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Assessment of Photoluminescent Material During Office Occupant Evacuation

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Proulx, G.; Tiller, D.K.; Kyle, B.R.; Creak, J.

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Assessment of Photoluminescent Material During Office Occupant Evacuation

by

Guyène Proulx, Ph.D. and Dale Tiller Ph.D., [Institute for Research in Construction,](#)
[National Research Council of Canada](#)

Brian Kyle, [Public Works and Government Services Canada](#)

John Creak, [Jalite PLC](#), UK.

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This work was jointly funded by the [National Research Council of Canada \(NRC\)](#), [Public Works and Government Services Canada \(PWGSC\)](#) and [JALITE PLC](#), UK.

Assessment of Photoluminescent Material During Office Occupant Evacuation

G. Proulx, D. Tiller, B. Kyle & J. Creak

Executive Summary

A field study was conducted to assess the potential use of photoluminescent material (PLM) as a safety wayguidance system to support office occupant evacuation. The three research partners, the [National Research Council of Canada](#), [Public Works and Government Services Canada](#), and [JALITE PLC](#), worked closely together to conduct this research.

The Jean-Talon highrise office building at Tunney's Pasture, in Ottawa, was selected for this study. An un-announced evacuation drill was carried out with approximately 500 occupants on three upper floors under emergency lighting conditions. Floor 10 had been equipped with PLM directional hanging signs while Floors 9 and 11 were untouched. The following experimental design was established for the four identical, windowless, stairwells of the building: one stairwell was equipped with PLM signs and wayguidance lines without any additional lighting during the evacuation; a second stairwell, also equipped with PLM signs and wayguidance lines had reduced emergency lighting at an average of 74 lux; a third stairwell had reduced emergency lighting, to 57 lux ; and the last stairwell was untouched with full lighting.

Twenty cameras were used to gather behavioural and time data on the three floors studied and in the four stairwells. Infrared cameras were used in the two stairwells that had the PLM installation. A questionnaire was distributed to evacuees as they exited, to obtain their assessment of their evacuation, the PLM signs and wayguidance system.

Results from the questionnaire show that the evacuees assessed the quality of the lighting in the two stairwells with reduced emergency lighting as very good or acceptable. There was no difference in the assessment of the stairwell with full lighting compared with the stairwells with reduced emergency lighting. The majority of evacuees (70%), who descended the PLM-equipped stairwell, assessed the lighting quality as very good or acceptable, a very positive assessment of the system.

Video recordings provided a complete account of the movements of every occupant evacuated during the evacuation drill. The time to start the evacuation in this building was highly dependent upon the evacuation procedure, since the occupants were expected to wait to start by the exit door for voice communication messages. The average time taken by the first occupants to arrive at each stairwell was 1 min 12 s, which is longer than results obtained in other office buildings. The average time to start descending the stairwells was over 5 min after the sound of the fire alarm when the Evacuation Message was issued. Overall, the full evacuation lasted some 20 min.

The most important finding is the speed of movement of a natural crowd descending the four stairwells under different lighting conditions. Results show that, irrespective of the lighting conditions tested, speeds of movement measured are comparable to mean speed obtained in previous studies of stairwells with full lighting. While the results indicate that the stairwell equipped only with the PLM safety

wayguidance system had the slowest speed of movement of 0.57 m/s, this stairwell also had the largest crowd, the highest density and disruption due to the upward movement of 3 firefighters which slowed down the descending occupants. The stairwell with full lighting was second slowest at 0.61 m/s; it was the second most crowded of the four stairwells. Evacuation in the two stairwells with reduced emergency lighting was faster with 0.70 m/s and 0.72 m/s for the one with PLM and reduced lighting. These stairwells had the fastest overall speed as well as the least amount of people and lowest density. Close examination of these results leads to the conclusion that the decrease in speed in the different stairwells is thus more related to the increase in crowding and the density of occupants than to the lighting conditions.

This study's findings show the interesting potential of PLM signage to assist occupant evacuation. Such signage, properly installed, can address certain deficiencies in the traditional approach of emergency lighting associated with power failure or smoke-logging of high-mounted luminaires. In order to obtain the expected outcome though, it is essential to properly install the signs, material and wayguidance components. Setting up a PLM wayfinding system appears as a cost-effective addition to, or even a potential replacement for, traditional electrical emergency lighting, since it does not consume energy, requires no wiring, minimum maintenance, and is completely reliable provided it is installed in locations where sufficient activation is ensured from normal illumination maintained on the evacuation route. The occupants' behaviour, their speed of movement and their subjective appraisal of the material are all in concordance to indicate that PLM signs and safety wayguidance system could be a worthwhile addition improving occupant fire safety in office buildings.

Évaluation de matériel photoluminescent pour l'évacuation des occupants d'un immeuble à bureaux

G. Proulx, D. Tiller, B. Kyle et J. Creak

Résumé

Une étude sur le terrain a été réalisée afin d'évaluer la possibilité d'utiliser du matériel photoluminescent comme système de signalisation de secours pour l'évacuation des occupants d'un immeuble à bureaux. Les trois partenaires de recherche, soit le [Conseil national de recherches du Canada](#), [Travaux publics et services gouvernementaux Canada](#) et [Jalite PLC](#), ont travaillé en étroite collaboration pour mener à bien cette recherche.

L'immeuble à bureaux Jean-Talon du Parc Tunney, à Ottawa, a été retenu pour cette étude. On a effectué un exercice d'évacuation surprise dans des conditions d'éclairage d'urgence impliquant quelque 500 occupants de trois étages situé au haut de l'immeuble. Le 10^e étage avait été agrémenté de panneaux de signalisation photoluminescent suspendus tandis que les 9^e et 11^e étages n'avaient pas été modifiés. Le design expérimental suivant a été établi pour les quatre escaliers identiques sans fenêtre du bâtiment: une cage d'escalier était munie de signes photoluminescents et de lignes de guidage et ne recevait aucun autre éclairage pendant l'évacuation; la deuxième, également munie de signes photoluminescents et de lignes de guidage, recevait un éclairage d'urgence réduit de 74 lux; la troisième recevait un éclairage d'urgence réduit de 57 lux ; la dernière n'avait pas été modifiée et recevait un éclairage normal.

Vingt caméras ont été utilisées pour recueillir des données sur le comportement des occupants et les temps d'évacuation des trois étages étudiés et dans les quatre cages d'escalier. On s'est servi de caméras infrarouges dans les deux cages d'escaliers munies de matériel photoluminescent. Un questionnaire a été distribué aux personnes évacuées à leur sortie afin de recueillir leurs commentaires sur le processus d'évacuation, la signalisation photoluminescente et le système de guidage.

Les résultats démontrent que les personnes évacuées jugent très bonne ou acceptable la qualité de l'éclairage dans les deux cages d'escalier ne recevant qu'un éclairage de sécurité réduit. Les évacuées ont jugés de manière comparable l'éclairage de la cage d'escalier normalement éclairée et les deux cages d'escalier qui recevaient un éclairage de sécurité réduit. La majorité des personnes évacuées (70 %) qui ont emprunté la cage d'escalier dotée de matériel photoluminescent ont jugé très bonne ou acceptable la qualité de l'éclairage, ce qui constitue une évaluation très favorable du système.

Les enregistrements vidéo ont fourni un compte rendu exhaustif des mouvements de chaque occupant pendant l'exercice d'évacuation. Les délais observés pour commencer à évacuer sont étroitement liés à la procédure d'évacuation de ce bâtiment puisqu'on demande aux occupants d'attendre près de la porte de sortie les instructions transmises par le système de communication phonique. En moyenne, les premiers occupants ont atteint chaque cage d'escalier en 1 minute 12 secondes, ce délai est plus long que les délais mesurés dans d'autres immeubles à bureaux. Les occupants ont

commencé à descendre les escaliers plus de 5 minutes après le déclenchement de l'alarme, lorsque le message d'évacuation a été diffusé. Il a fallu au total une vingtaine de minutes pour évacuer complètement le bâtiment.

Le résultat le plus probant de cette étude touche à la vitesse de déplacement naturel d'un groupe de personnes descendant les quatre escaliers dans différentes conditions d'éclairage. Les résultats montrent qu'indépendamment des conditions d'éclairage, les vitesses de déplacement mesurées étaient comparables aux vitesses moyennes enregistrées au cours d'études antérieures dans des cages d'escaliers normalement éclairées. Bien que les résultats indiquent que la cage d'escalier équipée uniquement d'un système de signalisation photoluminescent obtenait la vitesses de déplacement la plus faible, soit 0,57 m/s, c'est aussi dans cet escalier que l'on a observé le plus fort encombrement, les plus fortes densités ainsi que la perturbation créée par le mouvement vers le haut de trois pompiers, ce qui a ralenti la descente de tous les occupants. L'escalier éclairé normalement s'est classé au deuxième rang pour ce qui est de la lenteur d'évacuation, la vitesse moyenne de déplacement étant de 0,61 m/s. Dans les deux escaliers avec éclairage de sécurité réduit, l'évacuation a été plus rapide, les vitesses de déplacement étant de 0,70 m/s et de 0,72 m/s pour la cage équipée de matériel photoluminescent avec l'éclairage réduit. C'est dans ces deux derniers escaliers que l'on a enregistré les vitesses moyenne les plus élevées ainsi que le plus faible encombrement et la plus faible densité. Après examen minutieux de ces résultats, on a conclu que la lenteur de déplacement était davantage liée à une augmentation de l'encombrement et de la densité des occupants qu'aux conditions d'éclairage.

Les résultats de cette étude montrent bien l'utilité de la signalisation photoluminescente pour faciliter l'évacuation des occupants. Lorsque correctement installé, cette signalisation peut pallier certaines défaillances de l'éclairage de sécurité habituel, notamment lorsqu'il y a une panne d'alimentation et que les luminaires installés au haut des murs ou au plafond sont occultés par la fumée. Pour obtenir le rendement attendu cependant, il est essentiel d'installer correctement les panneaux, le matériel et les éléments de guidage. La mise en place d'un système de signalisation photoluminescent apparaît comme un ajout rentable, voire un substitut potentiel, au système classique d'éclairage d'urgence, puisqu'il ne consomme pas d'énergie et ne nécessite donc pas de câblage, n'exige qu'un minimum d'entretien et qu'il est extrêmement fiable s'il est installé dans un endroit où une activation suffisante est assurée par l'éclairage normal le long du chemin d'évacuation. Le comportement des occupants, leur vitesse de déplacement et leur évaluation personnelle du matériel indiquent tous que les panneaux photoluminescents et le système de guidage de secours peuvent améliorer la sécurité des personnes en cas d'incendie dans un immeuble à bureaux.

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1.0 INTRODUCTION

A photometric survey, carried out by the National Research Council of Canada (NRC) in 6 Public Works and Government Services Canada (PWGSC) office buildings, found many public areas in near or total darkness during emergency lighting conditions [1]. The study also found electrical wiring practices that could result in nonactivation of the emergency lighting during partial power interruptions. While the emergency lighting did conform to [Canadian Occupational Safety and Health regulations \(COSH\)](#), which applies to these buildings, the results suggest that occupants would benefit from additional lighting along evacuation routes.

A review of published emergency lighting studies suggests that lighting conditions can have a significant impact on occupants' speed of movement [2]. The cost of providing additional electrical emergency lighting in existing buildings could be prohibitive. The alternative of installing a Photoluminescent Material (PLM) safety and wayguidance system along evacuation routes appears to be a potential means of improving occupants' fire safety.

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 and offshore platforms [3, 4]. 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 as an alternative to installing emergency lighting in some areas of new or refurbished buildings. Research and experience show that PLM can contribute to the improvement of fire safety in buildings [5].

2.0 PHOTOLUMINESCENT MATERIAL

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 energy from normal lighting and will restore this energy as a useful light source when the illuminating, activating energy is extinguished.

The PLM materials contain a zinc sulphide compound that is energized in moments by the ultra violet and blue light wavelength energy that is present in common light sources such as daylight, tungsten filament and fluorescent lights. This high-energy source is converted into a lower energy source of light which can be repeatedly recharged by re-exposure to light. This low-energy light source is yellowish-green in colour, the most readily perceived by the human eye in total darkness. Over time, the

material will diminish in brightness, but will remain visible to the dark-adapted eye for a period of time varying upon the type of material. Tests have shown that the light emitted from the luminous material may be still visible to the dark adapted eye for as long as 40 hours [6]. The commonly accepted criteria for the characterisation of such materials is the time required for the luminance of the material to decay to 0.3 mcd/m^2 , this being 100 times the threshold limit of the dark adapted human eye. Commonly used zinc sulphide pigments based materials will reach this point in some 5-8 hours and the newer alkaliearth aluminate based materials, in excess of 15-20 hours when activated with some 100 lux or greater from ordinary white fluorescent light sources.

There are several different test methods available for the characterization of photoluminescent materials. They are all based on the following principles:

- activation of the material with a standard light source of a given luminous flux output and radiant energy type and power;
- stopping the activation after a given time; and
- measurement, after specific time intervals from the stopping of activation, of the level of brightness of the emitted luminous flux using photometric techniques and/or by comparison to standard calibration samples.

All the published test methods excite the photoluminescent material with a powerful light source; 150W/100W tungsten or xenon source giving 1000 lux (100 foot-candle) luminous flux for 1 or 5 min prior to testing. The intention is to achieve maximum excitation before measurement of the emitted luminance values over time after excitation has been stopped.

The most common test method, used in Europe, is according to the Deutsche Norm DIN 67510 1974. This standard asks for the description of the material tested, the luminance value at 60 minutes from the end of excitation and the time required for the luminance to decay to 100 times the perception level of the human eye (a value of 0.3 mcd/m^2) and, finally, the colour of the emitted light.

The Photoluminescent Safety Products Association (PSPA) in the UK has developed a classification system for photoluminescent products based on this standard, as presented in Table 1. Three classes have been adopted to classify the luminance performance of PLM. The material classification is used to determine the subsequent application of the products in escape route marking systems.

Table 1: Characterization of PLM

Material Class	Luminance Millicandella/m ² (mcd/m ²)			Time to 100x Perception Limit min	
		10 min	30 min		60 min
Class III	<	12.0	2.8	1.1	160
	>	8.5	1.5	0.5	80
Class II	<	17.0	4.0	1.7	240
	>	12.5	2.9	1.2	170
Class I	>	17.0	4.0	1.7	240

Class I materials are recommended for high-risk areas having no supplementary emergency lighting. Class II materials provide the minimum standard for the production of safety signs and for evacuation guidance using isolated visual clues. Class III materials may be used to complement evacuation route marking systems using adequate quantities of Class I and/or Class II materials in conjunction with emergency lighting.

If properly installed, some of the benefits of using a PLM wayfinding 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 intensity as the stored light is emitted; however, this is compensated for, to some degree, by the fact that the eye is also adapting to the light;
- 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 intensity or 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.

3.0 LITERATURE REVIEW

In the UK, Webber and his colleagues have completed several studies on the usefulness of PLM as a wayfinding system. In one study, they looked at the speed of movement and subjects' evaluation of the system. They compared the use of PLM to emergency lighting meeting [British Standard BS 5266 Part 1 \[7\]](#) of 0.2 lux, as measured along the centreline of the evacuation route, in two different environments of a laboratory setting [8]. One situation was in a long corridor, the other on a set of stairs. The researchers found that speed of movement of 24 working-age subjects under PLM illumination was slightly faster on the stairs, and subjects rated the material more

favourably, and the movement as being less difficult. Speeds in the corridor were quicker under the emergency lighting illumination, and subjects rated the PLM less favourably, and the movement as more difficult. Researchers found that movement up the stairs was improved by the PLM marking on each riser. They concluded that the performance of the subjects under the PLM conditions was similar to that under emergency lighting. Finally, based on subjects' ratings they concluded that PLM could provide a viable alternative to emergency lighting [8, 9, 10].

In another study, Aizlewood and Webber [11] compared the use of PLM to three other wayfinding systems in a laboratory setting with 48 subjects. These systems were electroluminescent, incandescent (tungsten filament), and traditional emergency escape route lighting (at British Standard luminance). Subjects were allowed to adapt to a lighting level of 500 lux, then the lights were switched off and the subjects were asked to follow a path through a corridor and downstairs using each of the four different materials. On the third trial, obstacles were introduced onto the route. From this study, the researchers found that, although speed of movement under PLM conditions was similar to that of the other wayfinding systems, it was difficult for the subjects to see obstacles, and they rated the system worse than the other three electrical wayfinding systems.

Webber has also conducted laboratory studies on the visibility of wayfinding systems and lighting systems in smoke [9, 12, 13, 14]. The wayfinding systems of these studies consist of low-mounted luminous continuous tracks, emergency exit door markings and exit signs installed to provide wayfinding guidance on egress routes. In one study, Webber had each subject in a long corridor, under two conditions. First, he allowed the subject to adapt to light at 0.3 lux. Then, with a small amount of smoke in the corridor, he had the subject move forward until the material was visible, and then legible. In the second study, the subject stood stationary, and the room was filled with smoke until the material was no longer visible. The purpose of the studies was to assess the visibility of eight different wayfinding systems, namely electroluminescent, miniature incandescent, LED with pictogram signs, LED with vertical signs, PLM signs and marking, PLM with high-mounted emergency luminaires, fluorescent pictogram signs with high-mounted emergency luminaires and reflective pictogram signs with high-mounted emergency luminaires. 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 more than 15 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.

Jensen in Norway [15] tested 84 subjects in dense smoke with seven different wayfinding or 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 a PLM strip of 25 mm wide, built into a directional rail, performed the best amongst other systems at high smoke densities of OD 1.49 m. At higher smoke densities, subjects could not move at all, regardless of the wayguidance system.

Heskestad and Pedersen [16] 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 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.

4.0 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. The impact of the social interactions between occupants during evacuation has been identified in previous studies as an important variable [15]. Also, it appears 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.

5.0 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. Such a field study required the careful selection of the building, the occupants studied and the experimental design. Detailed explanations of the methodology for evacuation drill studies can be found in IRC Internal Report No. 730 [18].

5.1 Building and Participants Selection

PWGSC as one of NCR's two partners in this research, collaborated to find a suitable office building to conduct the field study. The selected building had to meet the following criteria:

- the building had to have at least 3 comparable windowless staircases;
- the building had to be over 5 floors in height, to allow for sufficient occupant movement in the staircases; the longer the descent, the better the measurement of speed differences related to stairwell conditions;
- the building had to meet the applicable regulations for emergency lighting;
- the building occupants had to be a typical office crowd with mixed gender, ages and physical challenges;
- a minimum of 50 occupants should use each stairwell studied during the evacuation; and

- support was required from the building Fire Safety Team to organize and conduct the evacuation drill.

After a long search to find the most suitable building among PWGSC stock, the Jean Talon Building at Tunney's Pasture in Ottawa was selected. This building offered premium features to conduct this study. Statistics Canada is the tenant of the building. Excellent staff support was obtained in this building to conduct the field study.

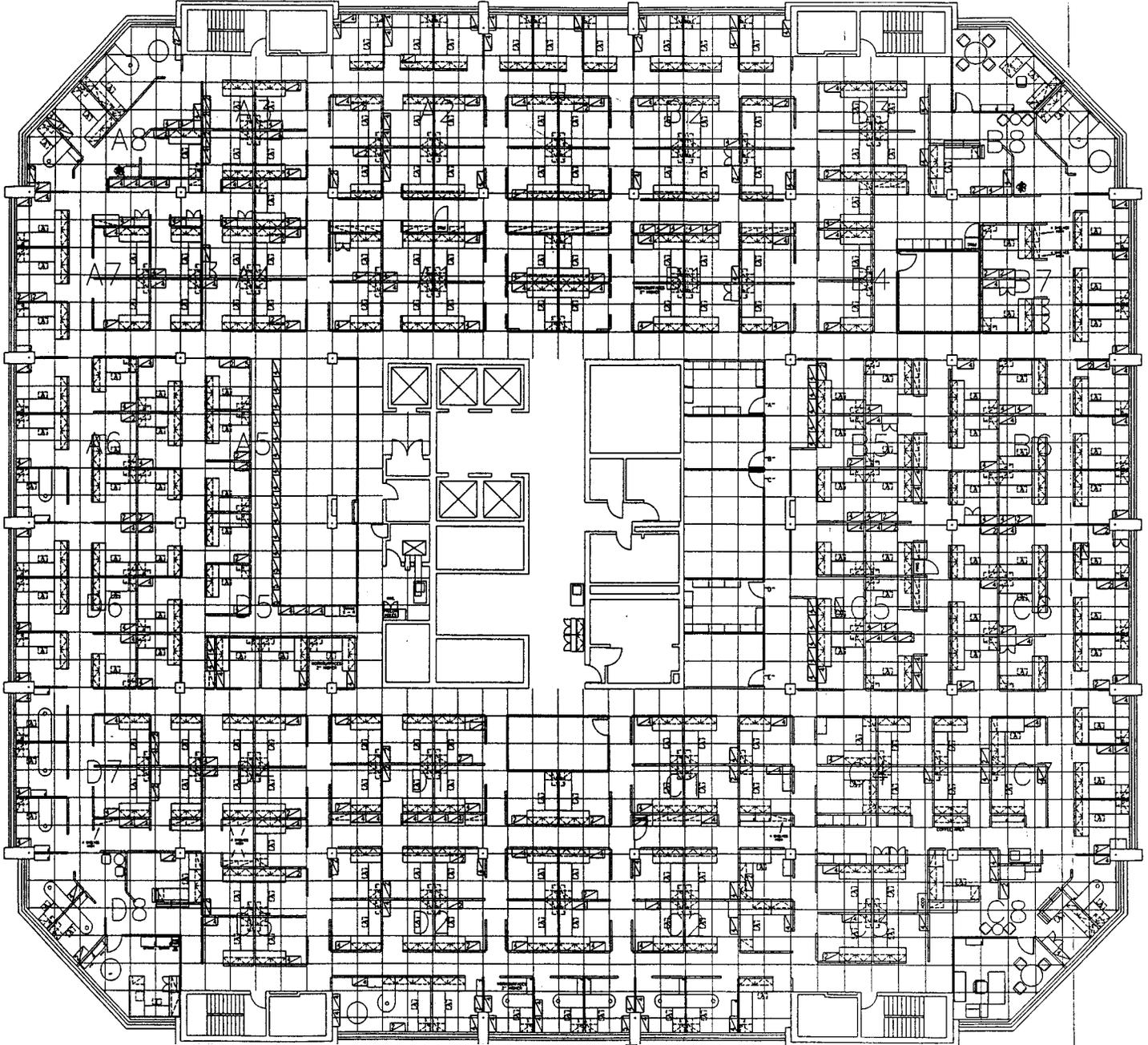


Figure1: The Jean Talon Building

The Jean Talon Building is a 13-story concrete structure built in 1979. The building, glazed on all sides, is almost square in shape, as presented in Figure 1. Each floor area of 3700 m² (approximately 65 m x 57 m) is an open plan concept divided into 4 quadrants, identified A, B, C and D. Work stations are divided with partition walls of 1.7 m in height. On the three floors studied (9, 10, 11), partition wall arrangements are similar. In the centre of the building is the core area, with elevators, washrooms, storage areas and a few enclosed meeting rooms. There is an average of 150 office workers on each floor doing research and clerical activities. The building has four identical windowless stairwells leading to the outside of the building. Figure 2 presents a typical floor plan of the Jean Talon building.

Stairwell A

Stairwell B



Stairwell D

Stairwell C

Figure 2: Typical Floor Plan of the Jean Talon Building

There are 9 alarm bells positioned on pilasters throughout the floor. There are speakers on the storey, at each of the exit doors and in the stairwell at mid-landing for the voice communication system. Also, at the entrance to the stairwell, there is firefighting equipment located in the cabinet below the voice communication speakers. At Stairwell D, there are two evacuation chairs for assisting occupants with mobility impairment in their descent of the stairwell.

5.2 Experimental Design

In collaboration with Statistics Canada, it was decided to study Floors 9, 10 and 11 of the Jean Talon Building. The tenth floor was equipped with PLM hanging signs, while the 9th and 11th floors served as comparison floors with no special treatment. During the evacuation drill, the regular lighting was turned off leaving only the building emergency lighting on the 3 studied floors.

The building's four identical stairwells presented different conditions, as shown in Table 2 and Figure 3. It is important to mention that, in this building, the stairwell emergency lighting is the full lighting with double-tube luminaires on every floor and mid-landing which provides a very well-lit stairwell of an average lighting of 245 lux. For this study, the lighting conditions in three of the stairwells were modified. Lighting in Stairwells A and D was modified to obtain a reduced output maintained above the COSH [19] requirements of an average of 10 lux and not less than 3.3 lux. To obtain this reduced 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 an average lighting, slightly higher, of 74 lux. Stairwell D also had 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 2: Stairwell Experimental Design

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

Twenty cameras were used to gather data. A camera was placed at the entrance to each of the four stairwells on floors 9, 10 and 11. There were also cameras placed in the stairwells on the landing between the fifth and sixth floors. For the two stairwells that had the PLM installation, infrared cameras were used. These cameras are able to film in complete darkness and to produce a black and white image. Four cameras were also placed outside, 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.



Figure 3: Pictures of the Four Stairwells

The picture on the upper left corner is Stairwell B with full lighting at an average of 245 lux. The picture on the upper right corner is Stairwell A with lighting reduced to 57 lux. The picture on the lower left corner is Stairwell D with PLM signs and a wayguidance system, and lighting reduced to 74 lux. The picture on the lower right corner is Stairwell C with PLM signs and a wayguidance system and no other lighting source provided.

5.3 Evacuation Procedure for the Jean Talon Building

The procedures in case of an emergency in the Jean Talon Building are detailed in a procedure manual available to all staff and used in the training of floor fire wardens [20]. A summary of the procedure is posted by the elevators and exits on all floors.

The evacuation procedure, in case of a fire during working hours, is planned as a sequential or phased evacuation. The building benefits from a complete voice communication system as well as trained fire wardens on all floors to assist the occupants with this procedure. The fire orders for that building are as follows:

If the Fire Alarm Sounds during Normal Working Hours:

- Calmly, assemble near voice communication speakers
- Bells will ring for approximately one (1) minute
- Once bells silence, comply with voice communicator's instructions
- If bells continue to ring, evacuate immediately using the nearest safe EXIT
- Obey all instructions of Fire Officials
- Mobility-impaired persons must have assigned monitors
- Once outside, clear the building by at least 100 m
- Return to the building only when authorized by fire officials

This procedure implies that when the fire alarm is activated, all occupants gather at the closest exit door by the voice communication speaker and await instructions. Then the sequential or phased evacuation is planned to work as follows: "...if a fire breaks out on, say, the 10th floor, that floor, the 9th and 11th are immediately evacuated. Because smoke and hot gases rise to the top of a building, the 12th floor is evacuated next, followed by the other floors in ascending order. When top floors have been completely evacuated, the 8th floor is to be evacuated followed by the other floors in descending order." [20]. 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 are most at risk 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 closed evacuation exit awaiting instructions. For the study, the 10th floor was the fire floor, so the 9th, 10th and 11th floors were evacuated. The voice communication messages delivered to occupants stated that an evacuation drill was going to be conducted under emergency lighting conditions, then 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 the D stairwell and stand by for instructions.

The research team remained outside the building during the drill, except for the principal researcher who mingled with the evacuees on Floor 10 and went down Stairwell C with PLM signage only. Also, a technician took sound measurements of the fire alarm output on the 10th floor. The video recordings provided information on the occupants' behaviour, the time to respond to the alarm, the direction of movement and the speed and flow in the staircases. At the bottom of each stairwell, a questionnaire

was distributed to evacuees to obtain their assessments of the evacuation and their experience with the PLM. The evacuation was carried out with the participation of the Ottawa Fire Department.

Before and after the evacuation drill, data was also gathered on the lighting conditions in the different areas of the building under normal conditions, with emergency lighting and after installation of the PLM signage. This data will enable comparison with past or future studies.

5.4 Material Installation

Before installing the PLM wayfinding system to support occupant evacuation, it was important to develop a plan for installation. All routes suitable for use in an emergency were identified, as well as all exits on the route, refuge floor, and final exits. It was decided to follow the Photoluminescent Safety Products Association (PSPA) Standard 002 Part 1 1997 [21] and JALITE PLC manufacturers recommendations for the design of the PLM safety wayguidance system.

Researchers have made several recommendations for installing wayfinding systems [5, 9,22]. They suggest that all doors be marked at both eye and floor level, that the route to the exit should be clear and unambiguous, and that if the emergency exit is not visible, directional markers be provided. In open plan areas, it is important to mark the path and the door. Stair characteristics and changes of level should all be marked; the material should be placed on the nose of the riser, and on the handrails. Webber also recommends highlighting any hazards on the route, and indicating where the fire pull box and equipment are located.

JALITE PLC provided all the PLM signs, wayguidance lines and components which met the Luminous Class 1 specification of the PSPA as measured by the German Standard DIN 67510 Part 1 1992 [23]. JALITE also planned and supervised the PLM installation. After the evacuation drill, a piece of material was taken to the UK to measure the luminance values. Table 3 shows the comparative results of the material's luminescence decay characteristics as measured on shipment to Canada in March 1997 and a sample of the same material after the evacuation drill in December 1998. This performance was measured after activation at 1000 lux for 5 min, which is a standard test according to DIN 67510 Part 1. As presented, no change in properties was observed. The table also presents the estimated performance of the material on location with an average activation of 50 lux of Cool White fluorescent for 5 min.

Table 3: Material Luminance mcd/m²

Test Date / Location	Elapsed Time in min			
	2	10	30	60
March 1997	142	26.7	8.1	3.6
December 1998	143	27.1	8.0	3.6
On site	89.1	21.7	7	3.2

All signs with wording content were bilingual, meeting the [Treasury Board of Canada](#) requirements for signage [24]. These signs also presented the "running man" pictogram which is an [ISO](#) standard [25]. On the 10th floor, PLM hanging signs were positioned throughout the floor to direct occupants toward the four exits. Special attention was made to position signs right above the narrow corridors between partition walls leading to the exits. Directional signs were provided at each decision point [26]. Floor signage was suspended using stretch wire suspension kits. The full installation of the 10th floor required over 80 signs.

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 PSPA Standard 002 Part 1 1997 [21], and safety signs according to BS 5499 Part 1 1990. As shown in Figure 3, the stairwell was equipped with two continuous wayguidance lines of 10 cm in width. One line was at the skirting board and the other 1 m from the floor. Directional signs were enclosed within these continuous lines. A 2 cm strip of PLM 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 final exit. The material and installation costs for the stairwells were estimated at \$2500/floor.

5.5 Measurements of Lighting Output

Ambient light levels provided by the emergency lighting system were measured on the 9th, 10th, and 11th floors, and Stairwells A, B, and D of the Jean Talon Building. The emergency lighting system was activated on each of the three floors using wall mounted switches that switched off all lighting with the exception of those luminaires providing emergency lighting. The overhead lighting on all three floors was provided by fluorescent lamps, mounted in a coffered ceiling system. The furniture used throughout the three floors of the building offered occupants several task lights at each workstation, which supplemented the overhead emergency lighting.

Emergency lighting in the stairwells was provided by the regular lighting system. This consisted of one two-lamp luminaire (Sylvania Optron 4100K 32W F032/841 lamps)¹ mounted on every landing 2.5 m (97.5 in.) from the floor, which normally remained switched on at all times. For the purposes of this experiment, the lighting in the stairwells was modified as described in Section 5.2.

Light levels were measured on the building floors and in the stairwells 1 m above floor level using recently calibrated Minolta T-1M illuminance meters. The meters were connected to an automated data acquisition system presented in Figure 4, which polled the meters and stored the resulting readings on a computer hard disk.

¹ Certain commercial products are identified in this report in order to adequately specify the experiment procedure. In no case does such identification imply recommendations or endorsement by the National Research Council, nor does it imply that the product or material identified is the best available for the purpose.



Figure 4: Data Acquisition in Stairwells

The picture on the left shows the configuration used in the stairwells (the stairwell depicted was not one measured in this study). The illuminance meters are mounted on a pillar such that the plane of the detectors is 1 m above the stair tread. The operator manually directs the software and data acquisition hardware mounted on the laptop computer to poll the illuminance meter, and store the measured values on the computer hard disk. Once the polling operation has been completed, the operator moves the apparatus to the next measurement location, and repeats the operation. The picture on the right shows the configuration used to collect measurements on the floors. The operator pushes the device along the centreline of the measurement path. As the calibrated wheel (circumference 1 m) turns, the data acquisition system is directed to poll the illuminance meters and store the resulting value in the computer once every 25 cm of travel.

For the stairwells, a total of 12 readings were collected between each floor as follows: three readings were collected at the door landing and the mid-landing, and one each at the top, middle and last stair of each staircase. The data acquisition system software was configured so each reading was polled by the operator manually once the apparatus was correctly placed. All stairwells were windowless, so no daylight supplemented the electric lighting.

On Floors 9, 10 and 11, the operator pushed the measuring system along the centreline of the measurement path using a specially designed cart, presented in Figure 4. The operator walked the automated data acquisition system down the centreline of every path available to the occupants of these floors, following COSH recommendations (6.10.1.B) [19]. In accordance with IESNA [27] recommendations, measurements on the building floors were collected at night (IESNA, 1993, p. 60). Summary statistics describing illuminance measurements are presented in Table 4 and Figures 5 and 6.

Table 4: Illuminance Summary Statistics

	Stairwell A	Stairwell B	Stairwell D	Ninth Floor	Tenth Floor	Eleventh Floor
NUMBER	177	188	174	2489	2518	2557
MEAN	57.18	244.13	74.49	30.00	68.41	66.88
MEDIAN	43.26	235.23	39.25	7.88	10.73	8.46
MODE	31.42	178.86	110.63	0.00	37.40	0.00
MAX	191.14	487.97	518.22	301.86	574.40	737.81
MIN	7.77	24.66	1.51	0.00	0.00	0.00
STD DEV	43.04	90.96	83.12	53.02	125.74	133.88

As expected, light levels were higher in Stairwell B, which remained unmodified, than in either Stairwells A or D, where the lighting had been modified to reduce the ambient levels that would have been provided normally.

COSH [19] emergency lighting requirements specify an average level of 10 lux (6.10.2.B), with a minimum of not less than one third the average (i.e., 3.3 lux (6.11.1)). In all cases, the average requirement of at least 10 lux was achieved. Emergency lighting in Stairwells A and B met this criterion, but the emergency lighting provided on the 9th, 10th and 11th floors, and in Stairwell D, did not meet the minimum requirement of at least 3.3 lux.

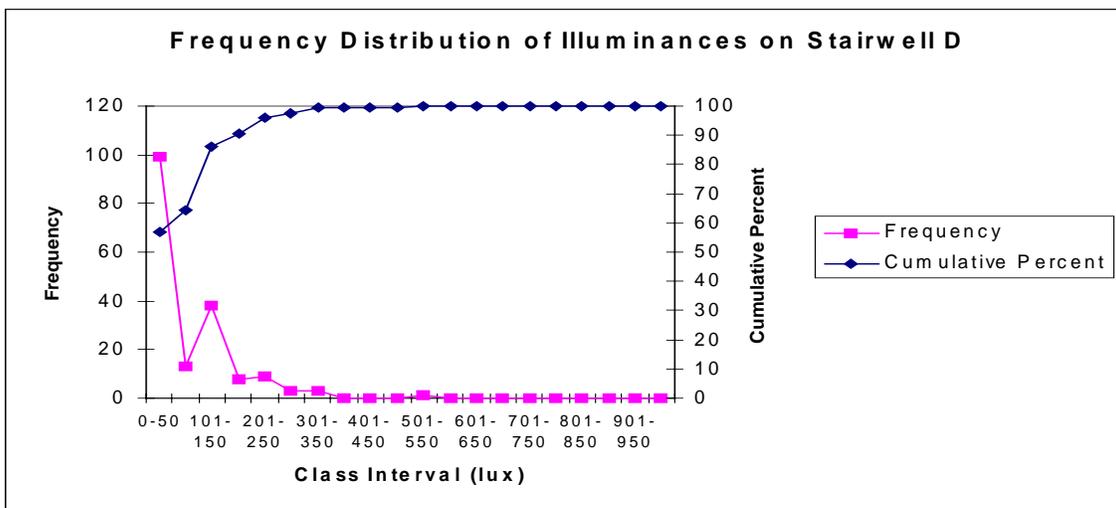
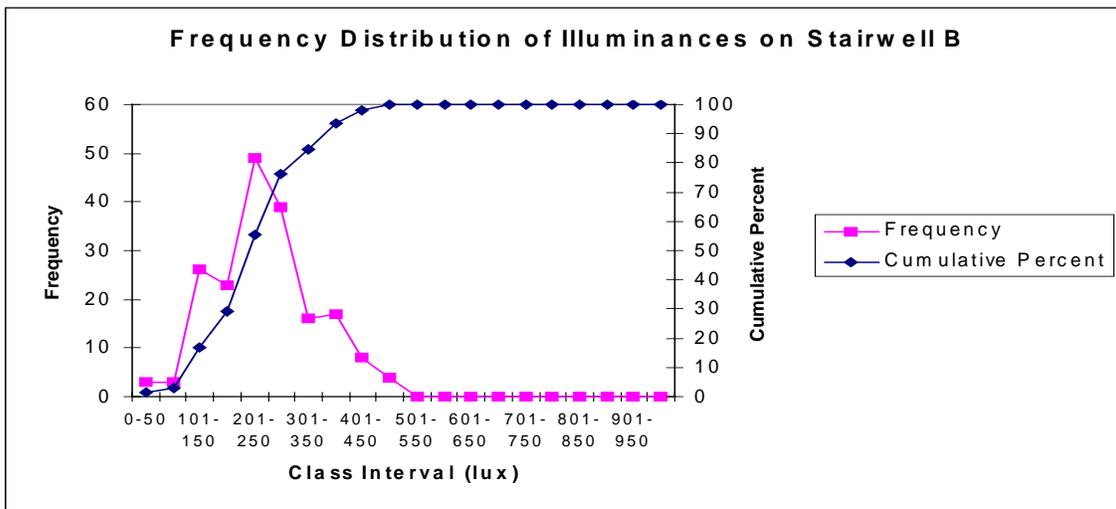
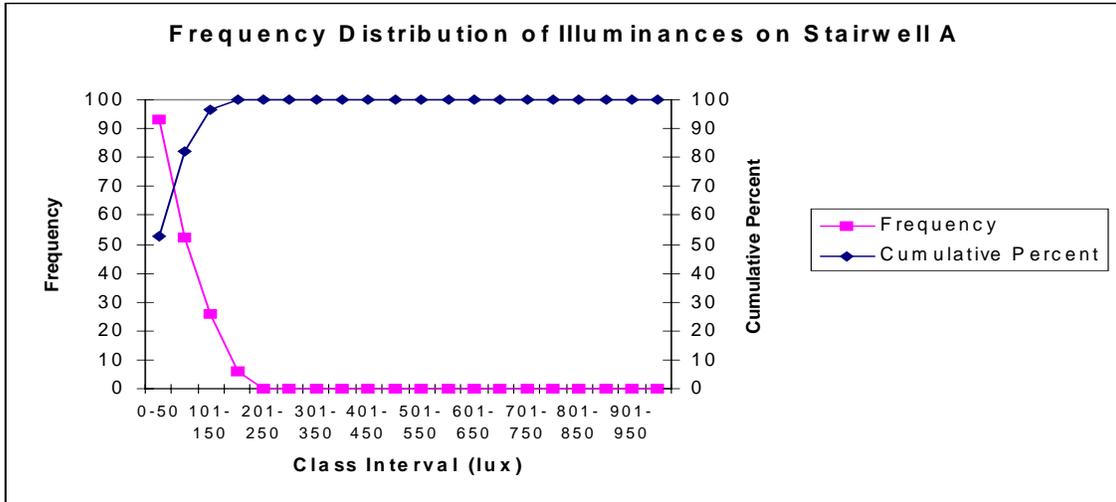


Figure 5: Frequency and Illuminance Distributions in Stairwells

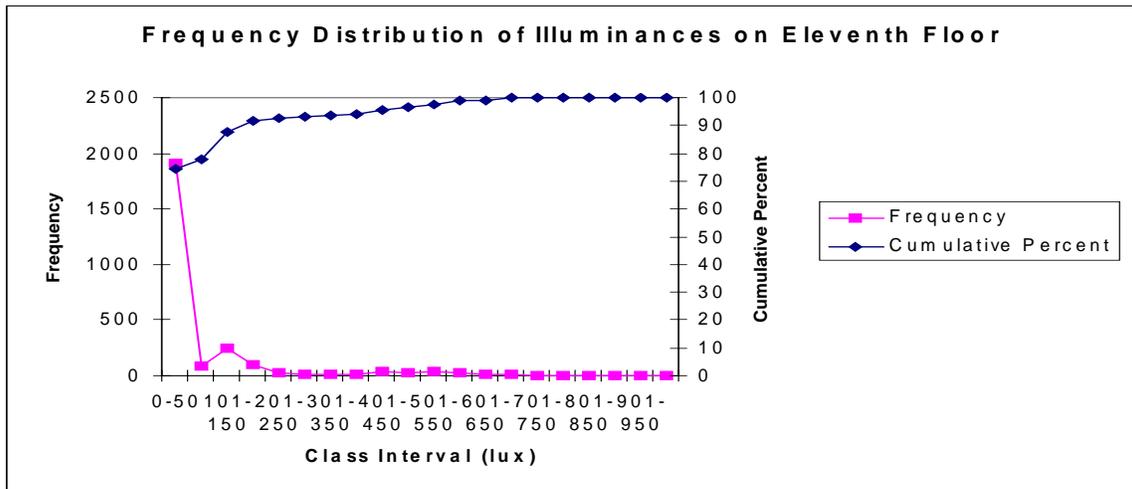
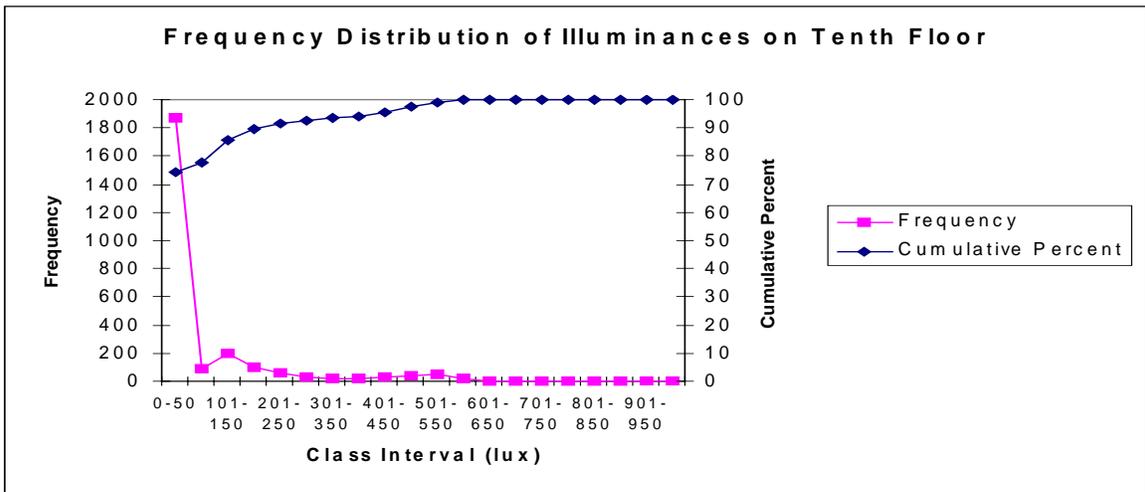
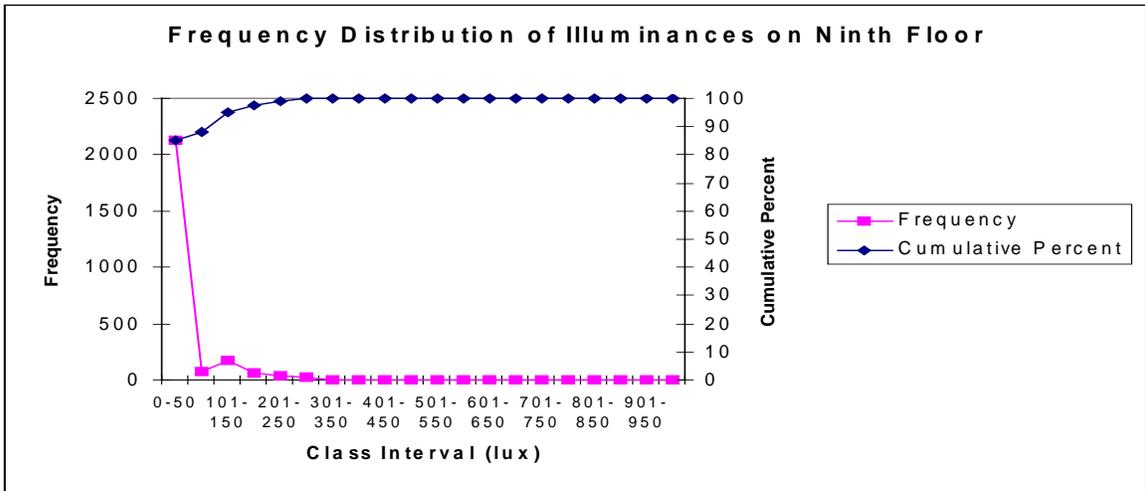


Figure 6: Frequency and Illuminance Distributions on Floors 9, 10 and 11

6.0 FIELD STUDY RESULTS

The evacuation drill unfolded as planned without any unexpected incident to report. The drill was on Wednesday, 18 November 1998, at 13:45. This day and time allowed for a maximum of occupants to be in the building. The temperature outside was -3°C with light snowflakes coming down. The fire alarm was activated by a staff member of Statistics Canada's fire safety team on the 10th floor. The alarm bells started ringing immediately. Overall, the evacuation drill took less than 20 min.

Data from the questionnaires and the video recordings were analyzed. For all tests, the level of significance is $\alpha < 0.05$.

6.1 Questionnaire Results

A questionnaire was distributed to each evacuee after they left the building, at each of the four stairwells. The questionnaire contained 21 questions and was divided into 4 parts. A copy of the bilingual questionnaire and cover letter is enclosed in Appendix 1. At the conclusion of the evacuation, two of the researchers offered questionnaires to everyone on the three floors who evacuated to make sure that everyone had the opportunity to fill out the questionnaire. This included those individuals who were unable to leave the floor, but who did participate in the evacuation. Three red boxes to return the questionnaire were put out for 1 week, one in each of the elevator lobbies of Floors 9, 10 and 11. Over 450 questionnaires were handed out. A total of 216 questionnaires were returned.

6.1.1 Respondent Profile

Among the 216 questionnaires returned, 3 respondents did not indicate their age. There was a great range of ages of the respondents as presented in Table 5.

Table 5: Age of Respondents

Age	Number	Valid Percent
20 – 30	32	15%
31 – 40	55	26%
41 – 50	86	40%
51 – 60	38	18%
61 +	2	1%
Total	213	100%

Out of the 216 questionnaires, 120 (56%) people did not indicate their gender. Of the remaining 96 who did, 31 (32%) were female and 65 (68%) were male.

As presented in Table 6, 12 of 212 people (6%) indicated having limitations that could impede their evacuation. The questionnaire provided 9 possible limitations from which to choose.

Table 6: Limitations That Could Impede Evacuation

Limitation	Frequency	Percent
Emphysema	0	0.0%
Asthma	2	0.9%
Pregnancy	0	0.0%
Arthritis	3	1.4%
Overweight	0	0.0%
Injury	2	0.9%
Vision impairment	1	0.5%
Mobility impairment	3	1.4%
Hearing impairment	1	0.5%
Total	12	5.6%

6.1.2 Fire Safety Knowledge and Experience

Overall, the participants were knowledgeable about fire safety. Of the 216 respondents, 201 (93%) reported having taken part in an evacuation drill in this building in the past. Two hundred and ten of 215 (98%) indicated that they knew where to go to evacuate their floor. One hundred and forty-three of 216 (66%) were able to identify the fire warden for their floor or in their work area. The majority, 207 of 214 (97%), considered that they are required to obey the instructions of the fire wardens. Three (1%) did not believe it was required to obey the wardens, while the remaining 4 people (2%) were not sure.

6.1.3 Alarm and Voice Communication Information

Two hundred and eleven or almost 100% of 212 respondents reported hearing the fire alarm. One person reported not hearing the fire alarm, it was the same person who reported having a hearing impairment. Participants were asked about the volume of the alarm. Among the 211 who answered this question, 178 (84%) of them reported that the fire alarm was loud enough. Thirty-one people (15%) felt the alarm was too loud, and 2 (1%) felt it was not loud enough.

Eighty-four percent of 212 respondents (178 people), reported being at their desk when the alarm sounded, while the remaining 34 (16%) were away from their desks. Participants were asked to choose one item from a list of 10 to describe their first action upon hearing the fire alarm. The most common answer was that respondents got dressed upon hearing the alarm. This was reported by 68 of 212 (32%). The least common response, less than 1% (1 person), was to evacuate the floor. Interestingly, 21 people (10%) reported that they continued working when they heard the fire alarm. The frequencies for the other choices are shown in Table 7.

Table 7: First Action Upon Hearing the Fire Alarm

Action	Frequency	Valid Percent
Got dressed	68	32%
Followed instructions on P.A.	26	12%
Went to meeting point	25	12%
Secured files/information	24	11%
Continued working	21	10%
Return to office	20	9%
Gathered valuables	14	7%
Sought more information	10	5%
Evacuated the building	3	1%
Evacuated the floor	1	1%
Total	212	100%

After the alarm, several messages were given over the voice communication system. Two hundred and ten of 213 respondents, (99%) reported hearing the message. Three people (1%) reported that they did not hear a message. One of these three was the participant with the hearing impairment, another indicated that he/she was in the washroom at the time and, therefore, did not hear the message, and for the third, there was no explanation of why he/she did not hear the message.

Participants were asked to write down what the message was. Each response was later fit into one of several categories as reported in Table 8. There were actually four messages given, each with a different piece of information. No participant correctly identified all four pieces of information. Fifty-one of 216 (24%) left this question blank. Twenty-four people (11%) wrote that they did not know or did not remember. Many people wrote an answer but it was incorrect or did not contain enough information to be put into any category. For example, one participant wrote, "Something about this being a drill," and another wrote, "Wait for instructions." Responses such as these were coded as wrong/incomplete and this occurred for 81 (37%) of the participants. When the 'don't know', 'wrong/incomplete', and 'left blank' categories are combined, it suggests that 156 or 72% of the people could not recall the content of the messages delivered.

Table 8: Respondents Reports of Message Given

What was the message?	Frequency	Valid Percent
1- Lighting reduced on floors 9, 10, 11	26	12%
2- Incident on floor 10; Evacuate 9, 10, 11	21	10%
3- Do not use elevators	0	0.0%
4- If assistance needed, go to Stairwell D	0	0.0%
Message 1 and 2	12	6%
Message 1, 2, and 4	1	0%
Wrong or incomplete answer	81	37%
Question left blank	51	24%
Don't know	24	11%
Total	216	100%

6.1.4 Floor Evacuation

As the three floors studied were under emergency lighting conditions, participants were asked to assess, from four choices provided, the quality of this lighting for evacuating. A total of 210 people responded to this question. Ninety-three (44%) rated the lighting as being very good. One hundred and four (50%) rated it as being acceptable. Eight people (4%) said the lighting was poor and the remaining 5 (2%) rated it as being dangerous.

Photoluminescent signs to direct evacuation movement were placed only on the 10th floor. All questionnaires asked if these signs were seen on the floor, if they were useful to direct evacuation, and to rate the visibility of the signs. Some people who were not from the 10th floor reported seeing these signs. As this was not possible, their data for these three questions was discarded. Only the data from people reporting to be from the 10th floor was used. As presented in Table 9, 30 people did not indicate from which floor they were, so floor information is available for only 186 people.

Table 9: Floor of Origin

Reported Floor of Origin	Frequency	Valid Percent
11	54	29.1%
10	70	37.7%
9	58	31.2%
3	1	0.5%
5	1	0.5%
7	1	0.5%
21	1	0.5%
Left blank	30	
Total	216	100%

Out of the 70 respondents on the 10th floor, 54 (77%) people indicated seeing PLM signs. Twenty-five people of 49 respondents from the 10th floor (51%) reported that these

signs were useful in finding their way on the floor. As reported in Table 10, 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.

Table 10: Visibility of PLM Signs on the 10th Floor

Assessment	Frequency	Valid Percent
Very Good	32	60%
Acceptable	16	30%
Poor	2	4%
Dangerous	3	6%
Total	53	100%

6.1.5 Stairwell Evacuation

This section examines responses for the four stairwells together. The next section discusses the results of the individual stairwells.

One hundred and fifty-five of 168 respondents (92%) reported that they used the stairwell that was closest to them to evacuate. One person added to the questionnaire that he/she was told by his/her warden to use another stairwell (not the closest one). Four other people who did not use the closest stairwell reported having this same warden. It is not known why the remaining 8 did not use the closest stairwell; however, one of them did report being away from his/her desk when the alarm sounded.

In response to the question as to whether signs were noticed in the stairwell, 130 of 211 (62%) reported yes. Eighty-one (38%) reported that they did not notice signs.

The assessment of the quality of lighting of the stairwells for the entire sample was examined. Two hundred and two people provided lighting ratings from a choice of four. Eighty-five people (42%) rated the lighting as being very good. Ninety-two (46%) rated it as being acceptable. Fourteen people (7%) said the quality of lighting was poor. The remaining 11 (5%) rated it as being dangerous.

No one indicated that furniture prevented them from entering the stairwell. However, 63 of 204 respondents (31%) reported that people were crowding around the entry to the stairwell.

It was reported that people entering at other floors blocked the descent of 65 of the 202 respondents (32%). Respondents mentioning that people entering at other floors blocked their descent differed significantly depending on which floor the respondents left from, $\chi^2 = 14.06$, $df = 2$, $p < 0.001$. As could be expected, more people from Floor 11 reported this as being a problem than did people from Floors 9 and 10. Difficulty finding the handrail was a problem for 23 of 201 (11%). Forty-two of 201 (21%) said that there was difficulty seeing due to poor lighting.

Of 201 people, 27 (13%) said people were moving upward in the stairwell. Fifty-two of 204 (26%) claimed that people in front of them were moving too slowly. Seven people of 160 (4%) reported that people were standing on the landings. Of 203 people, 44 (22%) answered that they felt dizzy from the long descent. No one reported that they had difficulty finding the exit door at the base of the stairwell.

Upon exiting the staircase, 207 of 212 (98%) reported being outside. One person exited onto another floor, 2 people exited into a hall or lobby, and another 2 exited underground. As presented in Table 11, 6 of 210 (3%) reported that they waited for instructions after leaving the staircase, 133 (63%) went to the meeting point, and 71 (34%) left the premises.

Table 11: Action After Leaving Stairwell

After Leaving Stairwell	Frequency	Valid Percent
Went to meeting point	133	63%
Left the premises	71	34%
Waited for instructions by stairs	6	3%
Total	210	100%

6.1.6 Evacuation in Each Stairwell

Of the 216 respondents, it was not possible to determine which stairwell was used by 5 people. Of the remaining 211, 47 (22%) descended in Stairwell A, 48 (22%) used Stairwell B, 77 (37%) used Stairwell C, and 39 (19%) descended in Stairwell D as presented in Table 12.

Table 12: Stairwell of Descent According to Questionnaire

Stairwell of Descent	Frequency	Valid Percent
A- Emergency lighting at 57 lux	47	22%
B- Full lighting	48	22%
C- PLM alone	77	37%
D- PLM and emergency lighting at 74 lux	39	19%
Total	211	100%

From Stairwell A, 15 of 47 people (32%) reported noticing signs in the stairwell. Fifteen people of 46 (33%) from Stairwell B reported seeing signs in the stairwell. Sixty-four of 77 (83%) using Stairwell C noticed signs and 36 of 39 (92%) from Stairwell D noticed signs. These frequencies are significantly different ($\chi^2 = 45.51$, $df = 3$, $p < 0.001$). There were significantly more people noticing signs in Stairwells C and D which were equipped with the PLM signs and wayguidance system.

Both Stairwells C and D had PLM signs and wayguidance system. Seventy-six people of 77 (99%) using Stairwell C reported seeing the PLM signage in the stairwell. From Stairwell D, 34 of 39 (87%) reported seeing the PLM signage.

As reported in Table 13, 69 of 72 respondents (96%) from 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 signage and reduced lighting, reported the signs to be useful.

Table 13: Rating of Usefulness of PLM Signs in Stairwells

Usefulness of PLM Signs	Frequency		Valid Percent	
	Stair C	Stair D	Stair C	Stair D
Yes	69	14	96%	45%
No	3	17	4%	55%
Total	72	31	100%	100%

The visibility of the PLM signs and wayguidance system was assessed by choosing one of four options listed in Table 14. 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 signage 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 is dangerous.

Table 14: Rating of Visibility of PLM Signs

Visibility of PLM Signs	Frequency		Valid Percent	
	Stair C	Stair D	Stair C	Stair D
Very Good	33	16	44%	52%
Acceptable	34	12	45%	39%
Poor	5	2	7%	6%
Dangerous	3	1	4%	3%
Total	75	31	100%	100%

From Stairwell C, 61 of 74 (82%) reported that the PLM signs facilitated the evacuation movement as presented in Table 15. Ten of 31 (32%) from Stairwell D stated that the PLM signs facilitated the evacuation. These frequencies are significantly different, $\chi^2 = 16.34$, $df = 1$, $p < 0.001$.

Table 15: PLM Signs Facilitated Evacuation Movement

PLM Facilitated Evacuation	Frequency		Valid Percent	
	Stair C	Stair D	Stair C	Stair D
Yes	61	10	82%	32%
No	13	21	18%	68%
Total	74	31	100%	100%

Respondents were asked to report whether the brightness of the signs got brighter, darker, or did not change. As reported in Table 16, 10 people of 74 (14%) using Stairwell C reported that the signs got brighter. Two (3%) said the signs got darker. The majority, 62 (84%), reported that the brightness did not change. Thirty people from Stairwell D answered this question: 2 (7%) stated that the signs got brighter, 1 (3%) reported that they got darker, and 27 (90%) reported that the brightness of the signs did not change.

Table 16: Brightness of the PLM Signs in Stairwells C and D

Brightness during descent	Frequency		Valid Percent	
	Stair C	Stair D	Stair C	Stair D
Became Brighter	10	2	14%	7%
Became Darker	2	1	3%	3%
Did not change	62	27	84%	90%
Total	74	30	100%	100%

Participants were asked to assess, from four choices, the quality of the lighting in the stairwell. The results are presented in Table 17. In Stairwell A, 26 out of 47 (55%) stated that the lighting was very good: 18 (38%) stated that the lighting was acceptable; 3 (7%) reported that the lighting was poor. No one from Stairwell A rated the lighting as being dangerous. In Stairwell B with full lighting, 27 of 45 respondents (60%) reported that the lighting was very good: 18 (40%) reported that the lighting was acceptable. No one from Stairwell B stated that the lighting was poor or dangerous. In Stairwell C with PLM only, 14 (20%) of 72 people reported the lighting to be very good: 36 (50%) said the lighting was acceptable; 11 (15%) reported that the lighting was poor and 11 (15%) stated that the quality of the lighting was dangerous. In Stairwell D with PLM and emergency lighting at 74 lux, 18 people of 36 (50%) reported the lighting to be very good and 18 (50%) stated that the lighting was acceptable. No one from Stairwell D reported that the lighting quality was poor or dangerous. The differing frequencies between the stairwells are significant ($\chi^2 = 32.39$, $df = 3$, $p < 0.001$). This difference is accounted for by Stairwell C which had more evacuees who judged the lighting as poor or dangerous compared to the evacuees of the three other stairwells. 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 that there was no emergency lighting in the stairwell they used so they left the question blank or 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. The wording of this question should be revised to reflect how a PLM wayguidance system can support occupants evacuation, if this questionnaire is to be used in future studies.

Table 17: Assessment of Quality of Lighting in the Stairwells

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

Twelve of 47 people from Stairwell A (26%) reported that they encountered crowding at the stairwell entry. Six of 44 (14%) using Stairwell B encountered crowding. Thirty-seven of 72 (51%) descending Stairwell C reported crowding. Of 39 people from Stairwell D, 7 (18%) encountered crowding at the stairwell entry. These frequencies differ significantly ($\chi^2 = 15.29$, $df = 3$, $p < 0.002$). This difference is between Stairwell C and the others since crowding was more important in Stairwell C.

Only 1 person of 46 using Stairwell A and 1 person of 68 from Stairwell C experienced difficulty opening the door to the stairwell. No one else had this problem.

From Stairwell A, 15 people of 45 (33%) reported that people entering from other floors blocked their descent. From Stairwell B, 8 of 44 (18%) encountered this problem. From C, 38 of 72 (53%) reported people from other floors blocking descent and, from D, only 3 of 39 (8%) had this problem. These frequencies differ significantly ($\chi^2 = 18.69$, $df = 3$, $p < 0.001$). Stairwell C differs from the others with this problem being encountered more often. Stairwells A and D differ from each other.

Six people of 46 (13%) in Stairwell A encountered too many people in the stairwell to enter. This was a problem for 4 of 44 (9%) entering B, and for 26 of 72 (36%) using C. For Stairwell D, no one encountered too many people to enter the stairwell. These frequencies differ significantly ($\chi^2 = 12.20$, $df = 3$, $p < 0.01$). It is Stairwell C that differs from all the others.

Only people in Stairwell C experienced difficulty finding the handrail. This was a problem for 23 of 70 (33%) of the people in Stairwell C. This differs significantly from the other stairwells ($\chi^2 = 14.62$, $df = 3$, $p < 0.002$).

No one from Stairwells B or D had difficulty seeing due to poor lighting. However, 2 of 46 (4%) in Stairwell A had difficulty seeing. From Stairwell C, 40 people of 71 (56%) reported having difficulty seeing. These frequencies are significantly different ($\chi^2 = 41.07$, $df = 3$, $p < 0.001$). This difference is between Stairwell C and the other stairwells.

People from Stairwells C and D reported encountering people moving upwards in the stairwell. For C, 25 of 71 (35%) reported this while only 2 of 39 (5%) in Stairwell D encountered people moving upward. These differences are significant ($\chi^2 = 15.65$, $df = 3$, $p < 0.001$). Stairwell C accounts for the difference. Several people from

Stairwell C wrote on their questionnaires that the people moving upwards were the firefighters.

People from every stairwell reported that people in front of them were moving too slowly. This was reported by 15 of 47 (32%) in Stairwell A, 9 of 45 (20%) from Stairwell B, 21 of 71 (30%) in Stairwell C, and 7 of 39 (18%) using Stairwell D. These frequencies do not differ significantly.

Seven people of 61 (12%) from Stairwell C reported encountering people standing on the landings.

There were people from each stairwell who reported feeling dizzy from descending. The frequencies in each stairwell do not differ significantly. From Stairwell A, 8 of 46 (17%) reported dizziness. Dizziness was reported by 13 of 44 (30%) from Stairwell B. Sixteen of 72 (22%) in Stairwell C reported dizziness. Dizziness was reported by 5 of 39 (13%) using Stairwell D. The proportion of people reporting dizziness is larger in Stairwell B (fully lit) but the number of people reporting dizziness is statistically similar for the four stairwells. Women, however, were significantly more likely to report dizziness than men (12 female vs 6 male) ($\chi^2 = 4.76$, $df = 1$, $p < 0.002$).

6.2 Alarm Sound Measurements

The sound output of the fire alarm signal was measured using a sound level meter manufactured by Larson-Davis Laboratories Model 800. Since the fire alarm sounded for less than 2 min, only 4 measurements were taken.

The first measurement was in the core area at the centre of the building in front of the fire alarm bell. At that location, the sound of the fire alarm was 90.1 dBA. The second measurement was taken in the men's washroom, with the main door to the washroom closed. The sound was measured at 60 dBA. The third measurement was taken in a meeting room next to section D4 with the main door opened. The sound was measured at 65.8 dBA. Finally, the fourth measurement was taken in a work area by a window in section D7. This location is the furthest workers could be from the fire alarm. The sound was measured at 70.3 dBA.

6.3 Data from the Video Cameras

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. 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.

6.3.1 Voice Communication Messages

Two minutes after the alarm bell activation, at 1:47:50, the following Warning Message was broadcast through the voice communication system: *“Attention please attention. Please be advised that during this evacuation exercise lighting conditions will be reduced on Floors 9,10 and 11 as well as in Stairwells A, C and D. This is being done to test emergency lighting systems under emergency conditions.”* (Pause, message repeated). This same message was then broadcast in French twice. It took 3 min to issue this first bilingual Warning Message. This message was repeated as shown in Table 18.

After this Warning Message, the lights on each of the test floors were reduced to emergency lighting only. At the same time, the lights in Stairwell C were completely turned off (the emergency lighting had been reduced manually to an average of 57 and 74 lux through temporary switches in Stairwells A and D, 3 min before the beginning of the evacuation drill). At 1:50:54 the following Evacuation Message was delivered: *“Attention please attention. A minor incident has been reported on the 10th floor. All occupants of the 9,10 and 11th floors will now evacuate the building as a precautionary measure, using the nearest safe exit. Occupants of all other floors please standby for further instructions.”* Then this message was issued in French. This Evacuation Message lasted approximately 1 min. The message was repeated. From the beginning of the fire alarm ringing until the message to evacuate was completed, 6 min had passed. During the English part of the Evacuation Message all the occupants on the 9th, 10th and 11th floors started to evacuate the building. As presented in Table 19, there were a few individuals who left the floors early. There was also 30 occupants who left from other floors, who were not instructed to do so.

At 1:52:07, after the evacuation had started, the Evacuation Assistance Message in both languages was announced, lasting approximately 20 s. *“Persons requiring evacuation assistance, as well as assigned monitors, please report to Stairwell Number 4 (Stairwell D) and follow instructions of the floor emergency officer.”* These individuals went to the door to the stairwell, but did not evacuate. This message was repeated at 1:56:05.

At 1:53:05, the following announcement was made in both languages: *“Remember elevators are not to be used for evacuation purposes. Once outside the building, move away from the building.”* The message lasted for approximately 20 s. The message was repeated 3 times. During the repeated messages, the evacuees were instructed to move 300 m from the building once outside.

During the evacuation, firefighters made their way up Stairwell C from the 8th floor to the 10th and 11th floors where they assisted in making sure that all occupants of those floors were evacuated. The last evacuee to leave the building entered the stairwell at 1:58:07 and exited at 2:00:16 followed by all the firefighters 14 min 23 s after the alarm activation. The voice communication message informing occupants that the evacuation was over was delivered at 2:06:02. Table 18 presents the events in chronological order.

Table 18: Time Line of Events

Time	Event
1:40:00 – 1:41:30	Emergency lighting in Stairwells A and D
1:45:53 – 1:47:42	Alarm activated
1:47:50 – 1:50:50	Voice Communication: Warning Message
1:48:27	Emergency Lighting on floors 9-10-11 Lights out in Stairwell C
1:50:54 – 1:51:54	Voice Communication: Evacuation Message
1:52:07 – 1:52:28	Voice Communication: Evacuation Assistance
1:53:08 – 1:53:24	Voice Communication: Do not use elevators
1:54:43 – 1:55:12	Voice Communication: Evacuation Message
1:56:04 – 1:56:25	Voice Communication: Evacuation Assistance
1:56:46 – 1:57:07	Voice Communication: Do not use elevators
1:58:17 – 1:58:40	Voice Communication: Do not use elevators
1:59:20 – 1:59:59	Voice Communication: Warning Message
2:01:09 – 2:01:28	Voice Communication: Do not use elevators
2:04:33 – 2:04:40	Voice Communication: Stay away from bldg.
2:04:51 – 2:04:59	Voice Communication: Do not use elevators
2:05:22 – 2:05:43	Voice Communication: Evacuation Assistance
2:06:02 – 2:06:25	Voice Communication: Evacuation is over

6.3.2 Time to Start

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 exit door. Table 19 shows the arrival time of the first person at each exit door. The average time to reach the exit door is 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.

Table 19: Time to Arrive at Stairwell Exit Door

Stairwell	Floor	First to Arrive Actual Time h:min:s	Elapsed Time From the Fire Alarm min:s
A	11	1:47:14	1:21
	10	1:46:23	0:30
	9	1:46:30	0:37
B	11	1:47:43	1:50
	10	1:46:51	0:58
	9	1:46:52	1:00
C	11	1:48:13	2:20
	10	1:47:25	1:32
	9	1:47:15	1:22
D	11	1:47:20	1:27
	10	1:46:36	0:43
	9	1:46:34	0:41

In some areas, there were occupants who started evacuation before listening to the voice communication message regarding the need to evacuate. Table 20 shows the time at which the first and the last person left on the 3 floors studied for the 4 stairwells.

Table 20: Time to Start in Stairwell

Stairwell	Floor	First to Leave Actual Time h:min:s	Last to Leave Actual Time h:min:s
A	11	1:47:14	1:54:38
	10	1:51:06	1:51:59
	9	1:46:32	1:52:36
B	11	1:51:10	1:54:53
	10	1:51:10	1:55:20
	9	1:51:11	1:53:05
C	11	1:51:21	1:56:04
	10	1:51:14	1:55:51
	9	1:51:10	1:54:59
D	11	1:51:15	1:56:11
	10	1:46:40	1:53:36
	9	no one leaves	no one leaves

6.3.3 Speed of Movement

The speed of movement of each evacuee in each stairwell was important data obtained from the video recordings. The average speed of movement in each stairwell was calculated. The planned study was to evacuate Floors 9, 10 and 11; there were, however, 30 occupants who left from other, lower floors. These occupants were moving at a faster speed than occupants from Floors 9, 10 and 11. This is explained by two facts. First, these evacuees were alone in the stairwell so they could freely race down the steps. Second, occupants from lower floors have less distance to travel so they tend

to travel faster, not having to cope with fatigue. In fact, the longer the descent, the slower the mean speed of movement. There were 35 occupants who never left the 3 floors studied. Consequently further analysis looked only at the 392 evacuees who used the stairwells from Floors 9, 10 and 11.

The distance to travel to reach the outside exit varied in each stairwell since the exits were not exactly at the same level around the building. From the 11th floor, evacuees had to descend 138.8 m in Stairwell A and 136.8 m in Stairwell B to reach ground level. On the south side of the building, evacuees had to descend 121.4 m in Stairwell C and 126.9 m in Stairwell D. Speed of movement was calculated for each evacuee with the exact distance travelled in each stairwell.

The speed of movement in Stairwell A ranged from 0.41 m/s to 1.14 m/s. It should be noted that the slowest evacuees were usually fire wardens assisting others in exiting. The speed for Stairwell B, the fully lit control stairwell, ranged between 0.45 m/s and 0.84 m/s. In Stairwell C, speeds ranged from 0.39 m/s to 1.13 m/s; it appears that evacuees ahead of the crowd could travel at a pretty fast speed in this stairwell with PLM alone. Speed of movement for Stairwell D ranged between 0.64 m/s to 1.3 m/s. No differences were found between the speed of men and women.

The mean speed of movement in the 4 stairwells is presented in Table 21. The slowest mean speed of movement was in Stairwell C, where the mean speed was 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.

Table 21: 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	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 differences between stairwells. The *F*-test shows that there is a significant difference in the mean speeds of movement obtained for the 4 stairwells ($F = 36.73$, $df = 3, 388$, $p < 0.001$).

A multiple comparison procedure, called the Bonferroni test, was obtained with the one-way ANOVA procedure. This test was used to identify which pairs of groups have significantly different means. The results show that the mean speed of movement for evacuees in Stairwell C (PLM only) is significantly slower ($\bar{X} = 0.57$, $p < 0.05$) compared to Stairwell B ($\bar{X} = 0.61$, $p < 0.05$), Stairwell A ($\bar{X} = 0.70$, $p < 0.05$) and Stairwell D ($\bar{X} = 0.72$, $p < 0.05$). There is also a significant difference between Stairwell B (fully lit) ($\bar{X} = 0.61$, $p < 0.05$) and the two stairwells with emergency lighting reduced to 57 and

74 lux, Stairwell A ($\bar{X} = 0.70$, $p < 0.05$) and Stairwell D ($\bar{X} = 0.72$, $p < 0.05$). 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 and D.

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 obliged 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 was the second least crowded with 82 evacuees. Finally, Stairwell D with emergency lighting reduced to 74 lux and PLM signage, 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 the increase in crowding and not to the lighting conditions in each stairwell.

As presented in Table 22, 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/m² which is almost 3 people for every 5 steps. Stairwells A and B were similar with, respectively, 1.25 p/m² and 1.30 p/m². Finally Stairwell D had the lowest density with an average of 1.0 p/m². Pauls [28] 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. Calculated speed of movement is slightly higher than the observed speed of movement for Stairwells A, B, and D. For Stairwell C, the calculated speed is lower than the observed speed. Results of calculated speed of movement are presented in Table 22.

Table 22: Speed and Density in the Four Stairwells

Stairwell	Density p/m ²	Observed Mean Speed m/s	Calculated Speed m/s
A	1.25	0.70	0.72
B	1.30	0.61	0.70
C	2.05	0.57	0.49
D	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 [29, 30]. 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 the stairwell.

As expected, the mean speed of descent decreases for occupants from upper floors. Not considering the stairwell used, occupants leaving from Floor 9 had a mean speed of movement of 0.67 m/s, occupants of Floor 10 had a mean speed of movement of 0.64 m/s and occupants of Floor 11 descended at 0.57 m/s. Again, this is explained by the crowding in the stairwell. Merging with evacuees entering the stairwell appears to be the main factor slowing down descending occupants. Those on Floor 9 did not pass any other evacuating floors and were moving faster. The people from the 10th floor were slower, having to merge with occupants entering the stairwell on the 9th floor. Finally those from the 11th floor were the slowest, having to merge with evacuees from both the 9th and 10th floors.

In Stairwell D, where there was the least amount of crowding and lowest density, the data shows that evacuees from Floors 10 and 11 who evacuated (9 people did not evacuate) were able to move at the same pace. In this stairwell, there were only 65 people who evacuated, two thirds of them from the 10th floor. There was, therefore, very little merging at the 10th floor by those coming down from the 11th floor. As the data shows, with little merging and fewer people in the stairwell, the speed of movement was very similar among occupants.

There is a large range of speeds for each floor and stairwell from 0.39 m/s up to 1.31 m/s. Some of the slowest evacuees were wardens who assisted others and chose to be last to evacuate and close the stairwell. Some of the fastest people entered the stairwell from Floor 9 or lower. In many cases, the fastest occupants left their floor prior to the evacuation message and would, therefore, not be affected by crowding in the stairwell which would allow them to move at a quicker pace.

7.0 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. For the majority of the occupants who participated in the experiment, it was their first encounter with PLM signage. 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 go and most people just followed the evacuation flow. These observations are important since this material is fairly unknown to most Canadians.

For this study, two types of data were gathered. On one hand, subjective assessment by the evacuee was obtained from the questionnaire. On the other hand, the complete overview of evacuees' behaviour, movement and time was provided by the

video recordings. Both methods provide a comprehensive evaluation of the material for office building evacuation.

7.1 Evacuees' Subjective Assessment of PLM Signage

Questionnaire findings show that occupants are favourable to improved directional signage on their floor to facilitate movement to the evacuation stairwells, this despite the fact that this signage 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 this 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".

Among all the questionnaires, there were three respondents who systematically judged the building, its components and their evacuation negatively. They assessed that the emergency lighting was dangerous on their floor and in the stairwell they used. These three people went down Stairwell C and left the premises right away. Two of them added sarcastic comments on their questionnaire, one of them suggesting to destroy the building.

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 acceptable to the evacuees as full lighting.

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 quality of the lighting 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 PLM safety wayguidance systems 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 is not the highest that may technically be currently achieved. The material used in this study is not the most luminous on the market. JALITE PLC, as well as some other manufacturers, are now selling PLM signs and wayguidance components that present brightness levels up to 5 times greater than the tested material. The latter material was not used since the project was started in 1997 with the old product and after an interruption of one year when the project was started again, it was decided to continue with the old material. It is expected that a more luminous product would satisfy many of the criticisms obtained.

Thirdly, the amount of material installed may be increased. In an attempt to maintain the amount of material to the minimum required under the PSPA Standard 002 Part 1 [21] and according to the proposed BS 5266 Part 6 [31] 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 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 with PLM. Handrails on both sides could be directly identified with PLM instead of by reflection from the 1 m line installed only on the wall side. The landing and mid-landing could also be 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.

7.2 Occupant Movement

The second type of data obtained in this study is from the video recordings. This means provided a complete account of the movement of every occupant who evacuated during the evacuation drill. The most important results are the time to start and the speed of movement.

The time to start the evacuation in this building is highly dependent on the evacuation procedure, since occupants are expected to wait by the exit door for voice communication messages. This evacuation approach has been devised to obtain a phased evacuation for this highrise building. For this study, voice communication messages were tailored to the situation, so it took more than 5 min after the sound of the fire alarm to issue the Evacuation Message. A few respondents mentioned that the message was too long or that the message was not given soon enough after the alarm activation. The delay to deliver the Evacuation Message may appear long but it is mainly due to the repetition and the bilingual format. The average time to start for the first occupants arriving at each stairwell was 1 min 12 s, which is longer than results obtained in other office buildings.

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 [29, 32]. The results indicate that the stairwell with PLM signage had the slowest speed of movement at 0.57 m/s, but it also had the largest crowd and the highest 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 signage, 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 PLM a wayguidance system of 0.57 m/s, is comparable to previous findings of highrise office evacuation in fully lit stairwells [33]. 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.

Ouellette and Rea [34] suggested that in order to determine the illuminance requirements for emergency lighting, it is first necessary to determine our definition of safety. Past lighting studies have focused on 3 main concepts of safety. The first is based on the number of collisions with objects. It was found that illuminance must be above 0.25 lux to avoid collisions. A second definition uses the time it takes to escape, or the occupant's average speed of movement to assess safety. It is expected that a decrease below "normal" luminance will slow movement, and that the rate of the reduction of speed increases as the luminance decreases. A third definition is based on subjective appraisal of lighting. It was found that levels below 1 lux are considered unsatisfactory, while satisfaction is reached at 3 lux and appraisals continuously increase as lighting increases to 7 lux. This study was not conducted to look at the potential of collision with objects. There was, however, no occurrence of such collision during the evacuation as reported by the evacuees or observed on the videotapes. The speed of movement is considered acceptable and comparable to speed observed during other evacuation studies. Finally, most evacuees gave a favourable subjective assessment of the PLM signage. Clearly, these findings show that there is more to illumination and perception than the number of lux.

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 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 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 concordance to conclude that PLM signs and PLM safety wayguidance systems could be a worthwhile addition improving occupant fire safety in office buildings.

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APPENDIX 1

Letter and Questionnaire



Conseil national de recherches
Canada

National Research Council
Canada

Institut de
recherches en construction

Institute for
Research in Construction

Ottawa, Canada
K1A 0R6

CNRC - NRC

Fire Risk Management Program

Phone: (613) 993-9634

FAX: (613) 954-0483

11/18/98

Questionnaire on the Evacuation Drill

Questionnaire sur l'exercice d'évacuation

This survey is being conducted by Public Works and Government Services and the National Research Council in collaboration with the Facilities Management Bureau and Department of Security. The purpose of the study is to evaluate the effectiveness of the emergency procedures and the usefulness of the new photoluminescent sign system. Completing this questionnaire is voluntary but your assistance would be greatly appreciated. Your responses to this questionnaire will be kept confidential and will be processed only by NRC researchers.

Cette enquête est réalisée par Travaux publics et services gouvernementaux et le Conseil national de recherche du Canada en collaboration avec le service de gestion des installations et sécurité du Bureau. L'objectif de cette étude est d'évaluer l'efficacité des procédures d'urgence et l'utilité du nouveau système de signalisation photoluminescent. Remplir ce questionnaire est volontaire mais votre participation serait très appréciée. Vos réponses à ce questionnaire seront tenues confidentielles et seront accessibles uniquement aux chercheurs du CNRC.

The evacuation drill was carried out under emergency lighting conditions. This condition occurs frequently during actual fires when the regular power is shut off for firefighters' intervention, or if the fire attacks the electrical system of the building. The emergency lighting is provided by a separate generator to ensure your safety while you leave the building. Photoluminescent material was added on some floors and stairwells of the Jean Talon Building. This is part of a research study looking at the potential of this material as a safety communication system to support the evacuation of occupants under emergency lighting conditions.

Cet exercice d'évacuation a été réalisé dans des conditions d'évacuation d'urgence. Ce type de conditions est fréquent pendant les incendies lorsque les pompiers doivent interrompre le courant ou lorsque l'incendie endommage le système électrique du bâtiment. L'éclairage d'urgence est assuré par un générateur séparé qui assure votre sécurité pendant un évacuation du bâtiment. Une signalisation faite de matériel photoluminescent a été installée sur quelques étages et dans certains escaliers du bâtiment Jean Talon. Ceci fait partie d'une étude qui vise à évaluer le potentiel de ce type de matériel comme système de communication pour faciliter l'évacuation des occupants dans des conditions d'éclairage d'urgence.

Please make sure to answer each question, and return the questionnaire to the red box near the elevator before the end of the day.

S'il vous plaît, assurez d'avoir complété toutes les questions et avant la fin de la journée, déposez le questionnaire dans la boîte rouge qui se trouve près des ascenseurs.

Thank you for your participation.

Merci de votre collaboration.

Canada

Questionnaire on the Evacuation Drill

SECTION 1: Individual Profile	
1- Your age: 1. <input type="checkbox"/> 20-30 2. <input type="checkbox"/> 31-40 3. <input type="checkbox"/> 41-50 4. <input type="checkbox"/> 51-60 5. <input type="checkbox"/> 61 over	2- Sex: 1. <input type="checkbox"/> F 2. <input type="checkbox"/> M
3- Have you taken part in an evacuation drill in this building before? 1. <input type="checkbox"/> Yes 2. <input type="checkbox"/> No	
4- Who is the fire warden on the floor where your work? _____	
5- In your opinion, are you required to obey the instructions from the fire wardens? 1. <input type="checkbox"/> Yes 2. <input type="checkbox"/> No 3. <input type="checkbox"/> Don't know	
6- Do you have limitations that could impede your evacuation? If Yes, Please indicate the appropriate box(es):	
a. emphysema <input type="checkbox"/>	d. arthritis <input type="checkbox"/>
b. asthma <input type="checkbox"/>	e. overweight <input type="checkbox"/>
c. pregnancy <input type="checkbox"/>	f. injury <input type="checkbox"/>
	g. vision impairment <input type="checkbox"/>
	h. mobility impairment/disability <input type="checkbox"/>
	i. hearing impairment <input type="checkbox"/>

SECTION 2: The last evacuation drill
7- Did you hear the fire alarm during the last evacuation drill? 1. <input type="checkbox"/> Yes 2. <input type="checkbox"/> No
8- In your opinion, was the alarm: 1. <input type="checkbox"/> too loud 2. <input type="checkbox"/> loud enough 3. <input type="checkbox"/> too quiet
9- Were you at your desk when you heard the alarm or when the drill began? 1. <input type="checkbox"/> Yes 2. <input type="checkbox"/> No Where were you located: Floor _____ Area: <input type="checkbox"/> A <input type="checkbox"/> B <input type="checkbox"/> C <input type="checkbox"/> D
10- Which of the following actions did you first do when you heard the fire alarm (check only one)?
a. returned to office <input type="checkbox"/>
b. continued working <input type="checkbox"/>
c. sought more information <input type="checkbox"/>
d. secured files/information <input type="checkbox"/>
e. got dressed <input type="checkbox"/>
f. gathered valuables <input type="checkbox"/>
g. followed instructions from P.A. <input type="checkbox"/>
h. evacuated the floor <input type="checkbox"/>
i. evacuated the building <input type="checkbox"/>
j. went to meeting point <input type="checkbox"/>
11- Did you hear a message from the voice communication system? 1. <input type="checkbox"/> Yes 2. <input type="checkbox"/> No If Yes, what was this message? _____ _____

SECTION 3: The evacuation of your floor
12- You evacuated the building under emergency lighting conditions, how would you assess the quality of the emergency lighting <u>on your floor</u> , in the event that you would have to participate in an emergency evacuation of the building? 1. <input type="checkbox"/> Very good 2. <input type="checkbox"/> Acceptable 3. <input type="checkbox"/> Poor 4. <input type="checkbox"/> Dangerous
13- Did you know where to go to evacuate your floor? 1. <input type="checkbox"/> Yes 2. <input type="checkbox"/> No
14- Did you notice signs in a yellow-green glowing material (photoluminescent)? 1. <input type="checkbox"/> Yes 2. <input type="checkbox"/> No If Yes, a- Were these signs useful to find your way to the stairwell? 1. <input type="checkbox"/> Yes 2. <input type="checkbox"/> No b- How would you assess the visibility of these signs? 1. <input type="checkbox"/> Very good 2. <input type="checkbox"/> Acceptable 3. <input type="checkbox"/> Poor 4. <input type="checkbox"/> Dangerous

SECTION 4: Your evacuation by the stairwell

15- Which stairwell did you use? 1. Stairwell 1 or A 3. Stairwell 3 or C
 3. Stairwell 2 or B 4. Stairwell 4 or D

Was this stairwell your closest exit? 1. Yes 2. No

17- In the stairwell, did you notice a yellow-green glowing material (photoluminescent)? 1. Yes 2. No

If Yes, a- Was this material useful when finding your way in the stairwell? 1. Yes 2. No
 b- How would you assess the visibility of this material?
 1. Very good 2. Acceptable 3. Poor 4. Dangerous
 c- Did this material facilitate your evacuation movement? 1. Yes 2. No
 d- Did the brightness of the glowing material change as you came down the stairs?
 1. Brighter 2. Darker 3. No change

18- How do you assess the quality of the emergency lighting in the stairwell you used, in the event that you would have to participate in an emergency evacuation of the building?

1. Very good 2. Acceptable 3. Poor 4. Dangerous

19- While using the stairwell, did you encounter any of the following? 1. Yes 2. No

- | | | |
|--|--------------------------|--------------------------|
| a- furniture prevented you from entering the stairwell | <input type="checkbox"/> | <input type="checkbox"/> |
| b- people crowding around the entry to the stairwell | <input type="checkbox"/> | <input type="checkbox"/> |
| c- difficulty opening the door to the stairwell | <input type="checkbox"/> | <input type="checkbox"/> |
| d- people entering at other floors blocked descent | <input type="checkbox"/> | <input type="checkbox"/> |
| e- too many people in the stairwell to enter | <input type="checkbox"/> | <input type="checkbox"/> |
| f- difficulty finding the handrail | <input type="checkbox"/> | <input type="checkbox"/> |
| g- difficulty seeing because of poor lighting | <input type="checkbox"/> | <input type="checkbox"/> |
| h- people were moving upward in the stairwell | <input type="checkbox"/> | <input type="checkbox"/> |
| i- people in front of you moving too slowly | <input type="checkbox"/> | <input type="checkbox"/> |
| j- people were standing on the landings | <input type="checkbox"/> | <input type="checkbox"/> |
| k- feeling dizzy from the long descent | <input type="checkbox"/> | <input type="checkbox"/> |
| l- difficulty finding the exit door at the base | <input type="checkbox"/> | <input type="checkbox"/> |
| m- problems opening the exit door at the base | <input type="checkbox"/> | <input type="checkbox"/> |

20- Where were you when you exited the staircase?

1. outside 2. another floor 3. hall/lobby 4. underground

21- What did you do when you left the staircase?

1. waited for further instructions by the staircase 2. went to meeting point 3. left the premises

Thank you very much for your help.

Please return this questionnaire to the red box by the elevators.

If you have questions or comments regarding this questionnaire or the evacuation drill, please call the principal researcher of this project, Guylène Proulx of NRC at 993-9634.

Questionnaire sur les procédures d'évacuation

PARTIE 1: Votre profil

1- Votre âge: 1. 20-30 2. 31-40 3. 41-50 4. 51-60 5. 61 + 2- Sexe: 1. F 2. M

3- Avez-vous déjà participé à l'évacuation de ce bâtiment dans le passé? 1. Oui 2. Non

4- En cas d'incendie, qui est l'agent(e) désigné(e) sur l'étage où vous travaillez? _____

5- Selon vous, êtes-vous obligé(e) de suivre les instructions de l'agent(e)?

1. Oui 2. Non 3. vous ne savez pas

6- Avez-vous des limitations qui pourraient vous empêcher d'évacuer le bâtiment? 1. Oui 2. Non

Si Oui, cochez la ou les cases appropriées:

- | | | | | | |
|--------------|--------------------------|-------------|--------------------------|----------------------|--------------------------|
| a. emphysème | <input type="checkbox"/> | d. arthrite | <input type="checkbox"/> | g. handicap visuel | <input type="checkbox"/> |
| b. asthme | <input type="checkbox"/> | e. poids | <input type="checkbox"/> | h. handicap physique | <input type="checkbox"/> |
| c. enceinte | <input type="checkbox"/> | f. blessure | <input type="checkbox"/> | i. handicap auditif | <input type="checkbox"/> |

PARTIE 2: Le dernier exercice d'évacuation

7- Avez-vous entendu l'alarme d'incendie pendant l'exercice d'évacuation? 1. Oui 2. Non

8- Selon vous, l'alarme était: 1. trop forte 2. suffisamment forte 3. trop faible

9- Étiez-vous à votre bureau quand vous avez entendu l'alarme ou lorsque l'exercice a commencé? 1. Oui 2. Non

Où étiez-vous situé? L'étage _____ Section A B C D

10- Laquelle des actions suivantes avez-vous faite, en premier, après avoir entendu l'alarme? (cochez une seule case)

- | | | | |
|--------------------------------|--------------------------|--|--------------------------|
| a. retourner à mon bureau | <input type="checkbox"/> | f. prendre porte-monnaie, sac à main | <input type="checkbox"/> |
| b. continuer à travailler | <input type="checkbox"/> | g. suivre les instructions données par haut-parleurs | <input type="checkbox"/> |
| c. chercher de l'information | <input type="checkbox"/> | h. évacuer l'étage | <input type="checkbox"/> |
| d. mettre information sous clé | <input type="checkbox"/> | i. évacuer le bâtiment | <input type="checkbox"/> |
| e. vous habiller | <input type="checkbox"/> | j. aller au point de rendez-vous | <input type="checkbox"/> |

11- Avez-vous entendu un message transmis par haut-parleurs? 1. Oui 2. Non

SI Oui, quel était le contenu du message? _____

PARTIE 3: L'évacuation de votre étage

12- Vous avez évacué sous conditions d'éclairage d'urgence; comment évaluez-vous la qualité de l'éclairage sur votre étage dans l'éventualité où vous auriez à évacuer d'urgence ce bâtiment?

1. Très bon 2. Acceptable 3. Pauvre 4. Dangereux

13- Saviez-vous où aller pour évacuer votre étage? 1. Oui 2. Non

14- Avez-vous remarqué des signes d'un jaunes-verts brillants (Photoluminescent)? 1. Oui 2. Non

SI Oui, a. Est-ce que ces signes ont été utiles pour circuler sur votre étage? 1. Oui 2. Non

b. Comment évaluez-vous la visibilité de ces signes?

1. Très bon 2. Acceptable 3. Pauvre 4. Dangereux

SECTION 4: Votre évacuation par les escaliers

15- Quel escalier avez-vous utilisé? 1. Escalier 1 ou A 3. Escalier 3 ou C

2. Escalier 2 ou B 4. Escalier 4 ou D

Est-ce que cet escalier était la sortie la plus proche? 1. Oui 2. Non

16- Avez-vous remarqué des signes dans l'escalier? 1. Oui 2. Non

17- Avez-vous remarqué des signes d'un jaunes-verts brillants (Photoluminescent)? 1. Oui 2. Non

SI Oui, a. Est-ce que ces signes ont été utiles pour circuler dans les escaliers? 1. Oui 2. Non

b. Comment évaluez-vous la visibilité de ces signes?

1. Très bon 2. Acceptable 3. Pauvre 4. Dangereux

c. Est-ce que ces signes ont facilité votre évacuation? 1. Oui 2. Non

d. Est-ce que la brillance de ces signes a changé pendant que vous descendiez les escaliers?

1. Plus brillant 2. Moins brillant 2. Pas de changement

18- Comment évaluez-vous la qualité de l'éclairage d'urgence dans l'escalier que vous avez emprunté dans l'éventualité où vous auriez à évacuer d'urgence ce bâtiment?

1. Très bon 2. Acceptable 3. Pauvre 4. Dangereux

19- Au moment où vous avez utilisé les escaliers, avez-vous rencontré les situations suivantes?

1. Oui 2. Non

- | | | |
|--|--------------------------|--------------------------|
| a. des meubles encombraient l'entrée de la cage d'escalier | <input type="checkbox"/> | <input type="checkbox"/> |
| b. un trop grand nombre de gens empêchait d'entrer dans l'escalier | <input type="checkbox"/> | <input type="checkbox"/> |
| c. des difficultés à ouvrir la porte de la cage d'escalier | <input type="checkbox"/> | <input type="checkbox"/> |
| d. les portes aux étages empêchaient la descente des escaliers | <input type="checkbox"/> | <input type="checkbox"/> |
| e. trop de gens étaient dans l'escalier pour pouvoir entrer | <input type="checkbox"/> | <input type="checkbox"/> |
| f. difficultés à trouver la main courante (rampe d'escalier) | <input type="checkbox"/> | <input type="checkbox"/> |
| g. difficultés à voir à cause du mauvais éclairage | <input type="checkbox"/> | <input type="checkbox"/> |
| h. des gens montaient les escaliers à contre-courant | <input type="checkbox"/> | <input type="checkbox"/> |
| i. les gens devant vous étaient trop lents | <input type="checkbox"/> | <input type="checkbox"/> |
| j. des gens attendaient sur les paliers | <input type="checkbox"/> | <input type="checkbox"/> |
| k. se sentir étourdi de longue descente | <input type="checkbox"/> | <input type="checkbox"/> |
| l. difficultés à trouver la porte de sortie au bas de l'escalier | <input type="checkbox"/> | <input type="checkbox"/> |
| m. difficultés à ouvrir la porte pour sortir de la cage d'escalier | <input type="checkbox"/> | <input type="checkbox"/> |

20- A quel endroit étiez-vous lorsque vous avez quitté l'escalier?

1. à l'extérieur 2. autre étage 3. hall d'entrée 4. sous-sol

21- Qu'est-ce que vous avez fait une fois sortie de la cage d'escalier?

1. attendu les instructions près de l'escalier 2. allé au point de rendez-vous 3. quitté les lieux

Merci de votre aide.

S'il vous plaît, retourner ce questionnaire complété dans la boîte rouge qui se trouve près des ascenseurs.

Si vous avez des questions ou commentaires concernant ce questionnaire ou l'étude sous-jacente, contactez le chercheur principale Guylène Proulx au CNRC, 993-9634.