm wide only, and tilted to an angle of only 30º to the view direction. Amazingly, it performed well even at smoke densities of OD=1.47 m and OD=1.49 m.". At higher smoke densities, subjects could not move at all, regardless of the wayguidance system.

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 in office building environments. To enable this material to be used, results from field studies are needed. These studies should compare occupants' movement along routes with PLM to routes with conventional systems. The results of such studies will demonstrate the impact of PLM on actual occupants' movement during an evacuation.

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 with the participation of all occupants. It was also essential to evaluate the effectiveness of the material in an actual building with non-informed occupants. Assessment by the occupants of their experience during the evacuation was also gathered through a questionnaire distributed after the evacuation drill.

METHODOLOGY

To gather data on the usefulness of PLM to support office occupant evacuation, it was decided to conduct an unannounced evacuation drill in an office building. The building selected was a 13-storey concrete structure built in 1979, glazed on all sides and almost square in shape. Each floor area of 3700 m^2 was an open-plan concept divided into 4 quadrants, identified as A, B, C and D. Workstations were divided with partition walls of 1.7 m in height. In the centre of the building was the core area, with elevators, washrooms, storage areas and a few enclosed meeting rooms. There were approximately 150 office workers on each floor doing research and clerical activities. The building had four identical windowless stairwells leading to the outside of the building.

It was decided to study Floors 9, 10 and 11 of the building which had similar partition wall configurations. Floor 10 was equipped with over 80 PLM hanging signs positioned to direct occupants toward the four exits. The hanging signs were 45cm x 15 cm with 2.5cm high letters indicating “Sortie de secours” and “Fire Exit” with an arrow, as required by the Canadian Federal Identity Program.

Special attention was made to position signs directly above the narrow corridors between partition walls leading to the exits. Floors 9 and 11 served as comparison floors with no special treatment. During the evacuation drill, the regular lighting was turned off on the 3 studied floors leaving only the building emergency lighting. On the floors this meant that one out of five ceiling luminaires was on.

The dimension and design of the building's four stairwells were identical. Stairwell shafts were 4.8 m X 2.2 m with 3.6 m of floor height and each flight of stairs was 1.1 m in width with step riser of 18 cm. The four stairwells were set up with different conditions, as shown in Table 1. It is important to mention that, in the stairwells, the emergency lighting was the full lighting which provided a very well-lit stairwell of an average output of 245 lux. For this study, the lighting conditions in three of the four stairwells were modified. 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 obtain this output, 2 out of 3 double-tube luminaires were switched off in Stairwells A and D. With this design, Stairwell A had an average lighting of 57 lux and Stairwell D had a slightly higher average lighting of 74 lux. Stairwell D had also PLM signs and a wayguidance system installed. A few minutes before the evacuation, all lights were switched off in Stairwell C which had PLM signs and wayguidance system. Finally, Stairwell B received no treatment; it acted as the control stairwell.

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

Two of the four stairwells 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 which met the Luminous Class 1 specification (PSPA, 1997). As shown in Figure 1, the stairwell was equipped with two continuous wayguidance lines of 10 cm in width; one line at skirting board and the other 1 m from the floor. Directional signs of 30 cm x 10 cm, 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" on Floors 4, 9 and 13. Directional signs were positioned on each door and at mid-landing at 1.7 m from the floor. 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.

The typical illumination in the four stairwells prior to the fire alarm activation was 245 lux. When the alarm was activated, lights were switched off to meet the experimental conditions illustrated in Table 1. The material luminance in Stairwell C was 89.1 mcd/m^2 after 2 min of switch off and 7 mcd/m^2 after 30 min.

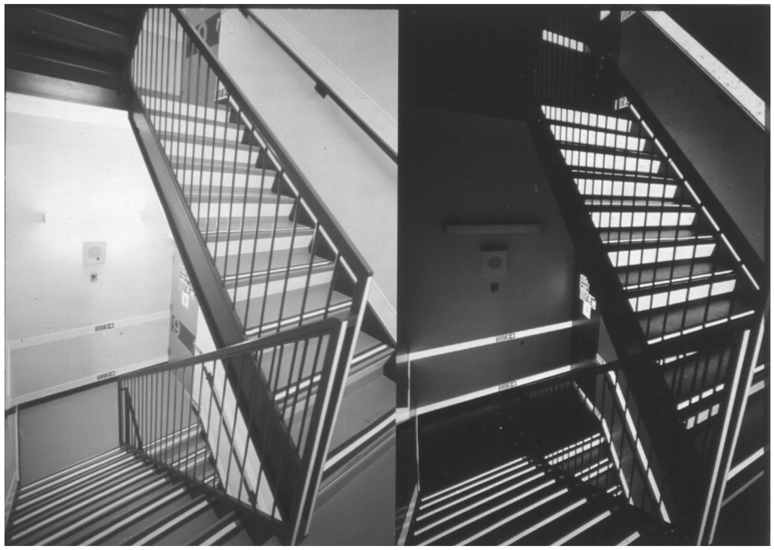

Figure 1: Stairwell C with PLM wayguidance system, lights on and off

Twenty video cameras were used to gather data during the evacuation drill. Cameras were placed at the entrance to each stairwell on floors 9, 10 and 11, on the landing between the fifth and sixth floors and at ground level at each exit door. At each of these outside cameras, two assistants handed out a questionnaire to evacuees as they exited the building.

The procedures in case of an emergency in the building studied are detailed in a procedures manual available to all staff and used in the training of floor fire wardens. A summary of the procedure was posted by the elevators and exits on all floors. This procedure required that all occupants gather at the closest exit door when the fire alarm is activated and await instructions. In the event of a fire, occupants receive instructions through the voice communication system to evacuate three floors, namely the fire floor, the floor below and the floor above. This procedure allows occupants who would be most at risk during a fire to exit first and would prevent crowding in the stairwells.

This evacuation procedure was unchanged for the study. It was an unannounced evacuation drill. The fire alarm rang throughout the building. Occupants gathered by their closest evacuation exit awaiting instructions. For the study, the 10th floor was assumed to be the fire floor, so Floors 9, 10 and 11 were evacuated. The voice communication message delivered to occupants stated that an evacuation drill was going to be conducted under emergency lighting conditions, that an incident had occurred on the 10th floor, so occupants on Floors 9, 10 and 11 should evacuate. Occupants with disabilities were told to gather at Stairwell D and stand by for instructions.

FIELD STUDY RESULTS

The evacuation drill unfolded as planned without any unexpected incident to report. The drill was on a Wednesday, in November, at 13:45. This day and time was chosen to obtain a maximum number of occupants in the building. The temperature outside was -3°C with light snowflakes falling. The fire alarm was activated by a staff member on the 10th floor. The alarm bells started ringing immediately. Overall, the evacuation drill took less than 20 min.

A questionnaire was distributed to each evacuee after they left the building, at each of the four stairwells. Over 450 questionnaires were handed out. A total of 216 questionnaires were returned.

Out of the 70 respondents from the 10th floor, 54 (77%) of them indicated seeing the PLM signs. Twenty-five people out of 49 respondents from the 10th floor (51%) reported that these signs were useful in finding their way on the floor. Of the 53 who rated the visibility of these signs, 32 (60%) reported the visibility to be very good, 16 (30%) rated it to be acceptable, 2 (4%) said the visibility was poor, and 3 (6%) said it was dangerous.

Most respondents (69 or 96%) who descended Stairwell C, reported that the PLM signs were useful in finding their way down the stairwell. Still, 14 people of 31 (45%) from Stairwell D with PLM signs and wayguidance system and 74 lux, reported the signs to be useful. It should be noted that in this illumination the signs were more reflective rather then being seen as “glowing in the dark”.

The visibility of the PLM signs and wayguidance system was assessed by choosing one of four options. Seventy-five people from Stairwell C responded to this question: 33 (44%) rated the visibility as being "very good"; 34 (45%) rated it as being "acceptable"; 5 (7%) rated the visibility as being "poor"; the remaining 3 (4%) rated it as being "dangerous". Thirty-one people from Stairwell D answered this question: 16 (52%) reported the visibility of the PLM signs as being very good; 12 (39%) said the visibility was acceptable; 2 (6%) rated it as being poor and 1 (3%) said the visibility was dangerous. The frequencies of the 2 stairwells did not differ significantly, $\chi^2 = 0.36$, $df = 1$, $p = 0.55$. It is interesting to note that among the 4 respondents who assessed the PLM signs and wayguidance system as dangerous, 2 of them also assessed the emergency lighting on their floor as dangerous. Also, a third person wrote cynical comments implying essentially that the whole building was dangerous.

From Stairwell C, 61 of 74 (82%) reported that the PLM signs facilitated their evacuation movement. Ten of 31 (32%) from Stairwell D stated that the PLM signs facilitated the evacuation. These frequencies are significantly different, $\chi^2 = 16.34$, $df = 1$, $p < 0.001$.

Participants were asked to assess, from four choices, the quality of the lighting in the stairwell they used. The results are presented in Table 2. It is important to note that the question was worded "How would you assess the quality of the emergency lighting in the stairwell you used?" Several respondents from Stairwell C added the comment on their questionnaire that there was no emergency lighting in the stairwell they used, so they left the question blank or they assessed the lighting as dangerous because it was non-existent. The objective of the question was to obtain a subjective assessment of the conditions in the stairwell. If this questionnaire is to be used in future studies, the wording of this question should be revised to reflect how a PLM wayguidance system can support occupant evacuation.

Table 2: Question "How would you assess the quality of the emergency lighting in the stairwell you used?"

Lighting Quality	Frequency (Valid Percent)			
Option	**Stairwell A**	**Stairwell B**	**Stairwell C**	**Stairwell D**
Very Good	26 (55%)	27 (60%)	14 (20%)	18 (50%)
Acceptable	18 (38%)	18 (40%)	36 (50%)	18 (50%)
Poor	3 (7%)	0 (0%)	11 (15%)	0 (0%)
Dangerous	0 (0%)	0 (0%)	11 (15%)	0 (0%)
Total	**47 (100%)**	**45 (100%)**	**72 (100%)**	**36 (100%)**

Recordings from the 20 video cameras used to survey this evacuation were analyzed. A total of 457 occupants were observed on 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 on the 5th floor and the final time of exiting. General behaviour of the evacuees was noted. The ascending movement of a group of firefighters in Stairwell C was also noted.

At exactly 1:45:53, the fire alarm bell sounded, and was quickly followed by the arrival of the fire trucks, which had lights and sirens turned on. The alarm rang continuously for close to 2 min before the first voice communication message was issued. This time delay, according to the building management, is the approximate time it would take an officer to consult the fire alarm panel and go to the microphone to issue a message in a real fire situation. During this time, as is the procedure for the building, the evacuees on all floors gathered around the nearest safe exit door to the stairwell to listen to the voice communication messages.

Due to the building's large surface area and the configuration of the partition walls, it was not possible to record the exact starting time of each occupant upon hearing the fire alarm. It was however possible to observe the time of arrival of the first person at each floor exit door. The average time to reach the exit door was 1 min 12 s. It can be estimated that the true Time to Start of each of these occupants was approximately 10-15 s prior to their arrival at the door.

The exact speed of movement for each evacuee was noted from the video then the average speed of movement in each stairwell was calculated, which is presented in Table 3. The slowest mean speed of movement was in Stairwell C (PLM only), where the mean speed was 0.57 m/s. Stairwell A (57 lux) had a mean speed of 0.70 m/s and Stairwell B (fully-lit) had a mean speed of 0.61 m/s. Finally, Stairwell D (PLM + 74 lux) had a mean speed of 0.72 m/s.

Table 3: Speed of Movement in the Four Stairwells

Stairwell	Experimental Design	Mean Speed m/s	Std Dev.	Number of Evacuees
A	Emergency Lighting at 57 lux	0.70	0.1556	82
B	Control: Full Lighting 245 lux	0.61	0.1016	101
C	PLM only	0.57	0.1202	144
D	PLM and Emergency Lighting at 74 lux	0.72	0.0854	65
Total		**0.63**	**0.1347**	**392**

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 (Bonferroni test), shows 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 B (fully-lit) ($\overline{X}$ = 0.61, p < 0.05), Stairwell A (57 lux) ($\overline{X}$ = 0.70, p < 0.05) and Stairwell D (PLM + 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 and 74 lux, Stairwell A ($\overline{X}$ = 0.70, p < 0.05) and Stairwell D ($\overline{X}$ = 0.72, p < 0.05). This difference indicates that the speed of movement is significantly slower in the fully-lit stairwell, compared to the two stairwells with reduced lighting. There is no significant difference in the mean speed of movement for Stairwells A (57 lux) and D (PLM + 74 lux).

The results indicate that the speed of movement was faster in the two stairwells that had the emergency lighting reduced to 57 and 74 lux, 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 (0.57 m/s), 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 forced evacuees, who were descending in a scattered fashion, to form a single line which backed up evacuees and slowed down all the descending occupants. Stairwell B with full lighting was second slowest (0.61 m/s), and was also the second most crowded of the stairwells with 101 evacuees. Stairwell A with emergency lighting reduced to 57 lux, was second fastest (0.70 m/s) and least crowded with 82 evacuees. Finally, Stairwell D with emergency lighting reduced to 74 lux and PLM signs and wayguidance system, had the fastest overall speed (0.72 m/s) and also the least amount of people in the stairwell with 65 evacuees. Therefore, the more plausible explanation for the decrease in speed in the different stairwells, is related to crowding and not to the lighting conditions in each stairwell.

As can be expected in a field study, the density of occupants descending varied for each stairwell. Density of evacuees was calculated for the three busiest minutes of the evacuation between 1:51:30 and 1:54:30. 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) developed, from 21 case studies of highrise office evacuations, a relationship between stairwell density and the expected speed of movement of occupants going down stairwells under normal conditions. This equation is

$$s = 1.08 – 0.29d \quad 1)$$

, where s is the speed of movement in m/s and d is the density.

The speed of movement as calculated with Equation 1, is slightly higher than the observed speed of movement for Stairwells A, B, and D. For Stairwell C, the calculated speed is lower then the observed speed. Results of observed and calculated speed of movement are presented in Table 4.

Table 4: Speed and Density in the Four Stairwells

Stairwell	Density p/m^2	Observed Mean Speed m/s	Calculated Speed m/s
A (57 lux)	1.25	0.70	0.72
B (245 lux)	1.30	0.61	0.70
C (PLM only)	2.05	0.57	0.49
D (PLM + 74 lux)	1.00	0.72	0.79

The counter-flow created by the upcoming firefighters in Stairwell C had a major impact on the speed of movement of the descending evacuees. The impact of speed reduction due to counter flows has been documented by different researchers (Bryan, 1995; Fruin, 1971). Occupants who were descending 2 x 2 or who were descending one along the inside and a step behind one along the outside of the stairwell, had to form a single line to the left. This created a queue of 28 evacuees on the 9th floor who had to wait for 34 s to enter Stairwell C.

DISCUSSION AND CONCLUSIONS

This study shows that occupants are prepared to travel in a stairwell with PLM signs and a wayguidance system without any other illumination source. The majority of the occupants who participated in the experiment, encountered the PLM signs and wayguidance system for the first time. Exclamations of people who first opened the door to Stairwell C was recorded on the videotapes; some said "gee, it is dark in here", others "wow, this stuff glows". Overall, the comments were positive. On two occasions, a brief hesitation was observed before the person entered the stairwell, but nobody refused to leave and most people just followed the evacuation flow. These observations are important since this material is fairly unknown to most North Americans.

Questionnaire findings show that occupants are favourable to improved directional signs on their floor to facilitate movement to the evacuation stairwells, despite the fact that the signs would have been far more conspicuous in the dark, compared to the tested conditions in conjunction with electrical emergency lighting. Half the occupants assessed the addition of these signs as a positive improvement to wayfinding on their floor. In fact, it appears to improve daily wayfinding since the signs were positioned directly above each corridor created by partition walls, thus facilitating movement of occupants around the space. One employee mentioned that "with these signs, now we know where the corridors are".

The very large majority of the evacuees assessed the quality of the lighting in 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 as acceptable to the evacuees as full lighting.

The "lighting quality" in the stairwell with PLM signs and a wayguidance system was assessed as "poor" or "dangerous" by 30% of the evacuees who used that stairwell. It was mentioned earlier that this question was badly worded, so respondents might have been inclined not to respond to this question or to give a negative answer. Nevertheless, the fact that close to one-third of the respondents assessed the "lighting quality" negatively is enough to raise a few concerns. Three areas for improvement are identified below.

Firstly, the occupants were completely naive and were probably experiencing a PLM wayguidance system for the first time. Education and training with such systems, in particular evacuation drills, carried out under such conditions, would remove the normal reaction to the unknown.

Secondly, 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, made of zinc sulphide, is not the highest that may technically be currently achieved. PLM manufacturers are now selling PLM signs and wayguidance components, made of alkaliearth aluminate for example, that present brightness levels up to 10 times greater than the tested material in the same activation illuminance conditions.

Thirdly, the amount of material installed could be increased. In an attempt to maintain the amount of material to the minimum required under the Photoluminescent Safety Products Association Standard (PSPA, 1997), it is possible that the quantity of material used was not enough for the location. An immediate improvement would be expected from wayguidance lines on both sides of the stairs instead of just the wall side. Several respondents wrote on their questionnaire that they had difficulty finding the handrail, others complained that the last step to the landing was not identified.

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 photoluminescent safety 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 results indicate that the stairwell with PLM signs and wayguidance system had the expected speed of movement for the observed density. In that stairwell, there was also the upward movement of 3 firefighters, which slowed down all descending occupants. Stairwell B with full lighting was second slowest at 0.61 m/s; it was also the stairwell with the second highest density. Stairwell A, with reduced lighting of 57 lux, was second fastest at 0.70 m/s and had the second lowest density. Finally, Stairwell D with reduced lighting of 74 lux and PLM signs and wayguidance system, had the fastest overall speed of 0.72 m/s and also the lowest density. Close examination of these results leads to the conclusion that the decrease in speed in the different stairwells is more related to the occupant density in the stairwell than to the lighting conditions.

Faster speed of movement in the two stairwells with emergency lighting reduced to 57 and 74 lux compared to the fully lit stairwell may seem, at first, incongruous. However, this result is explained by the fact that the reduced lighting had no impact on the occupants' speed: it is the density of occupants in the stairwell that had an impact on the speed of movement. Reduction of lighting output in stairwells could be considered a cost-effective decision without impact on occupant satisfaction and speed of movement in the stairwell.

The mean speed of movement obtained for Stairwell C (with a PLM wayguidance system) of 0.57 m/s, is comparable to previous findings of highrise office evacuation in fully-lit stairwells (Pauls, 1995). Considering that this stairwell had the largest crowd, a high density of users and that firefighters ascended the stairwell, results are deemed very good. It was not expected to obtain such a disproportionate crowd in that stairwell compared to the other three. Such outcomes 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 10th floor.

This study shows the interesting potential of PLM signs and wayguidance system to support occupant evacuation. Such provision, 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 at 1 m from the floor, and at the skirting board, with markings on steps and handrails, as well as identification and directional signs. The installation of a PLM wayguidance system appears to be an 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 PLM safety wayguidance systems could be a worthwhile addition in improving occupant fire safety in office buildings.

To establish photoluminescent material in North America it is necessary to develop a certification procedure for the consumers to know specifically the characteristics of the different products available. Further, a standard for the installation of this material should be developed and tested with occupants to evaluate its effectiveness. Finally, more field studies are needed to assess the performance of this material in different types of occupancy and with different types of occupants.

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