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Evaluation of the Effectiveness of Different Photoluminescent Stairwell Installations for the Evacuation of Office Building Occupants

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Proulx, G.; Bénichou, N.; Hum, J.K.; Restivo, K.N.

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ACKNOWLEDGMENT

We would like to thank the C.D. Howe building occupants who graciously participated in this evacuation drill, contributing data as they were descending the stairwells and through filling out our questionnaire; without your willing participation there wouldn't be any study. Thanks also to the Floor Emergency Officers who did an excellent job in directing and helping occupants during the evacuation drill. Despite the fact that this study was being conducted, this was the most timely evacuation drill ever conducted at the C.D. Howe building. This is certainly due to the contribution of all the individuals who together decided to make this exercise a success; a big thank you to all.

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[1] Since the preparation of this research report, Prolink North America now operates as Lumonall Inc.

Evaluation of the effectiveness of different photoluminescent stairwell installations for the evacuation of office building occupants

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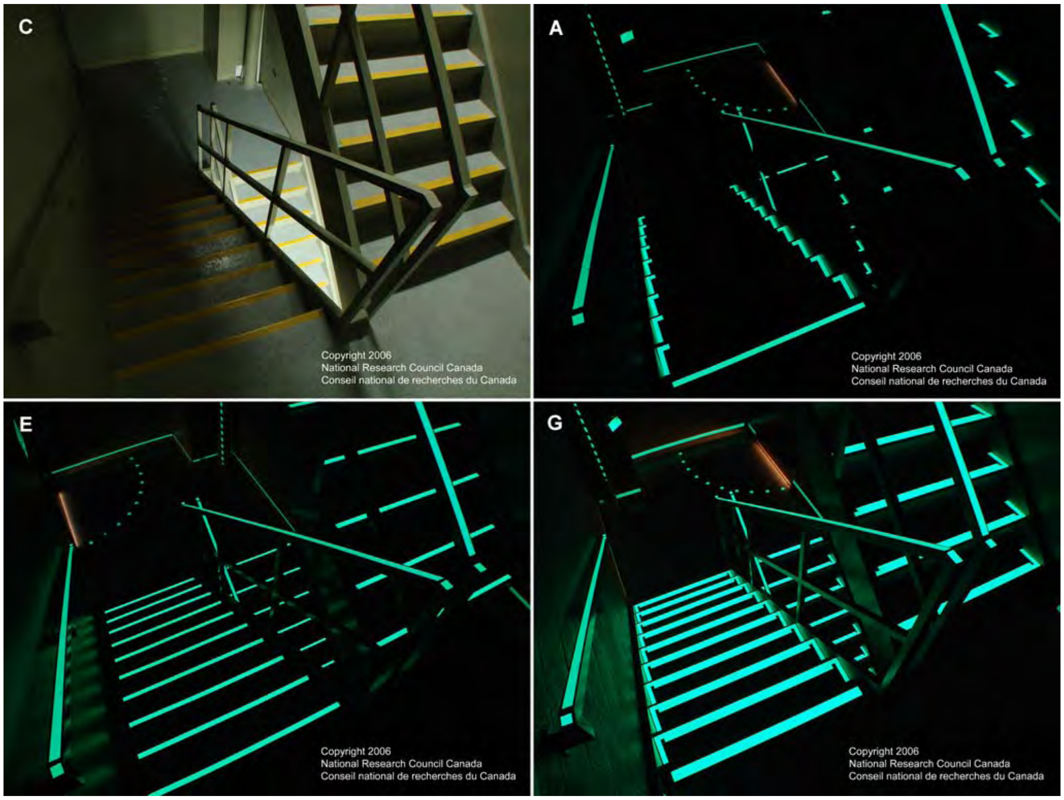
EXECUTIVE SUMMARY

A field study was conducted to assess the effectiveness of different photoluminescent material stairwell installations as a safety wayguidance system to support office occupant evacuation. The National Research Council of Canada and Public Works and Government Services Canada worked closely together, as research partners, to conduct this research with support from 3 photoluminescent manufacturers: Jalite USA, Jessup Manufacturing Company and Prolink North America.

The C.D. Howe building at 235 Queen Street, in Ottawa, was selected for this study. The building has six geometrically identical stairwells of which four are windowless. Around 4,000 employees could be in the building during working hours. The annual evacuation drill, usually set during Fire Safety Week, was the pretext for the experiment. The evacuation drill was conducted on Thursday October 5, 2006 at 10:35:23 a.m.

The following experimental design was established for the four windowless stairwells (see figure below): Three stairwells were installed with markings incorporating photoluminescent materials. Markings comprised of seven elements. Stairwell A had “L” shaped markers at edge corners of each step and marked handrails. Step marks represent installations based on New York City Local Law 26 for existing buildings. Extra marked handrails are not a requirement in New York City for existing buildings. Stairwell E represents New York City requirements for new buildings with continuous one-inch wide mark across each step and marked handrails. Stairwell G combines “L” shaped markers, marked handrails, and continuous two inch wide mark across each step which was a suggestion made by the executive architect of the New York City Department of Building who is reviewing current installations. The 4th stairwell studied or Stairwell C had no photoluminescent marking but had lighting reduced to an average level of 37 lux, as if the stairwell was under emergency lighting, this stairwell was the control stairwell.

Twenty-eight video cameras were used to gather movement time and the behaviour of evacuees in the four stairwells studied. A questionnaire was distributed to evacuees upon exiting the building through Stairwells A, C, E and G. The questionnaire contained questions on the participant’s characteristics, the evacuation drill experienced on that day, specific questions on the comfort and safety felt in the stairwell used, and overall appreciation of the photoluminescent markings.



Four studied stairwell installations

Results from the questionnaire show that overall, 65 to 75% of the respondents felt comfortable going down the stairwells with the photoluminescent markings or the stairwell with reduced lighting. Evacuees assessed visibility in the stairwell as good or excellent for Stairwells E and G while Stairwells A and C received less positive judgement. Over 90% of the respondents in the four stairwells studied “strongly agree” or “somewhat agree” that the handrail was easy to find. Overall, respondents from the four stairwells studied were positive when asked if the first step to each flight was easy to locate. It was easier, however, for evacuees to identify each step in Stairwells E and G, while it was more difficult to identify each step in Stairwells A and C. When asked about the ease of locating the last step of each flight, evacuees who used Stairwell A found it particularly difficult to locate the last step of each flight in that stairwell. There was no statistical difference among stairwells for the marking of obstructions, the identification of re-entry floor, or the marking of the final exit. If we take the stairwell attributes individually and look at the stairwell that received the most favourable appreciations for each attribute, it seems that Stairwell E is systematically in first place with Stairwell G second. Stairwells A and C are in turn at the third and last position. From the questionnaire it appears that respondents judged Stairwells A and C similar on several questions while these two stairwells appear less appreciated than Stairwell E and G. Stairwell E obtained the best appreciation despite the fact that this was also the stairwell that was felt most crowded, and where problems, such as occupants at the front moving too slowly, were identified.

Video recordings provided an account of the movement and behaviour of occupants evacuated during the evacuation drill. At 10:35:23, the fire alarm bell sounded and rang continuously for 11 minutes and 51 seconds. The average time taken by the first occupants to arrive at each stairwell was 1 minute and 9 seconds. Full evacuation required about 12 minutes.

One of the most important findings was the speed of movement of a natural crowd descending the stairwells under different lighting conditions. The results show that speed of movement in Stairwell A ranged from 0.33 m/s to 1.39 m/s. In Stairwell E, the speed ranged from 0.17 m/s to 1.03 m/s, in Stairwell G it ranged from 0.14 m/s to 1.53 m/s, and in Stairwell C from 0.38 m/s to 1.87 m/s. The slowest mean speed of movement was in Stairwell E, which had a speed of 0.40 m/s, Stairwell G had a mean speed of 0.57 m/s, and Stairwells A and C both had a mean speed of 0.66 m/s. Densities in the four studied stairwells were comparable from 1.56 to 1.60 p/m^2 during the five busiest minutes of the evacuation. Since the mean density was essentially the same in the four stairwells, it is surprising to note that Stairwell E had a significantly slower mean speed of movement of 0.40 m/s. Close study of the video recordings showed that two evacuees with mobility limitations had a major impact on the slow movement of Stairwell E. The crowd density and the occupants with limitations seemed to be the driving factors to explain the speed of movement obtained during this drill. The photoluminescent marking or the reduced lighting did not appear to play a role in the speed of movement. Previous evacuation drills at the C.D. Howe building typically take around 14 minutes, completion of the evacuation under 12 minutes demonstrates that the experimental set-up did not affect the speed of movement.

Stairwell E, with one inch wide marking across each step, received the best appreciation from the respondents despite the fact that it was the slowest stairwell due to two slow evacuees. The two stairwells with marking across each step received a better evaluation from respondents than the stairwells with “L” shaped markers or reduced lighting. The three stairwells with photoluminescent marking performed as well as the stairwell with reduced lighting for the speed of movement while the two stairwells with photoluminescent marking across each step received better appreciation from the occupants.

This study’s findings show the interesting potential of photoluminescent markings to assist occupant evacuation. Such markings, properly installed, can address certain deficiencies in the traditional approach of emergency lighting associated with power failure or smoke obscuration of high-mounted lighting. In order to obtain the expected outcome though, it is essential to properly install photoluminescent wayguidance components.

Photoluminescent wayfinding systems appear as a cost-effective addition to, or even a potential replacement for, traditional emergency lighting. Advantages are: no additional consumption of energy, no additional wiring, minimal maintenance, and complete reliability when installed appropriately. Occupant behaviour, speed of movement, and subjective appraisal of the material are all in concordance to indicate that photoluminescent markings would be a worthwhile addition improving occupant fire and emergency evacuation safety in office buildings.

Évaluation de diverses installations de matériaux photoluminescents pour l'évacuation des occupants dans des cages d'escalier d'immeubles de bureaux

G. Proulx, N. Bénichou, J.K. Hum et K.N. Restivo

RESUME

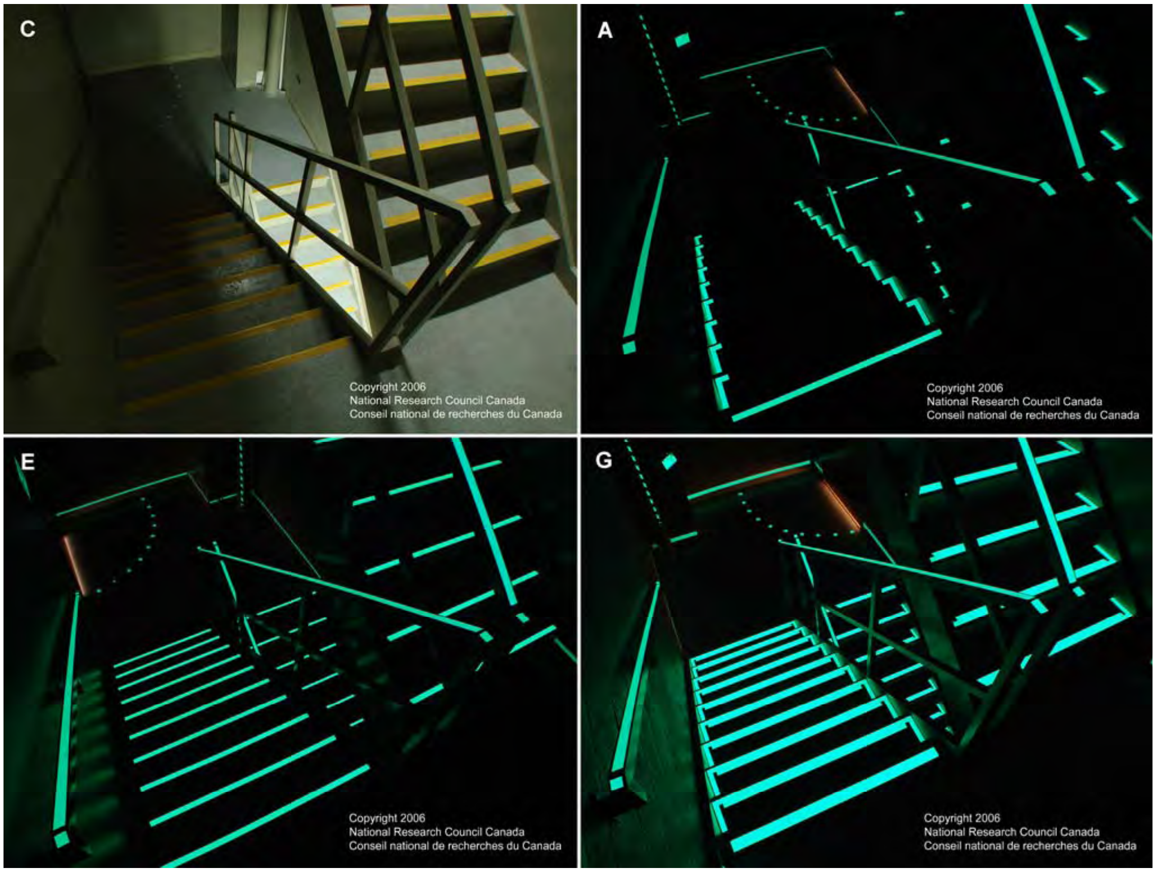
Une étude sur le terrain a été menée dans le but d'évaluer l'efficacité de diverses configurations de matériaux photoluminescents dans des cages d'escalier comme systèmes de signalisation de secours favorisant l'évacuation des lieux par les occupants d'immeubles de bureaux. Le Conseil national de recherches du Canada et Travaux publics et Services gouvernementaux Canada travaillent de concert en qualité de partenaires de recherche pour mener ce projet, avec l'appui de trois (3) fabricants de matériaux photoluminescents : Jalite USA, Jessup Manufacturing Company et Prolink North America.

On a choisi pour cette étude le bâtiment C.D. Howe, situé au 235 rue Queen à Ottawa. Ce bâtiment contient six cages d'escaliers géométriquement identiques dont 4 sont sans fenêtre. Aux heures de travail, ce bâtiment peut contenir près de 4 000 employés. L'exercice d'évacuation annuel, qui a lieu généralement pendant la semaine dédiée à la sécurité incendie, fut l'occasion de mener cette expérience. Les installations de matériaux photoluminescents ont été évaluées pendant l'exercice d'évacuation qui a eu lieu le jeudi 5 octobre 2006 à 10 h 35 min et 23 s.

Le plan expérimental suivant a été conçu pour les 4 cages d'escalier sans fenêtre (voir figures ci-dessous) : une signalisation conçue avec des matériaux photoluminescents a été installée dans trois cages d'escalier. Cette signalisation comprenait 7 éléments. Dans la cage d'escalier A, on a posé un marquage en forme de « L » aux coins extérieurs de chaque marche et marqué les mains courantes d'une bande continue. Le marquage des marches était conforme aux exigences de la loi 26 de la ville de New York (NYC Law 26) quoique le marquage des mains courantes ne sont pas requis à New York pour les bâtiments existants. La cage d'escalier E est conforme aux exigences de la ville de New York pour les nouveaux bâtiments avec une bande continue d'une largeur d'un pouce en travers de chaque marche et les mains courantes marquées. La cage d'escalier G combine le marquage en forme de « L » au coin extérieur des marches et un marquage continu de deux pouces le long de chaque marche en plus du marquage des mains courantes. Cette dernière installation était une suggestion faite de l'architecte responsable du 'Department of Building' de la ville de New York, lequel passe en revue les installations existantes. La 4^{e} cage d'escalier étudiée, soit la cage C, n'avait pas de marquage photoluminescent mais son éclairage était réduit à un niveau moyen de 37 lux, ce qui correspond à un éclairage de secours.

Vingt-huit cameras vidéos ont permis d'enregistrer les mouvements et le comportement des personnes évacuées dans les quatre cages d'escalier étudiées. Un questionnaire a été remis aux évacués au moment où ils sortaient du bâtiment par les cages A, C, E et G. Les questions portaient sur les caractéristiques du participant, l'exercice d'évacuation

de ce jour, l’impression de confort et de sécurité dans la cage d’escalier empruntée et l’appréciation globale de la signalisation photoluminescente.



Configuration des quatre cages d’escalier étudiées

Les réponses aux questions montrent que, d’une façon générale, 65 à 75 % des répondants se sont sentis en sécurité lorsqu’ils ont descendu les escaliers équipés de la signalisation photoluminescente ou d’éclairage réduit. Ils ont estimé la visibilité bonne ou excellente dans les cages d’escalier E et G, un peu moins bonne dans la A et la C. Plus de 90 % des répondants dans les quatre cages étudiées ont été « entièrement d’accord » ou « d’accord » avec le fait que la main courante était facile à trouver. En général, les répondants dans les quatre cages étudiées ont répondu positivement lorsqu’on leur a demandé si la première marche de chaque volée d’escalier était facile à trouver. En revanche, s’il a été facile d’identifier chaque marche dans les cages E et G, ce fut un peu moins facile dans les cages A et C. Quant à la facilité à localiser la dernière marche de chaque volée, les répondants ont mentionné que cela avait été particulièrement difficile dans la cage d’escalier A. Il n’y a pas eu de différences statistiques entre les cages d’escalier en ce qui concerne la signalisation des obstacles, l’identification de l’étage d’entrée ou la signalisation de la sortie. Si l’on considère les éléments des cages individuellement et si l’on regarde la cage qui a reçu le plus d’appréciations favorables pour chacun des éléments, il semble que ce soit la cage d’escalier E qui soit systématiquement en première place et la cage G en deuxième. Les cages A et C arrivent tour à tour en troisième et dernière position. Selon le questionnaire, il apparaît que les répondants ont jugé les cages A et C identiques sur plusieurs points et que ces deux cages ont été moins appréciées que les cages d'escalier E et G. La cage E a reçu la meilleure évaluation malgré le fait que c'était celle qui a été perçue comme étant la plus achalandé et dans laquelle des problèmes ont été soulevés, comme des personnes en tête qui avançaient trop lentement.

Les enregistrements vidéo ont rendu compte du mouvement et du comportement des occupants évacués pendant l'exercice. A 10 h 35 min et 23 s, l'alarme incendie a retenti et ce, de façon continue pendant 11 minutes et 51 secondes. Le temps mis par les premiers occupants pour arriver dans chaque cage d'escalier fut en moyenne 1 minute et 9 secondes. L'évacuation complète a duré un peu moins de 12 minutes.

L'un des résultats les plus importants est la vitesse de mouvement de la foule descendant les escaliers dans diverses conditions d'éclairage et de matériaux photoluminescents. La vitesse de mouvement dans la cage d'escalier A allait de 0,33 à 1,39 m/s. Dans la cage E, elle allait de 0,17 à 1,03 m/s, dans la cage G, de 0,14 à 1,53 m/s et enfin dans la cage C, de 0,38 à 1,87 m/s. La vitesse moyenne la plus basse a été observée dans la cage E, 0,40 m/s, la cage G affichant 0,57 m/s et les cages A et C, 0,66 m/s de moyenne chacune. Les densités dans les quatre cages étudiées étaient comparables, entre 1,56 et 1,60 p/m^2, au cours des cinq minutes les plus denses de l'évacuation. La densité moyenne étant pratiquement la même dans les quatre cages, conséquemment il est surprenant de noter que la cage E avait une vitesse moyenne de mouvement nettement plus faible que les autres cages d'escalier. Une étude approfondie des enregistrements vidéo a montré que deux évacués à mobilité réduite ont eu un impact majeur sur la vitesse d'évacuation de la cage E.

La densité de la foule et les occupants à mobilité réduite semblent avoir été des facteurs primordiaux pour expliquer la vitesse de mouvement obtenue au cours de cet exercice. Le marquage photoluminescent ou l'éclairage réduit n'a pas semblé jouer de rôle dans la vitesse du mouvement. Les exercices d'évacuation précédents dans le bâtiment C.D. Howe prenaient habituellement autour de 14 minutes, et donc une évacuation complétée en moins de 12 minutes démontre que le plan expérimental n'a pas eu de conséquences négatives sur la vitesse du mouvement.

La cage d'escalier E, dont chaque marche avait une bande photoluminescente d'un pouce, a reçu la meilleure appréciation de la part des répondants malgré le fait que la vitesse de mouvement y était la plus faible à cause des deux évacués à mobilité réduite. Les deux cages d'escalier dont les marches étaient marquées sur leur pleine longueur ont reçu une meilleure évaluation des répondants que les cages avec le marquage en « L » à l'extrémité des marches ou l'éclairage réduit. La vitesse de mouvement dans les trois cages pourvues de signalisation photoluminescente a été égale à celle de la cage avec l'éclairage réduit mais les deux cages dont les marches était marquées sur leur pleine longueur avec un matériau photoluminescent ont reçu la meilleure appréciation des occupants.

Les résultats de cette étude montrent le potentiel intéressant de la signalisation photoluminescente pour aider l'évacuation des occupants. De tels marquages, proprement installés, peuvent remédier à certaines déficiences dans l'approche traditionnelle de l'éclairage de secours associé à la coupure de courant ou de l'obscurcissement des luminaires en hauteur à cause de la fumée. Pour obtenir le résultat voulu cependant, il est essentiel d'installer proprement les éléments photoluminescents de la signalisation.

Les systèmes de signalisation photoluminescents apparaissent comme un ajout rentable, voire un remplacement potentiel de l’éclairage de secours traditionnel. Les avantages sont notamment : aucune consommation d’énergie supplémentaire, pas de câblage supplémentaire, un entretien minime et une fiabilité totale s’ils sont bien installés. Le comportement des occupants, la vitesse de mouvement et l’évaluation subjective du matériau concordent pour nous permettre affirmer qu’une signalisation par matériau photoluminescent constituerait un ajout appréciable améliorant la sécurité des occupants en cas d’urgence ou d’incendie dans les immeubles de bureaux.

Evaluation of the effectiveness of different photoluminescent stairwell installations for the evacuation of office building occupants

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1 INTRODUCTION

This study is a collaborative effort between the National Research Council of Canada (NRC) and Public Works and Government Services Canada (PWGSC). The objective of the conducted study was to evaluate different installations of photoluminescent material (PLM) in stairwells of a highrise office building. This report documents the findings of the study.

1.1 Photoluminescent material

Photoluminescent material (PLM) is made of inorganic chemical compounds, referred to as photoluminescent pigment phosphors, encased in flexible or rigid strata or dispersed in a liquid such as paint [1]. The photoluminescent pigments consist of crystals of aggregated elements and other agents. The crystals are characterized as being photoluminescent – phosphorescent due to the excitation they undergo when exposed to a light source and their ability to store light photons, consequently showing luminescence over time. After the crystals have been charged by a light source, the light can be cut off and the crystals will remain excited and continue to emit light. As time progresses, the energy stored in the crystals will continuously exhaust until its complete depletion; the material can then be recharged by re-exposing it to light. Certain terms and units are commonly used to characterize the material. Luminance is the luminous intensity or the optical brightness of a planar light source. It is measured for photoluminescent material in millicandelas (mcd) per unit area; square meters in metric units. The footlambert (fL) is also in common use (1 fL = 3.426 cd/m^2) in non-metric units. Illuminance is the amount of light that reaches a surface. It is measured in lumens per square foot (foot-candles) or lumens per square meter (lux or lx) [2]. One lumen per square meter is one lux. One lumen per square foot is one foot-candle. A lumen is a unit that measures the number of photons a light source emits. It is the amount of light produced by a light source [3].

Photoluminescent material has many applications. In fire safety, the most promising uses are for safety markings such as exit signs, directional signage, door markings, path markings, obstruction identification and other components that compose a safety wayguidance system. In black-out situations resulting from power failures or fires, photoluminescent safety markings in the form of paint, lines and safety signs can aid evacuation by guiding and directing people to safer locations; see Figure 1.

Photoluminescent material was first used in remote locations such as military installations, ships, offshore oil platforms, aircraft and trains, tunnels and the underground power plant industry.

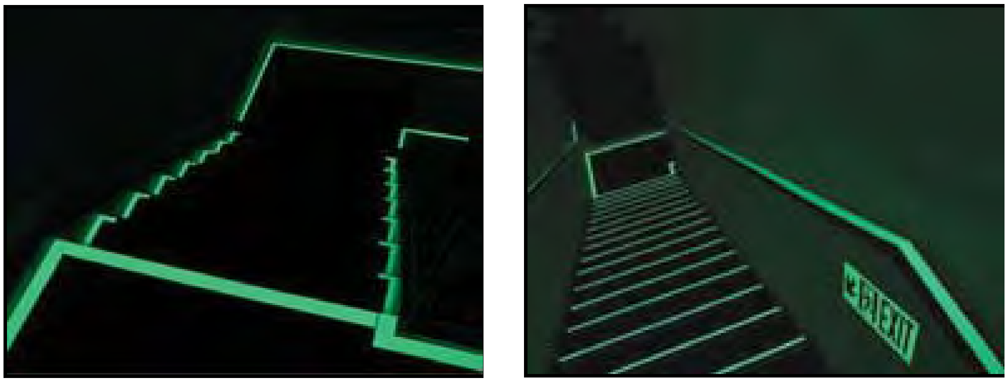

Figure 1: Examples of photoluminescent safety marking in stairwells [4]

1.2 Summary literature review

In 2006, a literature review was prepared by NRC to look into research studies that have been carried out on the use of photoluminescent material as a safety wayguidance system, see [5]. Experimental procedures and methodologies were highlighted as well as findings and conclusions attained by these early studies in order to better understand photoluminescent material and its applications. Below is a summary of this review.

Preliminary studies on photoluminescent material were initiated in the middle of the 1970s to present the idea of using photoluminescent safety markings as an aid or an alternative to emergency lighting for escape route lighting. However, the phosphorescent pigments existing at the time were weak photon absorbers, and the material had to be supported by an electrical power supply. With the advent of more persistent pigments such as improved zinc sulphide crystals in the early 1980s, studies began comparing different types of emergency lighting with photoluminescent systems. Comparative studies found that photoluminescent material could provide an acceptable alternative to conventional emergency lighting. Findings also indicated that the material provided a high level of performance when installed in stairwells. It was also found that low-level lighting wayguidance systems performed better than conventional emergency lighting. Studies with smoke concluded that the continuity of information of photoluminescent lines ensured an uninterrupted visual reinforcement, which provided a significant advantage over conventional emergency lighting, which became obscured by the smoke. Other advantages of the material were its easy installation in new or existing buildings, its cost-effectiveness and its low maintenance. Conversely, studies found that the disadvantage with the material was its relatively low visibility compared to lit systems.

In 1997, PWGSC and NRC collaborated on an initial project assessing the use of photoluminescent material to support office building occupant evacuation. The results revealed that 70% of the evacuees assessed the system tested as ‘very good’ or ‘acceptable’. Speeds of movement in stairwells were comparable in the stairwell equipped with PLM to the stairwell with full lighting [6]. Another study conducted by NRC under contract showed that in high-density smoke, the conventional overhead emergency lighting system was completely obscured while the PLM low-level marking system was still visible. The PLM used in these early studies was made of zinc sulphide pigments, which have since been replaced by alkaline earth aluminate-based materials (usually strontium), which have the ability to glow stronger and longer.

Following the bombing at the World Trade Center in 1993, where several thousands of office workers had to evacuate in total darkness, a PLM wayguidance system was installed in all the stairwells of the complex. This installation proved invaluable during the September 11, 2001 attacks. Although the lighting remained operative in most areas of the towers, 33% of Tower 1 and 17% of Tower 2 survivors stated being helped by the PLM marking in their movement to safety [7]. Renovations to the Pentagon following the September 11, 2001 attack included the addition of a PLM wayguidance system in corridors and stairs, while the United Nations installed such a system in 2003. New York City recognized as a result of the events of September 11, 2001, and the blackout of August 2003, that a PLM wayguidance system is an essential component to ensure occupant safety in highrise structures. Consequently, on May 31, 2005 New York City passed Local Law 26: "Photoluminescent low-level exit path markings" [8], which requires all existing or new highrise office buildings in New York City to install a PLM wayguidance system by July 2006. Other building codes are also in the process of adopting measures to use photoluminescent safety markings as a means of better defining escape routes and this technology will continue to be developed and used.

1.3 Rationale for further studies

Lessons learned from past tragedies and factual benefits of PLM wayguidance systems have led to the development of requirements, product technical standards and installation guides. For instance, New York City Local Law 26 [8], ISO 16069 [9] and ASTM 2030-04 [10] are installation standards. However, none of these installation standards have ever been tested with human subjects during an evacuation. The specifications of the existing standards are the best judgements from the standards committee members. Each standard proposes different installation set-ups with specific width of PLM on steps, walls, floors or handrails. However, it is not known if the installations proposed would be sufficient to guide occupants during an evacuation. Also, it is not known if the installations proposed are excessive, and are costing more than is needed.

Although international standards exist to regulate the material's usage, there are few research projects that have studied the performance of PLM systems in building evacuations. So far, only one study has installed the material and evaluated its performance in an office building. Therefore it can be argued that insufficient research has been conducted to fairly assess the material, which has changed since that initial study. Further research on photoluminescent material should consider meeting an actual standard to be more practical and equitable. Also, in most studies, the material was compared to electrically powered lighting to assess visibility. It is argued that this comparison is not useful, as the principal benefit of photoluminescent material is to provide continuous wayfinding information along an escape route; therefore, this system may not need to be as bright as electrically powered illumination systems to provide the appropriate support to evacuating occupants.

Newer and brighter photoluminescent materials with pigments based on alkaline earth aluminates such as strontium aluminates have not yet been studied to assess their performance in emergency egress situations. These new materials have great potential in supporting the safe evacuation of building occupants as they glow stronger and for a longer time compared to the old technology. It is concluded that there is more research needed on photoluminescent material for use as a safety wayguidance system to properly assess its current stage of technological development.

In Canada, the potential benefits of this new technology are just starting to be realized. PWGSC and NRC, as leaders in innovative technologies to ensure a sustainable and safe built environment for Canadians, would like to develop a set of guidelines which can be used to identify the installation of a PLM wayguidance system that would be the most efficient and cost-effective for office buildings. In order to develop such guidelines, data is needed on the effectiveness of different types of installation. The experimental study reported here was aimed at providing this essential information.

2 STUDY OBJECTIVES

The review of the PLM technology and its applications has led PWGSC to make three main recommendations. Firstly, PLM signage and wayguidance systems have a unique potential for buildings as an effective and sustainable wayguidance system to enhance the security of occupants during building evacuation. Secondly, further research and field tests are required to assess the effectiveness of the PLM wayguidance system under evacuation conditions. Thirdly, in order to ensure that the technology is used properly, a methodology for the installation of PLM wayguidance systems should be developed.

The project developed by NRC has three main objectives:

1. To assess the effectiveness of 3 stairwell installations of a PLM wayguidance system in an office building environment;
2. To compare the effectiveness of a PLM wayguidance system to an environment under emergency lighting condition; and
3. To develop, based on the research results, a set of guidelines for the installation of a PLM wayguidance system for PWGSC and Government of Canada office buildings.

Objectives 1 and 2 were pursued during an experiment involving a full building evacuation with human subjects. The findings of this experiment are reported herein.

This experiment tested the following hypotheses:

1. Occupants will be more efficient in terms of movement time with one of the three installations of the PLM wayguidance system.
2. Installations identifying each step of the stairwell with PLM will receive a higher level of appreciation by occupants.
3. Occupants who will evacuate in the PLM stairwell will be as fast as occupants travelling under emergency lighting.

The current study is a field study; it relies on an ecological representation of “real people” who participate in a “real evacuation drill” to obtain data. Contrary to laboratory studies, there is limited control over how many participants will use each stairwell and if they will travel the full height of the building. However, such a field study is a true representation of reality, so the findings can be easily generalized to other similar occupants and buildings thus offering strong internal and external validity.

3 METHODOLOGY

The best way to study how people respond to PLM installations is to measure people's movement time, ability to find destinations and to obtain people's appreciation of the installation. In this instance, these questions were addressed through the study of an evacuation drill in a real office setting at the C.D. Howe building, located at 235 Queen Street, Ottawa, ON, Canada.

3.1 Building Studied

Several buildings could have been selected for this study. A set of criteria were established to identify the building most suitable to meet the study objectives:

- Federal office building
- Minimum of 6-storeys
- Minimum of 4 identical windowless stairwells
- Minimum of 50 occupants on each floor
- Support by the building management as well as the building Fire Safety Organisation was required to successfully conduct this study

The C.D. Howe building at 235 Queen Street, Ottawa, met perfectly the study criteria; see Figure 2. The building, built in 1977, has a glazed rectangular shape that fills an entire city block in downtown Ottawa.

Figure 2: Picture of the C.D. Howe building

The building has 11 floors of office space plus 2 storeys of commercial space, making a total of 13 storeys of building height to evacuate down to street level (there is also one storey of commercial floor underground, a basement level and a 3-storey parking garage with designated stairwells going up to the street level separated from the tower stairwells; these lower floors were not studied). Each office floor area is approximately 8000 m^2 with a mix of closed and open plan offices, housing around 400 workers per floor. The building has 6 geometrically identical stairwells among which 4 are windowless; see Figure 3. The stairwell width is 1.1 m, with a square handrail on both sides. All stairwells discharge directly to the street. Several federal government offices occupy the C.D. Howe building among which are Industry Canada, the Office of the Auditor General, the Canadian Space Agency and Public Works and Government Services Canada. Excellent support was obtained to conduct the field study.

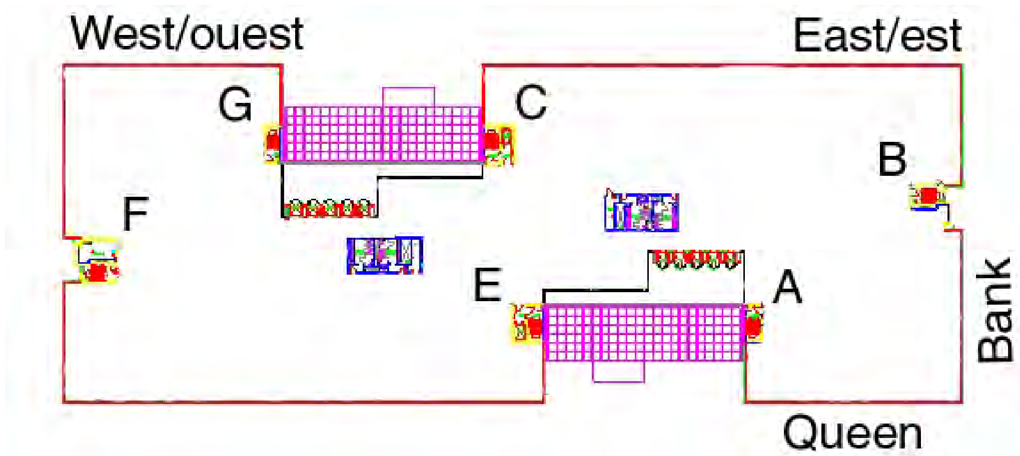

Figure 3: Stairwell locations

The building has a central fire alarm bell system with heat/smoke detectors and pull-stations. The sound of the alarm is a ringing bell with sounders scattered throughout the office floors. The building is not equipped with the temporal-three alarm signal, strobe alarm or voice communication. The building is fully sprinklered.

3.2 Participants' Selection

Although the C.D. Howe building is open to the public for the 3 commercial floors, access to the two banks of 5 glazed-elevators is restricted to staff working in the building who wear their magnetic ID card; see Figure 4. Security officers are meticulously ensuring at all times that nobody without proper identification is admitted in elevators leading to the office floors.

The subjects of this study were the employees working at the C.D. Howe Building, although a few visitors to the office floors or shoppers in the commercial level might have been involved. It is expected that around 4,000 employees could be in the building during working hours. This large number of occupants was interesting for this study to allow for measurement of the occupants speed of movement under crowd condition, which is representative of a realistic office building evacuation.

It is a requirement of the Canadian Occupational Safety and Health (COSH) regulations that all federal employees *"shall be instructed and trained in the procedures to be followed in the event of an emergency and the location, use and operation of fire protection equipment"* and that *"At least one evacuation drill involving all occupants shall be conducted annually in all Government of Canada occupied areas of buildings."* [11]. In concordance with COSH regulations, all occupants of the C.D. Howe building are expected to evacuate when the fire alarm is activated. Consequently, whoever was in the building on the office floors at the time of the annual 2006 evacuation drill could become a subject of this study if they used one of the four studied stairwells.

Occupants of the building are typical office workers aged between 18 and 65 years of age with a mix of men and women. It was expected that some occupants could have limitations preventing them from participating in the evacuation drill. Most of these occupants with limitations were already identified and had received specific instructions to proceed to Stairwell C to be evacuated by the freight-elevator. Members of the Building Emergency Organization, assisted by the Floor Emergency Officers, provided support to evacuees in accordance with their Fire Safety Plan.

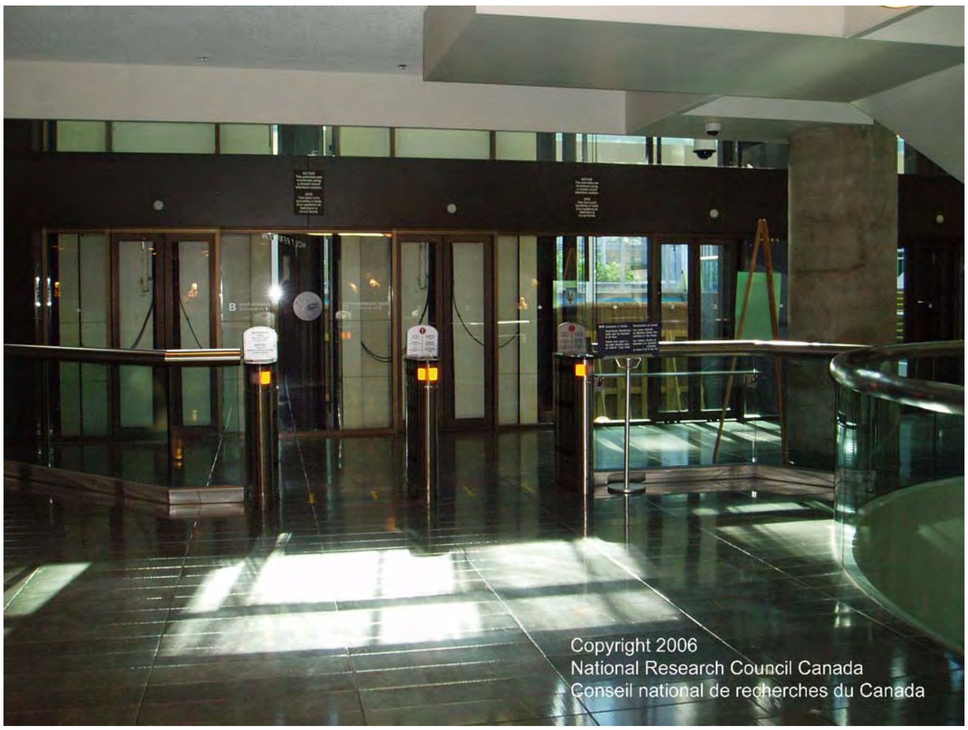

Figure 4: Elevator bank at the C.D. Howe building

3.3 Experimental Design

For practical reasons it was impossible to obtain signed consents from the potential participants to this study. It would have been impractical to have over 4,000 people sign a consent form moments before the experiment. Further, evacuation drills are usually unannounced, to better reflect the unexpected nature of emergencies; consequently, we could not provide information on the day and time of the drill for fear of altering the occupant response. Some suggested obtaining signed consent forms a few days prior to the study without specifying the time of the drill but building management voiced some concerns with the potential of people not showing up for work on that day. Even trickier with a signed consent form at the time of the drill, the research team would have had to withdraw occupants who had not signed and this would have been impossible. In order to somewhat alleviate the situation of not having a signed consent form, an information sheet was sent to all building employees a week prior to the experiment. This information sheet, see Appendix A, detailed the objectives of the study, the conditions under which occupants were to evacuate, the presence of video cameras, the fact that a questionnaire was going to be distributed to them and the contact number of the principal investigator to obtain further information. No mention was made of the date and time of the drill.

It is known that some building occupants may want to know the time of the drill to ensure that they do not plan an important meeting at the same time, or some might judge that they are unfit to participate. Contact information provided on the information sheet made it possible for occupants concerned to get in touch with the principal investigator.

One week prior to the evacuation drill, all office workers of the building received by e-mail the information sheet Appendix A. To increase the chance that building occupants would be aware of the upcoming studied drill, a summary of the information sheet was also posted in each elevator cabin of the building; see Figure 5. In the days following the e-mail and posting, the principal investigator received 5 requests for further information: 3 by e-mail and 2 by phone. Four of the requests were from occupants with disabilities who wanted to confirm that they were expected to follow the same procedure as in previous drills (the information sheet specified to "Follow the instructions, as you would normally do"). These occupants were directed to the Building Fire Emergency Organization who made arrangements in accordance with the COSH regulations. The fifth request for information was about precisions on the methodology used.

Figure 5: Information sheet posted in elevators

The annual evacuation drill, which is usually set during Fire Safety Week, was the pretext for the experiment. The evacuation drill was conducted on Thursday, October 5, 2006 at 10:35:23 a.m. As with all evacuation drills in that building, the building management team sounded the alarm. In accordance with training and the emergency procedure, all occupants, supported by the Floor Emergency Officers, started to move toward their designated stairwell. Addresses of offices and workstations in the building have a letter and a number; the letter identifies the zone where the person works and the name of the closest exit. For example, a person working in 348A would be on the third floor in zone A with the designated Stairwell A for evacuation.

As the alarm was activated at 10:35:23 a.m., the three stairwells with photoluminescent material, Stairwells A, E and G, were simultaneously put in total darkness. Stairwell C had two out of three double-tube fluorescent luminaires removed the day before the drill to put this stairwell under emergency lighting with an average level of lighting of 37 lux (see section 3.3.2 for emergency lighting measurements).

Video cameras, which were installed on the morning of the drill, were started 30 minutes before the alarm was activated and ran non-stop until after the drill was completed. The cameras were located inside the stairwells to capture the behaviour and speed of movement of evacuees. Sound was also recorded through the camera, which allowed for observation of the overall mood of those evacuating. Upon exiting the studied stairwells, evacuees were handed a questionnaire to fill out. Questionnaire drop boxes, specifically marked, were positioned at the two elevator lobbies on the ground floor immediately after the drill.

During the drill, there were a few members of the research team, observers and firefighters who descended the studied stairwells and were prepared to provide assistance to occupants. The Building Fire Emergency Organization with officers and wardens were also assisting occupants throughout the evacuation. Furthermore, the Ottawa Fire Department was on location inside the building and outside. The Ottawa Police Department temporarily closed Queen Street between Kent and Bank to ensure that evacuees spilling out onto Queen Street were in no danger from the traffic. The Ottawa paramedics used the drill as a training opportunity, and attended the building with their material and shelter bus; see Figure 6.

Following the drill, occupants received an e-mail providing feedback on their overall response during the evacuation drill (Appendix A). In essence, the evacuation went very smoothly; no incidents were reported. Overall the Building Emergency Organization assessed that the evacuation was completed in 12 minutes, which is an excellent time compared to previous drills, which usually took around 14 minutes. The “all clear” was given by the Ottawa Fire Service and the Building Fire Emergency Organization and all occupants were allowed to return into the building; see Figure 7.

In the days following the drill, 5 comments from evacuees were received by e-mail; one commented on the lack of lighting in Stairwell C, two commented on the difficulty to see ahead in the crowd and the fact that people were bumping the ones in front of them, one commented that the alarm was not audible in their area and one mentioned that the Floor Emergency Officers should have vests with photoluminescent material to be noticeable in the dark.

Figure 6: Ottawa paramedics' shelter bus on location

Figure 7: Evacuees returning to the building after the evacuation

3.3.1 Material installations

The three material suppliers, Prolink North America, Jessup Manufacturing Company and Jalite USA, provided and installed the photoluminescent marking and signs for this study in accordance with the research team requirements. All materials used had received certification in accordance with the New York City Building Code Local Law 26, Reference Standard 6-1 2004, Paragraph 1.0 [8]. Consequently the material brightness rating in the laboratory had a minimum of 30.0 mcd/m^2 at 10 minutes, 7.0 mdc/m^2 at 60 minutes and 5.0 mcd/m^2 at 90 minutes. Examples of MEA certifications provided by the manufacturers are found in Appendix B.

Three stairwells were equipped with a photoluminescent material installation, comprising the marking of 7 elements, see Figure 8.

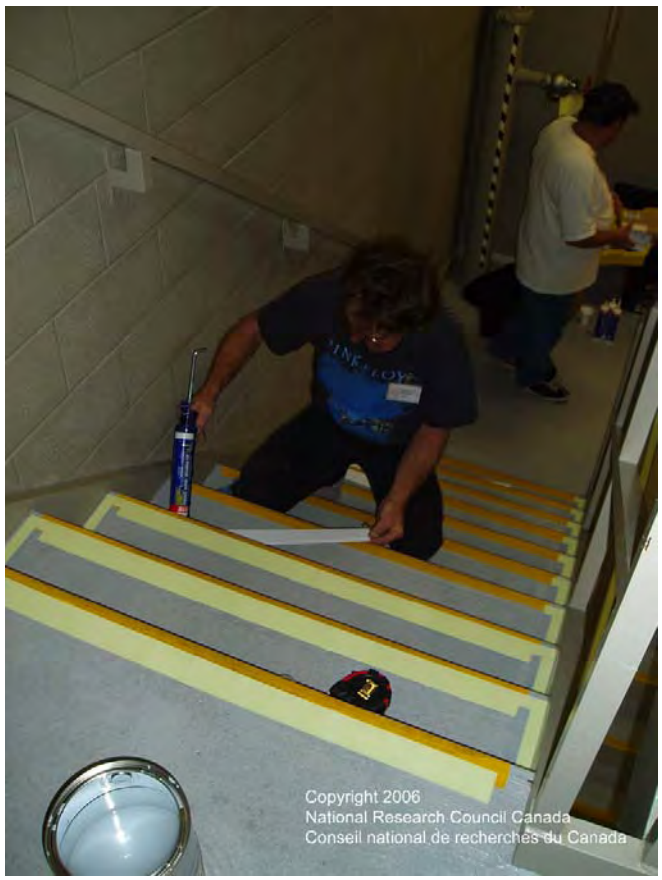

Figure 8: Stairwell installations

Table 1 summarizes the elements that were installed in the tested stairwells. Signs and markings were essentially the same for the three PLM stairwells except for the markings on the steps. Stairwell A had “L” markers at the edge of each step representing an installation similar to New York City Local Law 26 for existing buildings, except that marking on the handrail was added, which is not a requirement in New York City. Stairwell E represented New York City requirements for new buildings, with continuous marking of 1” width across each step and handrail marking. The installation in Stairwell G combined the “L” shaped markers, a 2” wide line across each step, and a 2” wide demarcation line around the landing, which was a suggestion made by the executive architect of the New York City Department of Buildings who is reviewing current installations. The 4th stairwell studied, Stairwell C, had no photoluminescent marking but had lighting reduced to an average level of 37 lux (see section 3.3.2 for emergency lighting measurements), as if the stairwell was under emergency lighting. This stairwell was the control stairwell. Figure 9 presents the 4 studied stairwells as experienced by the evacuees.

The PLM dots placed in a semi-circle on the door landing that can be seen in each stairwell in Figure 9 were not part of the study. These markings were installed by the building management a few years ago to minimize the problem of descending occupants being hit by the door being unexpectedly opened by evacuees entering the stairwell during an evacuation.

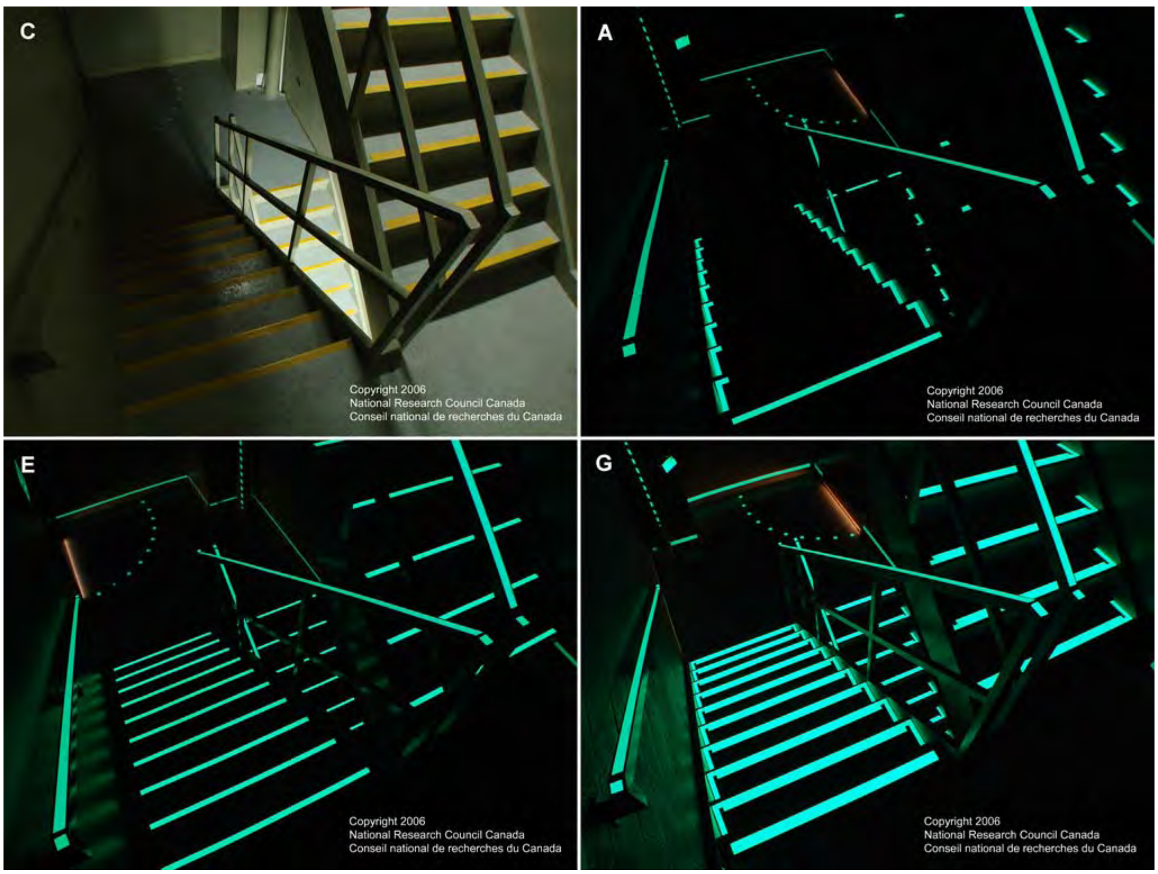

Figure 9: Four studied stairwell installations

Installation of the material took place in the two weeks prior to the evacuation drill. The step and handrail installations were conducted mainly over the weekend so occupants were not disturbed. Two days before the drill, the building management was invited to experience the stairwells in complete darkness during a pre-test conducted in the evening. Management was a little concerned with the safety of Stairwell A; they felt that the “L” markers on the outer edges of the steps were not making the steps readily perceivable, particularly the last step before the landing. Stairwells E and G in comparison appeared to them to be much more superior, with markings across each step. The decision was made to have some members of management, the research team and the Ottawa Fire Service to descend Stairwell A during the drill in order to provide support to occupants if needed.

3.3.2 Measurement of emergency lighting

Normally, the emergency lighting in the stairwells of the C.D. Howe building would be full lighting, fed by generators. However, the current code accepts that the emergency lighting be reduced to as low as 10 lux, see [11]. So for this study, in order to convert Stairwell C into emergency lighting, the regular lighting level was reduced.

Ambient light levels provided by the reduced or emergency lighting system were measured in Stairwell C. The reduced or emergency lighting system was activated in the stairwell by reducing the regular lighting system by 2/3, i.e., keeping the two-lamp luminaires (Brand: fluorescent Philips lamps with ALTO lamp technology) on the 1st landing and removing them on every 2nd and 3rd landings. For the building studied, the lighting was removed from 8 door landings and kept for the remaining 5 door landings.

Table 1: Experimental installation of the stairwells

Marking	Stairwell A	Stairwell E	Stairwell G	Stairwell C (Control)
Steps	L marker 1”	Marking across each step 1” Anti-slip strip 1”	Marking across each step 2” plus L marker Anti-slip strip 1”	No marking
Handrail	Continuous 1”	Continuous 1”	Continuous 1”	No marking
Demarcation on landing	Continuous 1”	Continuous 1”	Continuous 2”	No marking
Directional sign “running-man”	On each landing	On each landing	On each landing	No marking
Obstruction	Zebra marking and tag	Zebra marking and tag	Zebra marking and tag	No marking
Final Door	Around door 1” and sign “Final”	Around door 1” and sign “Final”	Around door 2” and sign “Final”	No marking
Additional signs	See Appendix E	See Appendix E	See Appendix E	No marking
Lighting	No	No	No	Average of 37 lux [11]

Light levels were measured in Stairwell C, 1 m above floor level, using a calibrated illuminance meter (the instrument used was LI-COR LI-250 Light Meter with a LI-210SA Photometric Sensor and a 2-m cord). The meter was read 2 meters away and below the plane of the sensor to ensure that the sensor could not "see" the person reading the meter. A total of 150 readings were collected or 12 measurements per floor as follows: three readings were collected at the door landing and the mid-landing, and one each at the top, middle and last step of each staircase; see Figure 10. Stairwell C was windowless, so no daylight supplemented the reduced electric lighting. We should mention that COSH [11] requires only two measurements in an area. A summary describing the illuminance measurements is presented in Table 2. The table shows some differences between the different floors.

COSH [11] 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)). The average requirement of at least 10 lux was achieved, as the average of the measurements was 37 lux. However, the emergency lighting provided did not meet the minimum requirement of at least 3.3 lux at one third of the points measured (49 out of 150 readings).

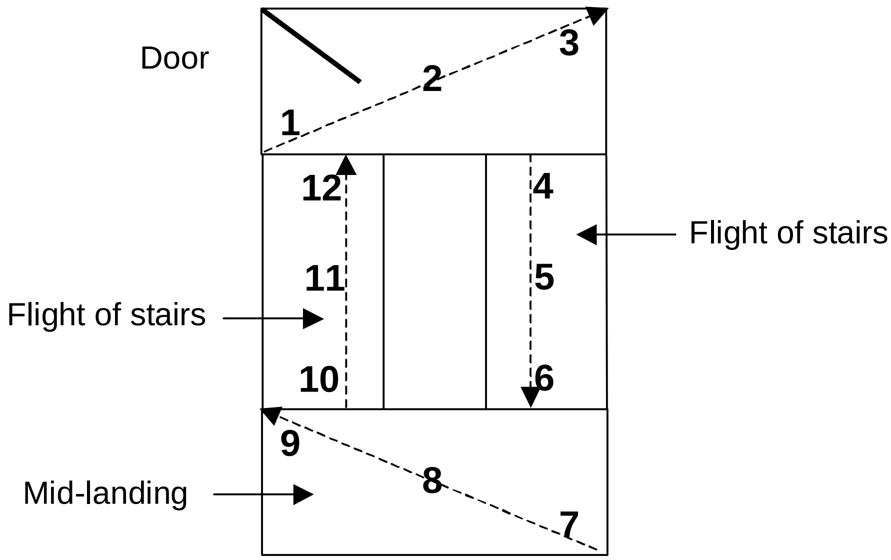

Figure 10: Staircase illuminance sampling locations

(A total of 12 readings were collected between each floor as follows: three readings were collected at the door landing (1-3) and three readings at the landing between each floor (7-9), and one reading in the middle at each of the top, middle and last step on flight of stairs (4-6 and 10-12))

Table 2: Illuminance measurements for Stairwell C emergency lighting

Floor number	Point of measurement												Average
	1	2	3	4	5	6	7	8	9	10	11	12	
C	12.9	8.8	7.6	7.1	2.5	0.9							6.6
1	100.8	135.3	91.3	116.0	48.8	22.6	18.6	14.0	82.9	84.8	36.5	15.9	64.0
2	16.1	8.0	2.6	2.3	1.6	0.9	0.7	2.3	3.1	3.0	49.9	102.1	16.1
3	1.1	1.4	0.9	4.7	48.8	74.0	72.6	90.1	68.3	75.9	32.6	17.1	40.6
4	84.2	111.7	74.1	96.6	40.3	22.2	15.8	11.2	2.5	3.4	1.8	1.2	38.8
5	21.1	10.3	3.3	3.1	2.0	1.0	1.0	2.0	2.8	2.8	53.6	95.4	16.5
6	1.0	1.5	1.5	4.8	64.7	96.1	101.1	123.9	89.7	98.5	39.8	22.0	53.7
7	59.5	77.8	49.7	63.9	25.7	14.4	10.3	7.5	1.8	2.2	1.4	1.1	26.3
8	21.5	10.2	3.2	3.3	1.8	0.9	0.7	1.7	2.5	2.6	37.8	64.5	12.6
9	1.0	1.5	1.5	3.4	57.0	98.6	102.4	127.0	94.1	99.0	43.1	22.9	54.3
10	78.5	109.1	70.7	106.0	41.7	21.9	16.2	13.8	2.5	3.2	2.1	1.3	38.9
11	7.1	2.8	1.5	3.4	3.3	1.4	0.8	3.3	3.1	3.4	49.4	88.2	14.0
Terrace	55.5	187.0	117.1	173.8	78.6	76.4	80.3	69.1	60.3	64.5	48.3	6.0	84.7

3.4 Data Gathering

The experimental design offered the advantage of comparing the speed of movement and occupant appreciation of three PLM stairwell installations, which could be compared to a stairwell with emergency lighting.

The size of the building and the large number of occupants provided a field study very representative of a highrise office evacuation. The simultaneous evacuation of the 13 floors allowed a dense crowd to form in the stairwells providing the most demanding stairwell conditions. The methodology of using video cameras to record movement and behaviour and a questionnaire to obtain feedback has been used in several prior studies providing excellent information.

3.4.1 Questionnaire

A questionnaire was handed to each evacuee upon exiting the building through Stairwells A, C, E and G: see Appendix C for the bilingual questionnaire. The questionnaire contained questions on the participant's characteristics, the evacuation drill experienced on that day, specific questions on the comfort and safety felt in the stairwell used and overall appreciation of the PLM wayguidance emergency evacuation systems.

3.4.2 Video cameras

Twenty-eight video cameras were used to gather data on movement time and behaviour of evacuees in the 4 stairwells studied. Cameras were positioned in each stairwell on floors 11, 9, 7, 5, 3, 1 and B or street level. For the stairwell with photoluminescent material, infrared cameras were used. The recordings allowed for precise measurement of the movement time, as well as providing information on the interaction between the evacuees and the system in place. The time at which each evacuee entered and exited the stairwells was captured. These recordings were used to obtain individual movement times and provided potential explanations for behaviour in the stairwell. Sound was also captured, which allowed for assessing the overall mood of the evacuees.

3.5 Evacuation Procedure for the C.D. Howe Building

Industry Canada has developed the Emergency Procedures for the C.D. Howe building. These procedures can be found in the Fire Safety Plan as well as on a CD that is used for training Floor Emergency Officers as well as occupants. The CD is distributed during training and the information is also available to building occupants through an intra-net website.

The emergency procedures are relatively simple. Upon hearing the sound of the fire alarm, which is emitted by vibrating bells, occupants should go to their designated stairwell and evacuate the building[2]. If they are away from their designated stairwell they should go to the nearest stairwell. If, during their evacuation in the stairs, occupants encounter smoke, they should re-enter the building on a crossover floor, which are located on the 4, 9 and T levels to proceed to an alternative stairwell. Occupants should follow instructions from the Floor Emergency Officers. Once outside the building, occupants should meet at an assembly area located 100 m away from the building. Occupants who have conditions that would prevent them from evacuating the building

[2] Since the studied evacuation of October 5, 2006 the fire alarm bells have been changed to an alarm emitted by speakers.

independently should contact a member of the Building Emergency Organization to make alternative arrangements.

Typically the Building Emergency Organization holds an evacuation drill once a year for all building occupants. Training is also organized periodically with Floor Emergency Officers. In the past years, full building evacuations have also taken place 2 or 3 times every year due to accidental activation of the system (for example, a contractor activated the system by cutting a wrong wire during the refurbishment of a floor).

4 FIELD STUDY RESULTS

The evacuation drill unfolded as planned without any unexpected incident to report. The drill was on Thursday, October 5, 2006 at 10:35 a.m. It was mainly clear at the time of the evacuation with an outside temperature of about 8°C.

Data from the questionnaires and the video recordings were analyzed using SPSS 13.0. For all statistical tests, the level of significance is $\alpha < 0.05$. Results are presented with the test value, degree of freedom if applicable between parenthesis and significance; non-significant results are termed *ns*.

4.1 Questionnaire Results

Two members of the research team were posted at the outside exit of each of the studied stairwells for the duration of the evacuation drill. They distributed a questionnaire to each of the exiting occupants. A very large majority of the evacuees took the questionnaire distributed. The questionnaires were returned in well-identified red boxes placed in the building at the entrance of the two elevator banks that all occupants had to use. All the questionnaires analyzed were returned in the next 24 hours. Questionnaire data was coded using the developed Code Book; see Appendix D.

4.1.1 Respondent Profile

In total, 489 questionnaires were returned from the 1191 evacuees observed on the video recordings. Assuming that this sample represents a random selection of the building evacuees, it is calculated that the questionnaire results can be generalized to the entire building population with a confidence level of 95% and a potential variation of 3 points. For example, take the question, “did you evacuate this building before,” which had 75% of respondents saying “yes.” This percentage could have varied from 72% to 78% if all the evacuees had filled out a questionnaire.

Among the returned questionnaires, 130 or 27% were from respondents who used Stairwell A, 132 or 27% were from Stairwell E, 128 or 26% were from Stairwell G, and 99 or 20% were from Stairwell C. As presented in Table 3, the sample of returned questionnaires represents a return rate of over 40%, which is good for this type of study [12]. More importantly, this is a good distribution of the returned questionnaires among the 4 studied stairwells. A statistical analysis on the number of observed evacuees counted through the analysis of the video recording and the number of returned questionnaires show that there are no statistical differences between the three photoluminescent stairwells ($\chi^2 = 5.757(3)$, ns). Consequently, it is possible to compare the tested stairwells in confidence knowing that the number of evacuees or returned questionnaires should have no effect on the other factors analyzed.

Table 3: Returned questionnaires

Stairwell used	Returned questionnaire	Evacuees observed	Return percent
A	130	345	38%
E	132	287	46%
G	128	281	46%
C	99	278	36%
Total	**489**	**1191**	**41%**

Responses to the questionnaire were obtained from occupants who work on every one of the 11 office floors of the buildings of both building towers as well as the sub-level floors (S and M on Figure 11) except for floor 5 West which was empty for refurbishment at the time of the drill. This distribution provides a good overview of the situation on every floor, as presented in Figure 11. About half the respondents (49%) worked in the building's East Tower and the other half came from the West Tower (51%). Most respondents had prior experience with the building as 75% of them had participated in an evacuation of this building in the past.

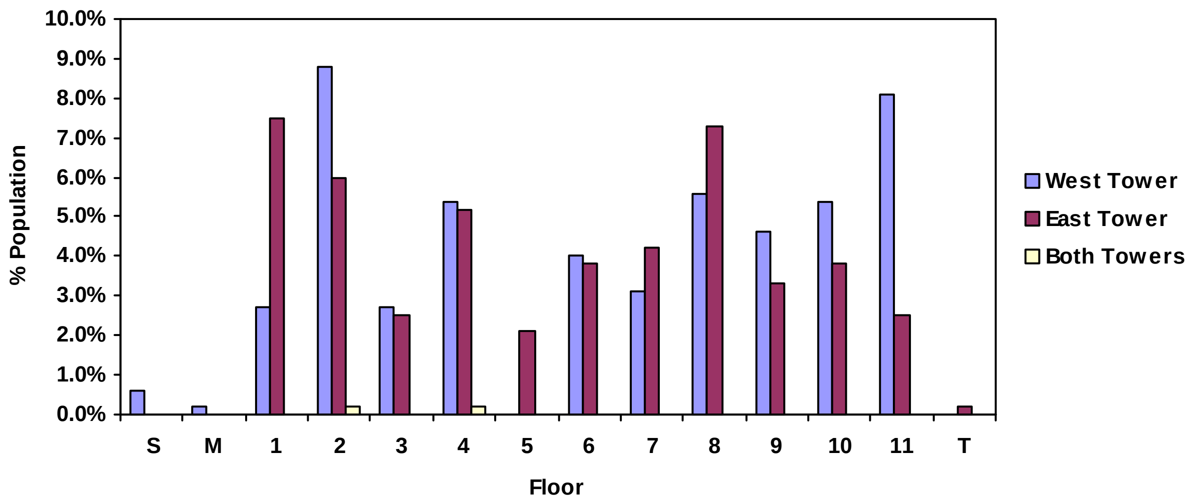

Figure 11: Respondents' working location

Of the 421 respondents, 65% were female and 35% were male. The age distribution of the respondents demonstrates a rather mature crowd. Figure 12 shows the distribution of the gender within each age group. A significant difference was found regarding gender and age, as men were relatively older then women (χ^2= 9.820(3), p< 0.020).

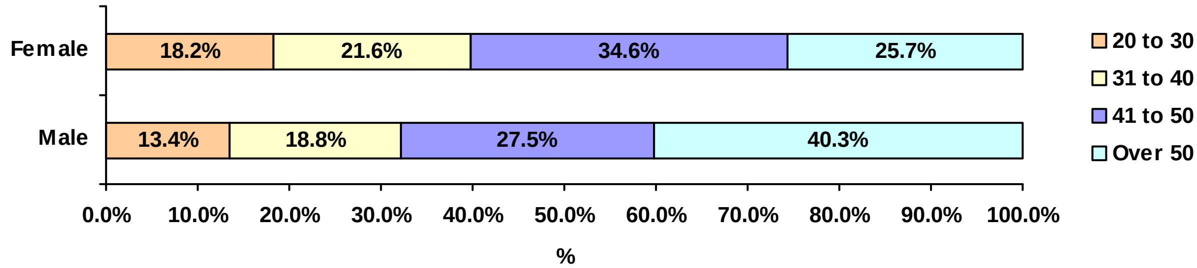

Figure 12: Gender and age of respondents

An important occupant characteristic that can have an impact on an evacuation is the presence of people with limitations. Among the respondents, 41 individuals or 8% stated that they had a form of limitation that could impede their evacuation from the C.D. Howe building. Nevertheless, all these respondents evacuated the building using a stairwell since they filled out a questionnaire. It is known that some additional individuals with limitations were present in the building; however, since they were evacuated by the freight elevator close to Stairwell C, these occupants did not fill out a questionnaire.

The questionnaire provided 8 categories of limitation to choose from as presented in Table 4, the category “others” refers to hand-written comments; one added claustrophobia and another one pregnancy. Out of the 41 respondents who identified a limitation 4 had multiple limitations all involving being overweight and other conditions.

Among the respondents the most prevalent condition reported was asthma at 26%, followed by being overweight at 23% and arthritis at 17%. The other limitations listed each obtained 6%. It is important mentioning again that occupants with a serious mobility limitation who could not use the stairwells to evacuate are not part of this sample.

Table 4: Limitation that could impede evacuation

Limitations	Frequency	Valid percent
Asthma	12	26%
Overweight	11	23%
Arthritis	8	17%
Heart condition	3	6%
Vision impairment	3	6%
Injury	3	6%
Mobility impairment	3	6%
Hearing impairment	3	6%
Others	2	4%
Total	**48**	**100%**

Respondents who reported a disability were well distributed in the studied stairwells; 8 used Stairwell A and 11 used each of the other stairwells E, G and C. No significant differences were found for the respondents with limitations with respect to the rest of the respondents in terms of initial response time to start the drill, appreciation of the stairwells and overall evacuation time.

4.1.2 Alarm and initial response

Among the respondents, 99% heard the fire alarm at the time of the evacuation. Only 3 respondents stated that they did not hear the alarm in their area. These occupants were located on floors 2, 5 and 6 of the East tower. In fact, these occupants did not hear the alarm in the initial moment but somebody rapidly came to warn them from another room or suite. None of them mentioned having a hearing limitation.

Of those who commented on the sound level of the alarm 76% found the alarm “loud enough”, however 21% or 102 respondents felt that the alarm was “too loud” and 3% or 14 respondents found the alarm to be “too quiet”. Among the 3 respondents mentioning a hearing impairment, 2 found the alarm “too loud” and 1 found it “loud enough”. Respondents of both genders provided appreciation of the alarm level in exactly the same proportion so no gender difference was found ($\chi^2 = 0.122(2)$, ns).

Respondents on every floor in both building towers complained that the alarm was “too loud”, except on floor 5 East which was empty for renovations at the time of the evacuation. For the 14 respondents who mentioned that the alarm was “too quiet” they were dispersed in the West Tower on floors B, 8, and 10, and in the East Tower on floors 6, 8, 9, 10 and 11.

At the time of the fire alarm, 53% of the respondents were in the West Tower of the building and 47% in the East Tower. When the evacuation drill started, the respondents were well distributed throughout the building as presented in Table 5 for the floor location when the alarm was heard.

Table 5: Floor location of respondents at the sound of the fire alarm

Floor location	Frequency	Valid percent
Terrace	1	0.2
11	51	12.3
10	34	8.2
9	33	7.9
8	50	12.0
7	32	7.7
6	32	7.7
5	6	1.5
4	49	11.8
3	20	4.8
2	60	14.4
1	45	10.8
B (exit to street)	1	0.2
Sub-level	2	0.5
Total	**416**	**100**

When the alarm sounded 81% of the questionnaire respondents were at their desks, others were in other locations such as meeting rooms, corridors and washrooms.

Respondents were asked if they completed any of a list of 8 actions before starting their evacuation. As shown in Table 6, the most prevalent action before starting evacuation was for 335 or 69% of the respondents to "get dressed". The other three most likely actions were to "gather valuables" with 54%, "secure files or information" 45%, and "follow warden's instructions" 43%. Interestingly, 14 respondents or 3% "continued working" after hearing the fire alarm. Men and women accomplished these different actions in the same proportion, except that significantly more women took the time to "gather valuables", such as their purse, (χ^2= 40.493(1), p< 0.00) and "follow warden's instructions" (χ^2= 6.218(1), p< 0.013). There was a significant difference between age groups for "seeking more information" since respondents in the age groups 20-30 and 50 and older were more likely to seek information (χ^2= 8.605(3), p< 0.035). Further, respondents 50 and older were more likely to take the time to "secure file or information" compare to younger respondents (χ^2= 10.576(3), p< 0.014).

Table 6: Action performed before starting evacuation

Action	Frequency	Percent
Get dressed	335	68.5
Gather valuables	265	54.2
Secure files or information	222	45.4
Follow warden's instructions	208	42.5
Return to office	75	15.3
Discuss with a colleague	56	11.5
Seek more information	23	4.7
Continue working	14	2.9

Building occupants could select among 6 stairwells to evacuate the building. Questionnaires were distributed only at the exits of the 4 studied stairwells. Each building occupant has a designated stairwell, which is usually the closest to each employee's workstation. During this evacuation 95% of the respondents reported using their designated stairwell and it was the closest exit stairwell for 92% of them. There were no statistical differences between gender or age and the stairwell used.

4.1.3 Evacuation times

Respondents were asked to estimate how much time they spent from the time the evacuation drill started to the time they decided to leave their floor. As presented in Table 7 and Figure 13, an overall 46% reported starting to leave in less than 1 minute, which is very good. However, some 29% decided to leave between 1 to 2 minutes, 14% decided to leave between 2 to 3 minutes, and 4% decided to leave between 3 to 4 minutes. Over 6%, or 31 respondents, took more than 4 minutes to start leaving, which is of concern. Respondents who took more than 4 minutes to start their evacuation were on every floor except the 5th floor. Interestingly, most of the late starters, 8 respondents, were on the top 11th floor, which should have been an incentive to start early as they had the longest travel distance to cover. Among the respondents who took over 4 minutes, 7 returned to their offices after hearing the alarm and completed tasks such as securing files and getting dressed. Another 6 continued working after hearing the fire alarm until they were told to leave. Finally, 6 of the late starters were Floor Emergency Officers who took time to ensure that their floor was empty before starting their evacuation.

Table 7: Time to start evacuation

Total time to decide to leave	Frequency	Valid percent
0:00-0:15	109	23.8
0:16-0:30	88	19.2
0:31-0:45	13	2.9
0:46-0:59	2	0.4
1:00-1:15	125	27.3
1:16-1:59	7	1.5
2:00-2:15	63	13.8
2:15-2:59	1	0.2
3:00-3:15	17	3.7
3:16-3:59	2	0.4
4:00-4:59	7	1.5
5 minutes or more	24	5.3
Total	**458**	**100**

Respondents have a tendency to roundup numbers when asked to estimate time as presented in Table 5. These numbers are estimations made by respondents, and they need to be contrasted with the data from the video recordings.

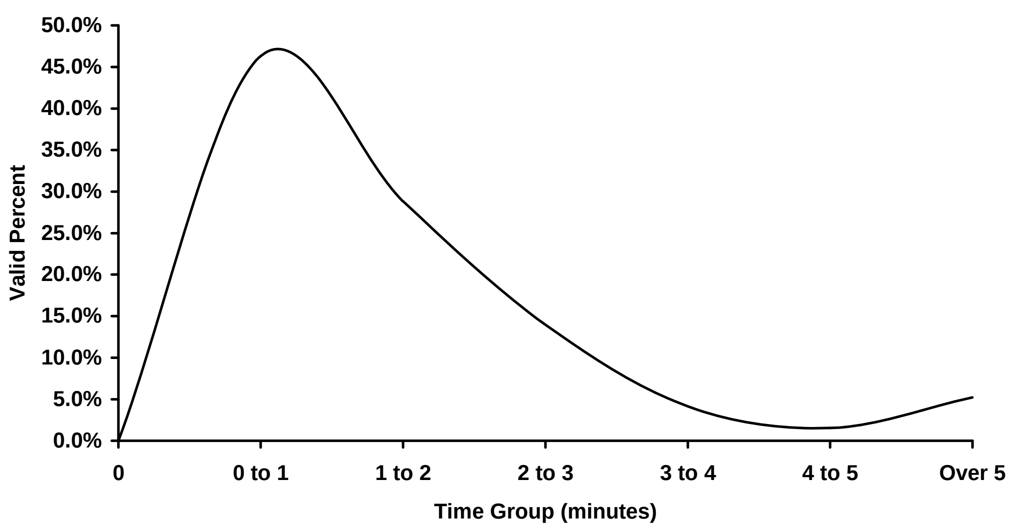

Figure 13: Distribution of time to start evacuation

Respondents were also asked to estimate how much time they spent overall to evacuate the building from the time the drill started to the time they reached the outside.
Table **8** and Figure 14 present the distribution of the estimated total time to evacuate.

Table 8: Total evacuation time

Time group	Count	Valid percent
0 to 1	12	2.9%
1 to 2	36	8.6%
2 to 3	49	11.7%
3 to 4	65	15.5%
4 to 5	33	7.8%
5 to 6	108	25.7%
6 to 7	15	3.6%
7 to 8	21	5.0%
8 to 9	22	5.2%
9 to 10	2	0.5%
10 to 11	44	10.5%
11 to 12	0	0.0%
12+	13	3.0%
Total	420	100%

Overall, 47% of the respondents estimated that they took less than 5 minutes to evacuate the building. Another 40% indicated that they took from 5 to 10 minutes, and 13% said that they took over 10 minutes to evacuate the building. The analysis of the video recordings provides exact times with which to compare these estimates.

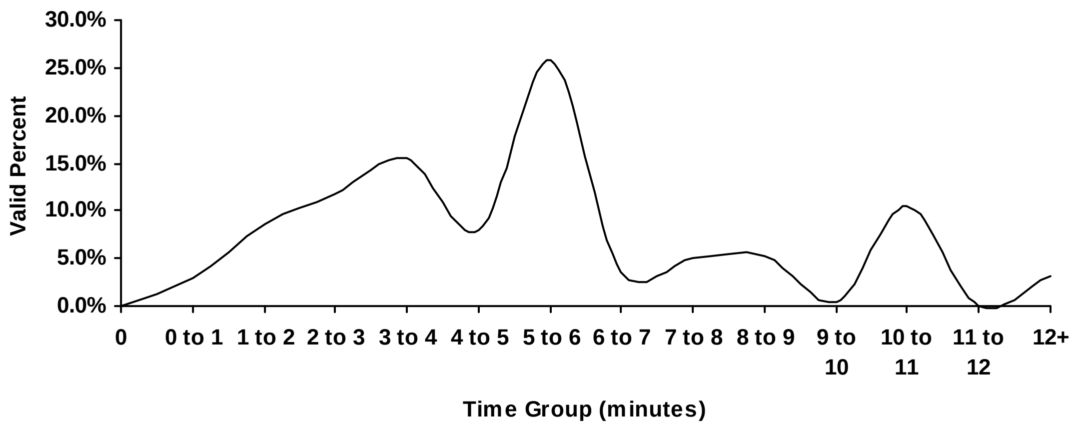

Figure 14: Distribution of time to evacuate

4.1.4 Stairwell Evacuation

Once occupants decided to evacuate their floor they moved toward the building's different stairwells. The questionnaire had several questions for respondents to express their experience descending one of the 4 studied stairwells. As presented in Table 9, out of 489 questionnaires returned, only 20% of the questionnaires were returned by Stairwell C users, compared to 26 to 27% from the other stairwells. A significant difference was found when comparing the number of returned questionnaires for all the stairwells (χ^2= 10.266(3), p< 0.016). It is because Stairwell C received significantly less returned questionnaires. When comparing the return of the 3 photoluminescent stairwells, no significant difference was found, consequently the questionnaire results for the 3 photoluminescent stairwells can be compared safely (χ^2= 5.757(3), ns). Although Stairwell C received significantly less questionnaires, its return rate of 36%, when considering that 99 people returned their questionnaires out of 278 occupants who were seen descending the stairwell, is still excellent. In this kind of study a return rate of 30% is usually considered acceptable [12]. Overall the number of questionnaires obtained by occupants who used each of the studied stairwells is sufficient to obtain a fair opinion of each stairwell.

Table 9: Number of respondents from each stairwell

Stairwell used	Respondent	Percent
A	130	27%
E	132	27%
G	128	26%
C	99	20%
Total	489	100%

No significant difference was found among stairwell users for gender (χ^2= 3.438(3), ns) or the age (χ^2 = 12.210(9), ns). Consequently similar proportions of men, ~ 35%, and women, ~ 65%, of the different age groups used the different stairwells; ~ 38% were between 20 and 40 years old and 64% were over 41 years old.

Question 15 of the questionnaire asked the respondents if they encountered any of 12 problems as they entered and negotiated the stairwells. Table 10 summarizes answers to each of these questions with the percentage of respondent who confirmed having experienced that problem for the 4 studied stairwells. The column entitled "Statistical difference" identifies a problem that was significantly more frequently identified by the users of that specific stairwell compared with the other stairwells.

No respondent mentioned furniture obstructing the entry to the stairwell. Less than a quarter of the respondents mentioned that crowding around the entry to the stairwell was a problem. The same proportion, approximately 22%, of the evacuees in the 4 studied stairwells encountered crowding around the entry. Only 2 respondents in Stairwell E and 2 in Stairwell C mentioned difficulty opening the exit stairwell door. Of these respondents who were in Stairwell E, one was a lady on floor 11 who felt the door was heavy to open, and another one was on the 9th floor. In Stairwell C, crowding on the 4th floor caused the difficulty opening the door for both respondents.

Difficulty entering the stairwell because too many people were coming down was felt as a problem by 23% in Stairwell A, 16% in Stairwell E, 20% in Stairwell G and 21% in Stairwell C. This problem in entering the stairwell because of crowding was similar in the 4 studied stairwells. Conversely, for occupants descending a stairwell, few identified as a problem occupants attempting to enter into the stairwell. Only around 10% of the respondents in each stairwell mentioned that problem. In the stairwells, finding the handrail didn't seem to be a problem as only 20 respondents overall mentioned that issue. It does not appear that finding the handrail was a problem in the 3 stairwells equipped with photoluminescent marking or in the stairwell with reduced lighting.

Table 10: Problems encountered in the stairwell

Problem	Percent of positive answer by stairwell				Stat. diff.
	A	E	G	C	
Furniture obstructed entry to staircase	-	-	-	-	
People crowding around the entry to the staircase	22%	20%	23%	21%	
Difficulty opening the staircase door	0	2%	0	2%	
Too many people were coming down the stairs to enter	23%	16%	20%	21%	
In the staircase, the opening of exit doors hampered movement	7%	8%	13%	10%	
Difficulty finding the handrail	6%	2%	7%	3%	
Difficulty seeing because of poor lighting	52%	52%	50%	45%	
People from lower floor were coming up	1%	1%	5%	1%	
People in front of you were moving too slowly	39%	57%	47%	38%	√
People were standing on the landing	14%	19%	14%	10%	
Difficulty finding the exit door at the base of the staircase	1%	2%	0	0	
Difficulty opening the exit door at the base of the staircase	1%	0	0	0	

The problem that was most frequently identified was the difficulty in seeing because of poor lighting. This problem was mentioned by 52% of the respondents from Stairwell A and as many in Stairwell E, 50% mentioned this problem in Stairwell G and 45% in Stairwell C. Overall there is no statistical difference between respondents in the different stairwells (χ^2= 1.437(3), ns). It can be concluded that around half the respondents felt that it was difficult to see around because of the poor lighting and this appreciation was comparable in the 4 studied stairwells.

Counterflow did not seem to be a problem in any of the stairwells studied. However, the second problem most frequently mentioned was that people in front of the descending evacuee were moving too slowly. This problem obtained a significant difference according to the stairwell used (χ^2= 10.669(3), p< 0.014). This difference is attributed to more respondents mentioning this problem in Stairwell E than in Stairwells A (χ^2=7.46, p<0.05) and C (χ^2=7.61, p<0.05). In Stairwell E, 57% of the respondents mentioned this problem. Stairwell G was statistically similar with 47% (χ^2=2.31, ns). The other two stairwells appear to systematically have been less of a problem with people moving too slowly as 39% of the respondents of Stairwell A mentioned that problem and 38% of Stairwell C.

Although the problem of having people standing on the landing seemed to be more prevalent in the three photoluminescent stairwells, no statistical difference was found for the 4 studied stairwells (χ^2= 3.971(3), ns). Around 14% of the respondents mentioned that people standing on the landing was a problem. It is not clear if the people standing were other occupants not moving or some of the Floor Emergency Officers who were holding the stairwell door open from within the stairwell.

Most respondents had no difficulty in finding and opening the exit door at the base since the last flight of stairs was fully lit; the stairwell led directly to the exit door and the exit door remained open automatically after the first evacuee opened it completely. Only one respondent from the 2nd floor in Stairwell A had problems with finding and opening the exit door. Another one had difficulty finding the exit door from the 1st floor in Stairwell E. No specific reasons were given.

Evacuees were asked, assuming they would have to evacuate under emergency lighting conditions, how they would judge the visibility in the stairwell they used. Respondents were provided with 4 qualifiers to select from: excellent, good, not very good and poor. Figure 15 shows the distribution of the answers obtained. There was no statistical difference found for the judgement of the visibility in the 4 stairwells (χ^2= 16.804(9), ns).

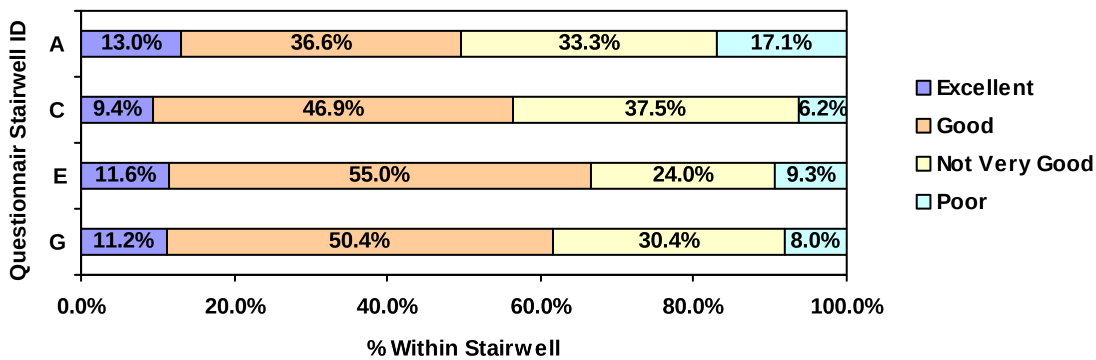

Figure 15: Judgement of the visibility in the stairwell used

For this question, no middle attribute was provided. This was to force respondents to give a positive or negative appreciation. Table 11 shows the same results as in Figure 15 but combining the judgements "excellent" and "good" versus "not very good" and "poor". As can be seen, Stairwells E and G received substantially more judgement that the visibility in these stairwells was good or excellent while Stairwells A and C received less positive judgement. In fact, for Stairwell A the opinions were perfectly divided as half the respondents considered that stairwell to have acceptable visibility while the other half considered the visibility to be poor.

Table 11: Judgement of the visibility in the stairwell used

Judgement	Percent of answer stairwell			
	A	E	G	C
Excellent and Good	50%	67%	62%	56%
Not very good and Poor	50%	33%	38%	44%
Total	100%	100%	100%	100%

Since the stairwell was fully lit below the 1st floor for the last 2 flights of stairs before the street exit, it is possible that the lasting impression of occupants came from these last two flights of stairs particularly for people who descended only a few floors under the test conditions. Judgement of visibility for the respondents who entered from the 3rd floor and lower and those who entered from the 4th floor and above was analyzed. Table 12 presents the judgement of the visibility according to the stairwell used for respondents who entered on a lower or upper floor.

Table 12: Judgement of the visibility for respondents from upper and lower floors

Stairwell	Judgement	Entered below 3rd floor	Entered from 4th floor and above
A	Excellent and Good	70%	40%
	Not very good and Poor	30%	60%
C	Excellent and Good	52%	57%
	Not very good and Poor	48%	43%
E	Excellent and Good	68%	67%
	Not very good and Poor	32%	33%
G	Excellent and Good	61%	61%
	Not very good and Poor	39%	39%

There was no statistical difference between respondents who entered on the lower floor for the different stairwells (χ^2= 10.134(9), ns). Overall 52% to 70% of these respondents judged the visibility as "excellent and good". There was however a difference among stairwells for respondents who entered from the upper floors (χ^2= 17.112(9), $p< 0.047$). It appears that 60% of the respondents from the upper floors in Stairwell A, judged the visibility as "not very good or poor" which is a significant difference from the respondents in the other stairwells, particularly respondents of Stairwell E (χ^2= 10.441, $p< 0.05$) who had a more positive judgement of the visibility. Except for Stairwell A, it seems that the fully lit last 2 flights of stairs did not have an influence on the judgement of the stairwell visibility. When comparing the respondents from lower and upper floors for each stairwell, the only significant difference found is in Stairwell A (χ^2= 15.317(3), $p< 0.002$). It seems that markedly respondents of Stairwell A who entered from an upper floor had a tendency to judge the visibility as "not very good and poor" which is probably due to the combination of the large number of people who were maintaining the stairwell doors open creating a glare in the stairs and the absence of photoluminescent marking across each step.

The evacuees were asked to provide their degree of agreement with 8 specific statements regarding wayguidance attributes that they experienced in the stairwell. The complete results to those questions are presented in Table 13.

Overall, the respondents of the 4 studied stairwells considered the handrail to be easy to find, with Stairwell E having a slightly larger number of respondents who strongly agree with this statement. In the 3 stairwells with photoluminescent markings, the same marking of 1" along the full length of the inner and outer handrails was provided, while there was no special marking in Stairwell C. Despite this difference over 90% of the respondents in all 4 stairwells "strongly agree" or "somewhat agree" that the handrail was easy to find. There was no statistical difference among the stairwells for finding the handrail (χ^2= 8.804(9), ns).

Table 13: Appreciation of wayguidance attributes in the stairwells

Statement	Percent of answer stairwell			
	A	E	G	C
The handrail was easy to find:				
Strongly agree	72%	85%	76%	75%
Somewhat agree	22%	12%	17%	19%
Somewhat disagree	5%	2%	4%	4%
Strongly disagree	1%	1%	3%	2%
The first step of each flight was easy to locate:				
Strongly agree	57%	74%	67%	55%
Somewhat agree	31%	18%	21%	32%
Somewhat disagree	8%	7%	6%	9%
Strongly disagree	4%	1%	6%	4%
Each step was easy to identify:				
Strongly agree	50%	72%	64%	54%
Somewhat agree	32%	21%	28%	33%
Somewhat disagree	11%	7%	5%	12%
Strongly disagree	7%	0%	3%	1%
The last step of each flight was easy to find:				
Strongly agree	45%	58%	52%	49%
Somewhat agree	27%	25%	26%	30%
Somewhat disagree	15%	11%	13%	17%
Strongly disagree	13%	6%	9%	4%
Directional signs were visible:				
Strongly agree	54%	66%	54%	46%
Somewhat agree	32%	30%	27%	25%
Somewhat disagree	12%	2%	11%	13%
Strongly disagree	2%	2%	8%	16%
Obstructions were well marked:				
Strongly agree	43%	52%	50%	45%
Somewhat agree	42%	37%	31%	25%
Somewhat disagree	10%	9%	10%	13%
Strongly disagree	5%	2%	9%	16%
Re-entry floors were well identified:				
Strongly agree	50%	57%	61%	52%
Somewhat agree	39%	33%	24%	30%
Somewhat disagree	8%	7%	6%	8%
Strongly disagree	3%	3%	9%	10%
The final exit was well marked:				
Strongly agree	69%	68%	69%	68%
Somewhat agree	30%	27%	24%	22%
Somewhat disagree	1%	4%	4%	8%
Strongly disagree	0%	1%	3%	2%

The respondents were asked if the first step to each flight was easy to locate. Overall respondents from the 4 studied stairwells were positive toward this statement with Stairwells E and G respondents providing a larger number of people who strongly agree that the first step was easy to locate, as seen in Figure 16. In this regard, Stairwells A and C appear similar with slightly less people who strongly agree that the first step was easy to locate. Overall, however, no statistical difference was found among the stairwells (χ^2= 16.736(9), ns).

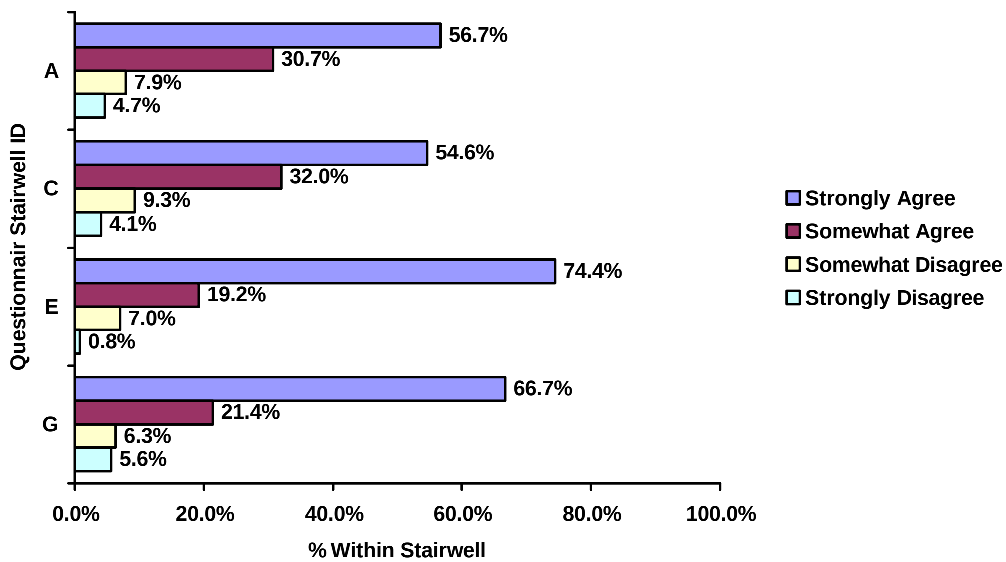

Figure 16: The first step of each flight was easy to locate

A significant difference was found for the 4 stairwells regarding the ease to identify each step, (χ^2= 27.782(9), $p< 0.001$). As presented in Figure 17, it was seen as much easier for evacuees to identify each step in Stairwells E and G, while it was difficult to identify each step in Stairwells A and C. This finding is not surprising as Stairwell A had only the "L" shape marking at the extremity of each step to identify the step and Stairwell C had no marking and reduced lighting which made each step more difficult to identify. Conversely, Stairwells E and G had markings over the full width of each step, which made the steps significantly easier to identify. The step marking of Stairwell E was 1" wide while in Stairwell G it was 2" wide, combined with the "L" edge marker. This additional marking in Stairwell G did not appear to play a significant role in the appreciation of the ease in identifying each step for users of that stairwell.

Respondents were asked about the ease of locating the last step of each flight. Several criticisms were handwritten on the questionnaires regarding this issue as evacuees who used Stairwell A found it difficult to figure out the last step of each flight in that stairwell. Overall, 28% of the respondents in Stairwell A, somewhat disagreed or strongly disagreed with the statement that the last step was easy to find. Of all stairwells, Stairwell A received the largest proportion of disagreement that the last step was easy to find. Stairwell E obtained the largest percentage of positive assessment that the last step was easy to find. However, no significant difference was found on this factor among the 4 studied stairwells (χ^2= 10.684(9), ns).

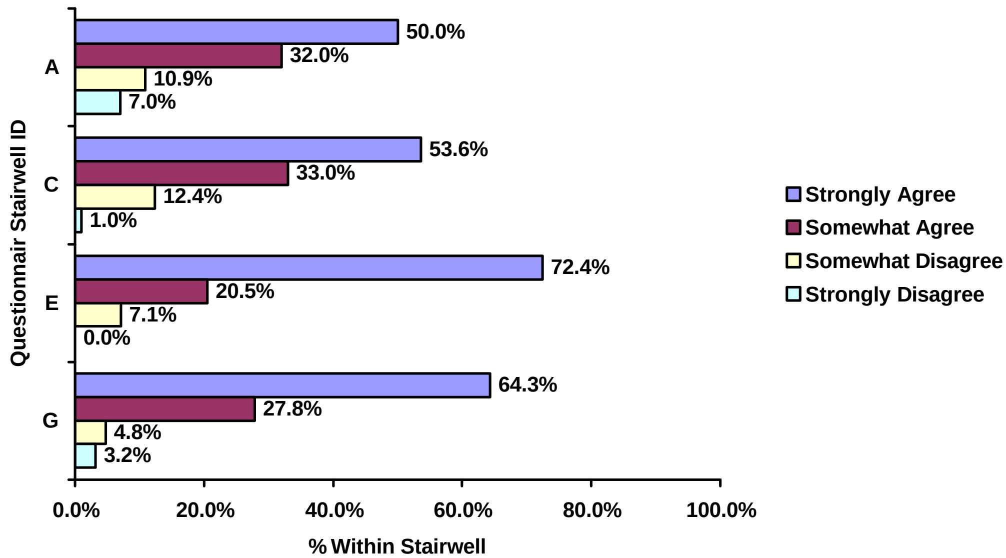

Figure 17: Each step was easy to identify

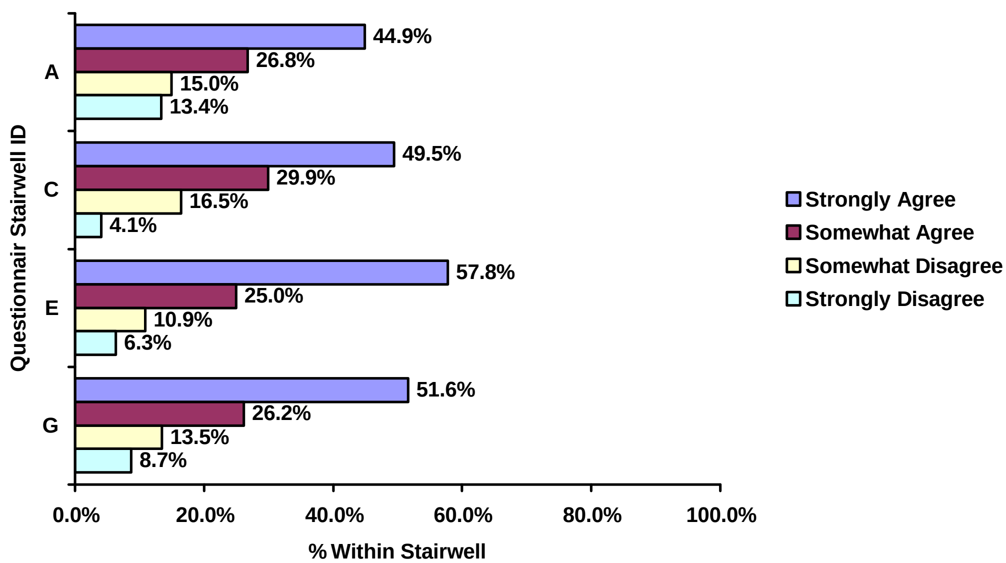

Figure 18: The last step of each flight was easy to find

There was a statistical difference among stairwells for the visibility of directional signs (χ^2= 37.183(9), p< 0.001). Stairwells C and G had no difference between them (χ^2= 3.59, ns), but respondents found that directional signs were less visible in these two stairwells than in either Stairwell A (χ^2= 7.32, p< 0.05) or Stairwell E (χ^2= 26.03, p< 0.05). Figure 19 shows the photoluminescent directional signs installed which combined the running-men and an arrow. These directional signs were positioned on every landing of the 3 photoluminescent stairwells.

Figure 19: Directional sign with the running-man

Figure 20 shows that Stairwell E scored the highest for the visibility of directional signs, although the directional signs were the same in all the photoluminescent stairwells. It is possible that since the evacuees of Stairwell E felt that it was slower and more crowded, compared to evacuees of the other stairwells, they had more time to look around and noticed the photoluminescent directional signs.

There was no statistical difference (non significant (ns)) among stairwells for the marking of obstructions (χ^2= 10.751(9), ns), the identification of the crossover floor (χ^2= 14.458(9), ns) or the marking of the final exit (χ^2= 12.304(9), ns). These markings were the same in the 3 photoluminescent stairwells. In Stairwell C there was no marking for the water pipe standing at the edge of each landing which could become an obstruction, however it appears that evacuees in that stairwell did not notice this absence of marking; see Figure 21. It is possible that unless a person collides with an obstruction or has to change course to avoid an obstruction this element is not necessarily noticed. Crossover floor signs were photoluminescent in the 3 tested stairwells and were standard signs in Stairwell C. Respondents seemed not to have noticed, as evacuees did not re-enter or attempt to re-enter on a crossover floor during this evacuation drill. The final exit had received a special treatment in the 3 stairwells with photoluminescent markings, as they were all equipped with a doorframe marking of 1”, door hardware marking and a sign indicating Final Exit. As the final flight of stairs was fully lit and the first person to exit the stairwell allowed the final exit door to automatically remain open, neither the photoluminescent markings or the lack of marking in Stairwell C were noticed.

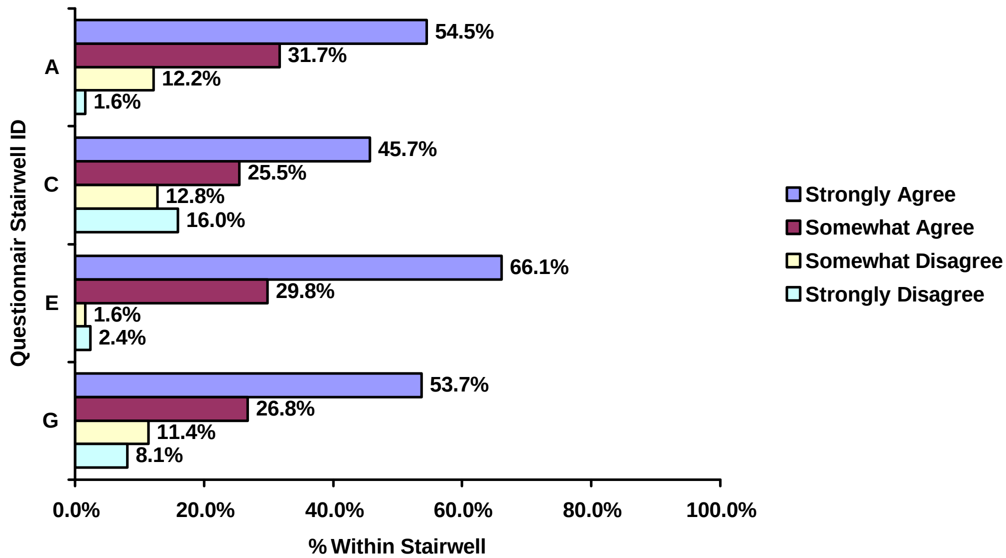

Figure 20: Directional signs were visible

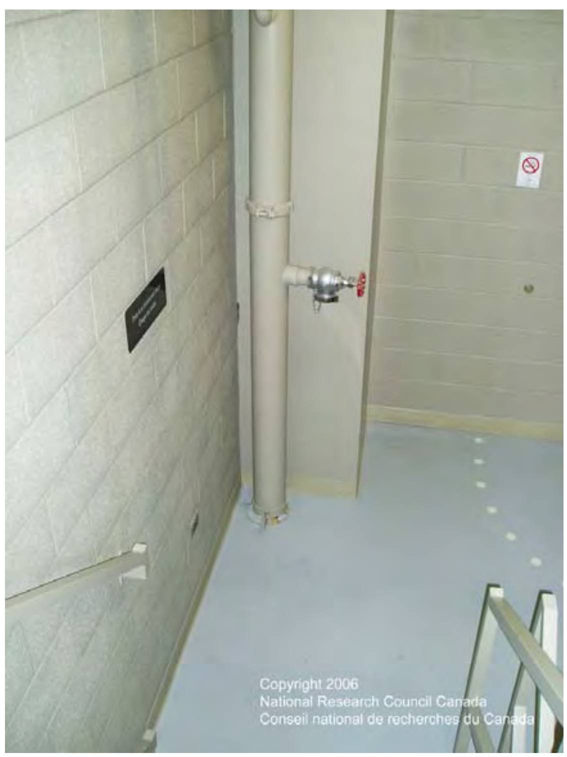

Figure 21: Water pipe obstacle in Stairwell C

If we take the stairwell attributes individually and look at the stairwell that received the most favorable appreciations for each feature, it seems that Stairwell E is systematically in first place with Stairwell G second. Stairwells A and C are in turn at the third and last positions.

Table 14: Rating of the stairwells for each attribute

Attribute	Rating			
	1st	2nd	3rd	4th
Handrail was easy to find	E	G	C	A
First step of each flight was easy to locate	E	G	A	C
Each step was easy to identify	E	G	C	A
Last step of each flight was easy to find	E	G	C	A
Directional signs were visible	E	G	A	C
Obstructions were well marked	E	G	A	C
Re-entry floors were well identified	G	E	A	C
Final exit was well marked	G	A	E	C

Evacuees were questioned on their sense of comfort while going down the stairs during the evacuation. No statistical difference was found between stairwells (χ^2= 3.245(3), ns). Overall, 65 to 75% of the respondents felt comfortable going down the stairwells with the photoluminescent marking or the reduced lighting.

Respondents were asked to judge the density of the crowd in the stairwell they used. Although Stairwell E is the stairwell which rated the best for the different attributes and markings it was felt that it was the most crowded during the evacuation as seen in Table **15**. This question indicated a statistical difference between the stairwells, as Stairwell E was judged significantly more crowded and slower than the 3 other stairwells which were judged by most as crowded but moving well (χ^2= 28.317(3), $p< 0.001$).

Table 15: Judgement of crowd density

Judgement	Percent of answer stairwell			
	A	E	G	C
Very crowded and slow	24%	50%	29%	31%
Crowded but moving well	67%	46%	62%	54%
Few others around	8%	4%	9%	14%
I was alone	1%	0%	0%	1%

In summary, the questionnaire results indicate that respondents judged Stairwells A and C similar on several questions while these two stairwells appear less positively evaluated than Stairwells E and G. In Stairwell A visibility was judged to be good by half the respondents and not good by the other half. That each step in the stair was difficult to locate, and the difficulty to locate the last step of each flight, appear to be important issues for several evacuees of Stairwell A. The overall evaluation of Stairwells A and C was not as good as for Stairwells E and G.

Stairwell E obtained the best positive evaluation despite the fact that this was also the stairwell that was felt to be the most crowded and that problems such as occupants at the front moving too slowly were identified. Stairwell G seems also to have been positively evaluated but somewhat less so than Stairwell E on some of the attributes. The larger 2” stair stripes combined with the “L” shaped marking as well as the 2” demarcation line of Stairwell G did not seem to play a role in the evaluation of the respondents. Visibility was judged good to excellent in these two stairwells and locating each step appeared to be easier with the photoluminescent marking of each step.

Overall, respondents experienced only the stairwell they used and for which they filled out a questionnaire so their judgement is unbiased by the other installations. As the number of returned questionnaires from each photoluminescent stairwell is comparable, it is concluded that Stairwell E was the stairwell that received the best rating for its features by respondents.

4.2 Data from the Video Cameras

Recordings from the 28 video cameras used to survey this evacuation were analyzed. A total of 1191 occupants were observed on the recordings. Data was encoded for each individual regarding gender, the time each entered the stairwell, the time each passed on floors 11, 9, 7, 5, 3, 1 and B and the final time of exiting. General behaviour of the evacuees was noted.

At 10:35:23, the fire alarm bell sounded. It rang continuously for 11 min 51 s. During this time, as is the procedure for the building, evacuees on all floors moved to the stairwells and began to descend towards the exit.

4.2.1 Time to Start

Due to the building’s large surface area and the configuration of the offices and cubicles, 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 each person at each exit door. Table 16 shows the arrival time of the first and last person at each exit door. The average time for the first person to reach the exit door after the alarm is 1 min 7 s. The average time for the last person to reach the exit door after the alarm is 5 min 29 s. It can be estimated that the true Time to Start or pre-movement time of each of these occupants was approximately 10-15 s prior to their arrival at the door. There was no significant difference in time for the first person to reach the exit door ($F(3,23)=1.49$, ns), however there was a significant difference in time for the last person to reach the exit door ($F(3,23)= 5.63$, $p< 0.05$). This difference is between Stairwells A and E. The last occupants to enter Stairwell E took a significantly shorter amount of time to get to the stairwell after hearing the alarm, while those in Stairwell A took a significantly longer time ($q=5.68$, $p<0.01$). The time of the last person to enter the stairwell on the recorded floor may vary according to a number of factors. Some occupants may have invested more time in preparation activities such as returning to their offices, getting dressed, gathering belongings or putting away working material. Among the last to enter the stairwells were Floor Emergency Officers, who have as part of their duty to ensure that the area under their responsibility is empty when they leave. Several took the time to visit each office as well as coffee rooms and washrooms before leaving their floor.

Table 16: Time to arrive at stairwell exit door

Stairwell	Floor	First to arrive Elapsed time from alarm min:s	Last to arrive Elapsed time from alarm min:s
A	11	1:28	9:07
	9	1:40	6:13
	7	0:52	8:27
	5	0:57	8:09
	3	0:22	9:11
	1	0:18	3:26
E	11	1:06	2:44
	9	2:23	3:51
	7	1:35	3:19
	5	0:35	2:47
	3	1:00	4:14
	1	0:53	3:52
G	11	1:25	3:59
	9	1:30	4:55
	7	1:19	6:02
	5	1:31	5:57
	3	0:40	7:40
	1	0:31	2:06
C	11	0:21	5:02
	9	0:42	6:28
	7	1:37	8:59
	5	1:56	5:08
	3	0:43	4:54
	1	1:24	5:10

4.2.2 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.

Despite the fact that the geometry was the same for all stairwells, the distance to travel to reach the outside exit varied below the 1st floor, as there is a small slope down from Sparks Street and Queen Street. From the 11th floor, evacuees had to descend 150.63 m in Stairwell A and 153.21 m in Stairwell E to reach the ground level exit on Queen Street. Evacuees had to descend 140.00 m in Stairwell G and 141.44 m in Stairwell C to exit on Sparks Street. Speed of movement was calculated in meters per second (m/s) for each evacuee with the exact distance travelled in each stairwell.

The speed of movement in Stairwell A ranged from 0.33 m/s to 1.39 m/s. In Stairwell E, the speed ranged from 0.17 m/s to 1.03 m/s, in Stairwell G it ranged from 0.14 m/s to 1.53 m/s and in Stairwell C it ranged from 0.38 m/s to 1.87 m/s.

The mean speed of movement in all stairwells is presented in Table 17. The slowest mean speed of movement was in Stairwell E, which had a speed of 0.40 m/s. Stairwell G had a mean speed of 0.57 m/s and Stairwells A and C shared the highest mean speed of 0.66 m/s.

Table 17: Speed of movement in the four stairwells

Stairwell	Mean speed m/s	Standard deviation	Number of evacuees
A	0.66	0.2462	345
E	0.40	0.1661	287
G	0.57	0.2133	281
C	0.66	0.3053	278
Total	0.57	0.2335	1191

An Analysis of Variance shows differences between stairwells. The results show that there is a significant difference in the mean speeds of movement among stairwells ($F (3,1118)=62.804$, $p<0.001$). A multiple comparison procedure, called Tukey's HSD, was then undertaken. This test was used to identify which pairs of groups have significantly different means. The results show that the mean speed of movement in Stairwells A and C are essentially the same at 0.66 m/s. That speed is significantly higher than the speed of movement in Stairwell G ($q=6.45$, $p<0.01$ and $q=6.01$, $p<0.01$, respectively) and Stairwell E ($q=17.64$, $p<0.01$ and $q=16.76$, $p<0.01$, respectively). The speed of movement is significantly different in Stairwells G and E as Stairwell E is significantly slower at 0.40 m/s ($q=11.09$, $p<0.01$).

It is essential to consider the speed of movement in relation to the occupant density in each stairwell. As presented in Table 18, the density of occupants descending varied slightly for each stairwell. Density of evacuees was calculated in people per meter squared (p/m^2) during the five busiest minutes of the evacuation between 10:37:23 (two minutes from the alarm) and 10:42:23 (seven minutes from the alarm), on levels 1, 3 and 5. Stairwells E and C had the highest density of occupants with an average of 1.60 p/m^2. Stairwell G had a density of 1.58 p/m^2, while Stairwell A had the lowest density of 1.56 p/m^2. There is no significant difference between the densities in the four stairwells, $F(3,80)=0.06$, ns. Pauls [13] 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 similar to observed speed of movement in Stairwells A, G and C. Stairwell E, however, demonstrates a marked difference as its observed mean speed of 0.40 m/s is considerably lower than its calculated speed of 0.62 m/s. Results of calculated speed of movement are presented in Table 18.

Table 18: Speed and density in the four stairwells

Stairwell	Density p/m^2	Observed mean speed m/s	Calculated speed m/s
A	1.56	0.66	0.63
E	1.60	0.40	0.62
G	1.58	0.57	0.62
C	1.60	0.66	0.62

Stairwell E had a high density, and also the lowest observed mean speed. This makes sense, as a higher density leads to more crowding, which slows down the descent of the evacuees. However, Stairwell C had the same density as Stairwell E as well as a high observed mean speed. Stairwell A was the least dense stairwell. Stairwells A and C had the highest observed mean speeds. Although, in light of the statistical similarity between the stairwells, it is difficult to make a conclusion based only on these calculations. The data, however, can be looked at in a different way. Figure 22 shows the density in each stairwell by time. The curves indicate that the density in Stairwells A, G and C began at a midpoint and peaked around 5 minutes after the alarm before tapering off. In Stairwell E, the density appears to peak at 3 minutes after the alarm. This indicates that Stairwell E was more crowded earlier in the evacuation than the other stairwells. This could help to explain why Stairwell E has a much lower observed mean speed of evacuation compared to the other stairwells. Having most of the evacuees entering the stairwell at the same time would cause a lot of crowding because of merging from all floors, and therefore reduce the speed of evacuation.

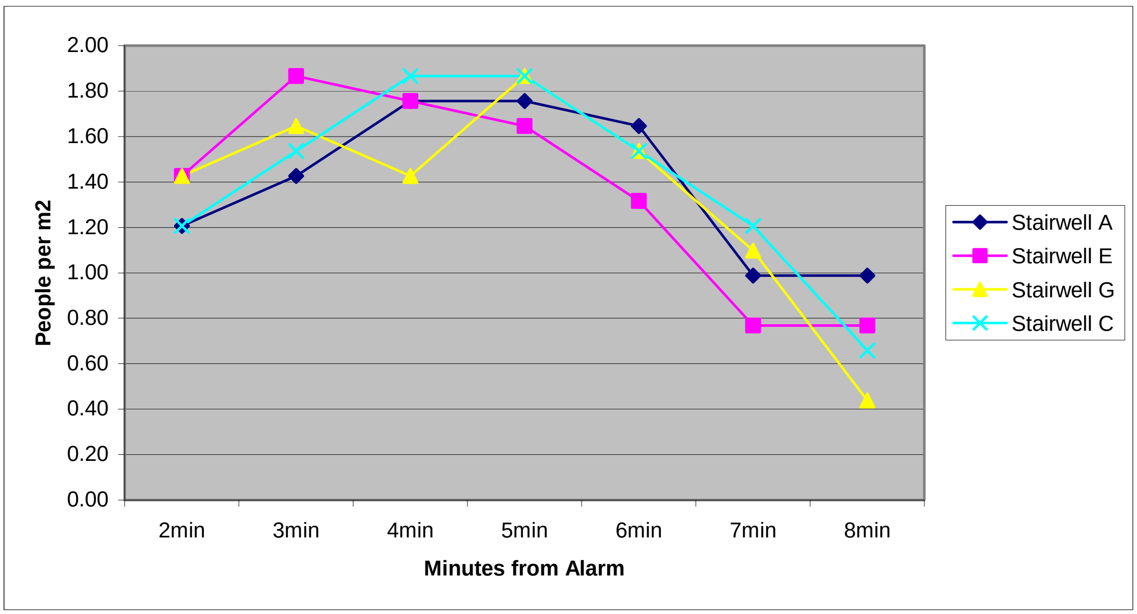

Figure 22: Density by time

When closely studying Stairwell E, it was noticed that two individuals with limitations had a major impact on the speed of movement in that stairwell. At 10:37:41, entering from floor 7, a heavy person started going down the stairwell one step at a time, moving with the body sideways to the stairs, holding the handrail with one hand and a jacket and vest with the other. Almost at the same time at 10:37:38, another person holding a cane entered from floor 1 with two other accompanying occupants, descended from behind. Nobody over took these two evacuees who were slower than the rest of the crowd in the stairwell, and a gap formed in front of them leaving a full flight of stairs empty. The impact on the descending crowd was substantial. It was noticed that on floor E3 the descending evacuees were stalled for 45 s, on E5 the standstill lasted 1 min 12 s, and on E7, 1 min 20 s, before the evacuation slowly resumed. Complete stop of evacuation movement longer than 15 s was not noticed in any other stairwell. It is interesting to note that the density at the busiest times during the evacuation was no more than 2.30 p/m^2.

It appears that occupants refused to increase this density by packing up more closely against others.

The videotapes show that the evacuees were spread out differently in each stairwell. Although Stairwell A had the largest number of people going through it during the evacuation, it also had the highest mean speed of movement. This seems incongruous, because a stairwell containing more people should move more slowly. However, the occupants in Stairwell A were more spread out over the entire evacuation compared to those in Stairwells E and G. Figure 23 shows the number of people that entered on each floor per minute, in all four stairwells. In Stairwell A, the first person to start evacuating entered the stairwell at 10:35:41, and the last person to start evacuating entered the stairwell at 10:44:53, making a difference of 9 min 11 s. In Stairwell C, the first person entered at 10:35:44 and the last person entered at 10:44:22, making a difference of 8 min 38 s. In Stairwell E, the difference is 6 min 10 s with the first person entering at 10:35:58 and the last entering at 10:42:08, and in Stairwell G, the difference is 4 min 54 s with the first person entering at 10:35:54 and the last entering at 10:40:48. Also, in Stairwell E, the last two evacuees descended much later than the rest, entering the stairwell 1 min 41 s and 2 min 31 s after the rest of the crowd. Not taking these two outliers into account, the difference between the first and last person to start evacuating in Stairwell E is 3 m 39 s.

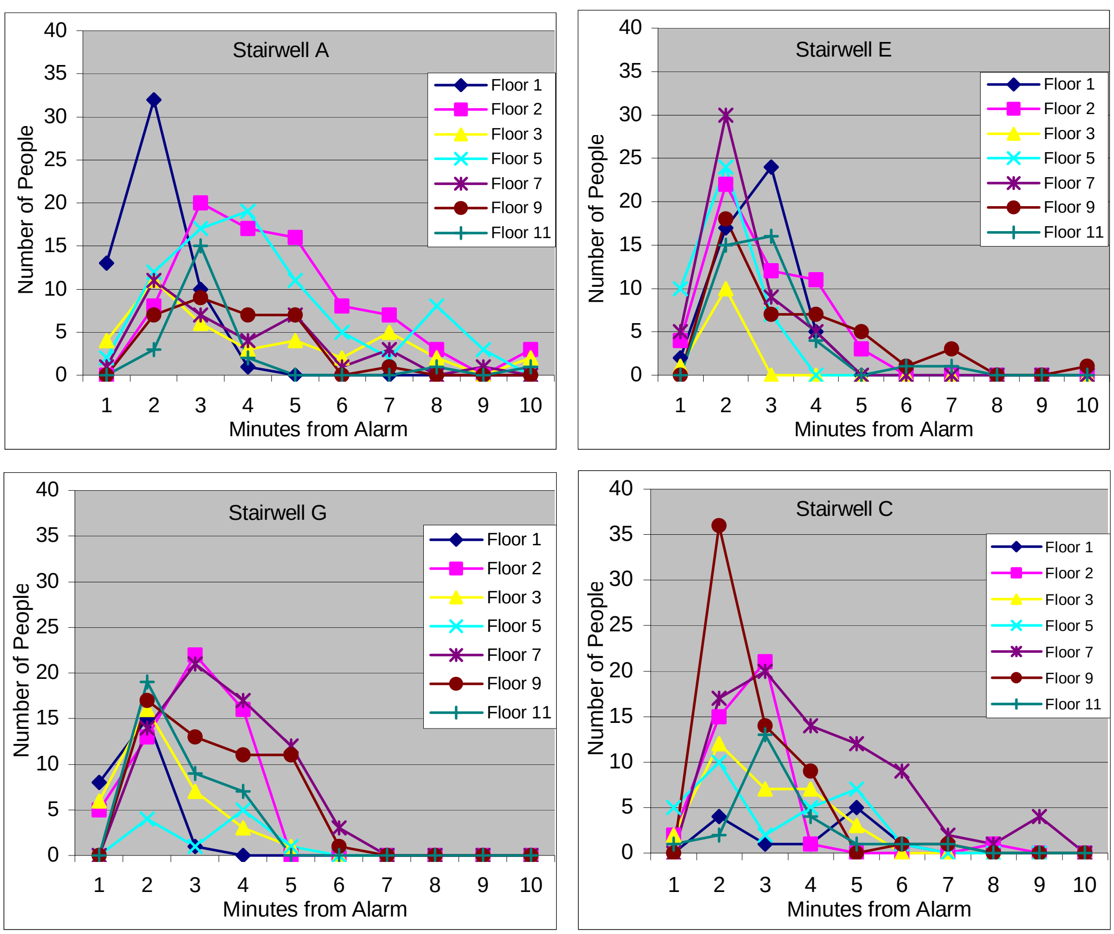

Figure 23: Number of evacuees entering the stairwell on each floor per minute by stairwell

As seen in Figure 23, the number of people entering on any floor tended to be higher at the beginning of the evacuation, and slowly dropped as the evacuation continued for Stairwells A, C and G. In Stairwell E, however, the number of people who entered peaked at 2-3 minutes from the alarm on all floors, and then fell steeply for the rest of the evacuation. This means that the majority of the evacuees in Stairwell E were all in the stairwell at the same time, causing crowding and congestion.

As shown in Table 19, the mean speed of descent is lower for occupants from upper floors. This decrease in speed is explained by crowding in the stairwell. Merging with evacuees entering the stairwell appears to be the main factor slowing down descending occupants. Those on floor 1 did not pass any other evacuating floors and were moving faster. Due to the simultaneous evacuation of all floors of the building, occupants on higher floors had to merge with an increasing number of people entering at lower floors. Evacuees entering the stairwell at floor 11 were required to merge with people entering at floors ten to one.

Table 19: Speed of movement by floor

Floor	Mean speed of movement by stairwell m/s			
	A	E	G	C
11	0.41	0.40	0.43	0.53
9	0.37	0.45	0.45	0.46
7	0.44	0.34	0.48	0.51
5	0.53	0.31	0.43	0.53
3	0.64	0.39	0.49	0.84
2	0.92	0.38	0.79	0.99
1	0.89	0.52	0.93	0.88

There is a large range of speeds for evacuees from each floor and stairwell from 0.14 m/s up to 1.87 m/s. The fastest evacuees were those who entered the stairwell at the 1st or 2nd floor quickly after the alarm activation. Because the stairwell was empty and they didn't have to merge with evacuees from lower floors, they were able to freely race down to the exit. The slowest evacuees were those who entered the stairwell at a higher floor, more than 2 minutes after the alarm sounded. They were immediately caught in the slowest part of the crowd until the exit.

4.2.3 Observed behaviour

Observations of the behaviour of the evacuees during the evacuation, such as crowding and holding of the handrails, were obtained from the video recordings.

It should be noted that two Floor Emergency Officers in Stairwell A and one in Stairwell E were using flashlights, which might have been an incentive for some evacuees to accelerate their descent. In Stairwell A on several floors, Floor Emergency Officers were holding the exit doors open to accelerate the entry of arriving evacuees. On one hand, holding the doors open facilitated the merging of descending and entering occupants, changing the flow and improving the speed of movement. On the other hand, holding the exit door open allowed the full lighting of the floor to diminish the visibility of the photoluminescent material in the stairwell. This also made it difficult for evacuee's eyes to adjust to the markings in the dark stairwell, and may have slowed down occupant movement.

There was significant crowding observed in all of the stairwells. The bottom few floors had the largest amount of evacuees, but tended to move along well because there was little merging with lower floors. The middle floors got congested very quickly, and during the busiest few minutes of the evacuation, movement could stop completely for up to 15 s in Stairwells A, C and G, and as long as 1 min 20 s in Stairwell E. This large discrepancy between stairwells is attributable to the two evacuees with limitations who entered Stairwell E and slowed down the evacuation behind them.

Holding of the handrail also contributed to crowding and slowing down movement in the stairwells. Evacuees using the handrails were descending at the sides of the stairwell, tending to favour the inside handrails. This caused them to descend single-file, which in turn slowed their speed of descent to the speed of the slowest person ahead of them. Some evacuees not using the handrails were able to pass through the middle of the stairwell. In some areas, 4-5 evacuees were observed in each stairwell holding on to the handrails on both sides, making it impossible for faster occupants to get by. No occupants were observed attempting to over take slower occupants such as people holding the handrail on both sides.

The frequency of people holding the handrail was recorded at floors 9, 5 and B for all stairwells. On floor 9, 88% were holding the handrail in Stairwell A, 81% in Stairwell E, 86% in Stairwell G and 71% in Stairwell C. On floor 5, 84% used the handrail in Stairwell A, 87% in Stairwell E, 80% in Stairwell G and 81% in Stairwell C. On floor B, which was fully lit, 31% used the handrail in Stairwell A, 55% in Stairwell E, 33% in Stairwell G and 61% in Stairwell C. Table 20 shows the frequency of handrail holding on each of these levels for the 4 studied stairwells. Two possible explanations may be offered for the difference between floor B and the upper floors 5 and 9. The first one is the lighting difference between the floors. Evacuees held on to the handrail more frequently on levels with less lighting. The second explanation is the proximity to the exit. On floor B (last flight of stairs to the exit), evacuees were moving well without any crowding because they were heading directly outside. Because they were so close to the exit, evacuees sped up and stopped using the handrail: several were seen buttoning or zipping their coat on this last flight of stairs. On floors 9 and 5, the stairwell was very crowded. Evacuees used the handrail while descending as well as to steady themselves at times when they were moving very slowly or standing still.

Density can be represented by showing the position of evacuees on the stairs, as in Figure 24, which shows density in Stairwell A on floor 3, at 2, 3, 4, 5 and 6 minutes from the alarm. These drawings were created for floors 1, 3 and 5 for all four stairwells, see Appendix F. These representations are helpful when analyzing the behaviour of the evacuees as they descend. For example, it was very rare to see two people descending the stairs side-by-side during this evacuation. There was not enough room in the stairwell for two to fit comfortably shoulder to shoulder, without one violating the other’s personal space. This was usually only seen when two friends were speaking to each other while descending. When the stairwell was relatively empty, evacuees kept to their right, as seen in Figure 24 at 2 and 3 minutes from the time of alarm activation. This tendency to stay on the right is explained by the fact that the staircase spirals downward to the right; keeping to that side allowed evacuees to descend faster. In order to stay to their right evacuees tended to descend the stairwells in a single file. This also had a slowing effect on the speed of movement, because evacuees were not taking advantage of the empty space on the left of the stairwell to descend faster or over take slower evacuees. When the stairwell was more crowded, such as at 5 minutes, the pattern of evacuees on the stairs became more scattered. They descended in a zigzag pattern to avoid walking too close to each other. Overall, people trying to stay out of each other's personal space and keeping to the right as much as possible dictated the pattern of evacuees descending the staircase. The representation at 5 min in Figure 24 shows the most crowded time of the evacuation, with 6-7 evacuees on one flight of stairs, representing 1.98 p/m^2. In Stairwell E, that type of density was maintained for a long period of time. The density drawings of Stairwell E, floor 5, at 3 and 4 minutes, as seen in Appendix F, depicts the same evacuees who have been standing in that position for over a minute.

Table 20: Frequency of evacuees holding the handrail

Stairwell	Floor	Number of evacuees holding handrail	Total number of evacuees	Percent
A	9	59	67	88%
	5	150	179	84%
	B	106	345	31%
E	9	48	59	81%
	5	79	91	87%
	B	159	287	55%
G	9	79	92	86%
	5	98	122	80%
	B	93	281	33%
C	9	34	48	71%
	5	137	170	81%
	B	170	278	61%

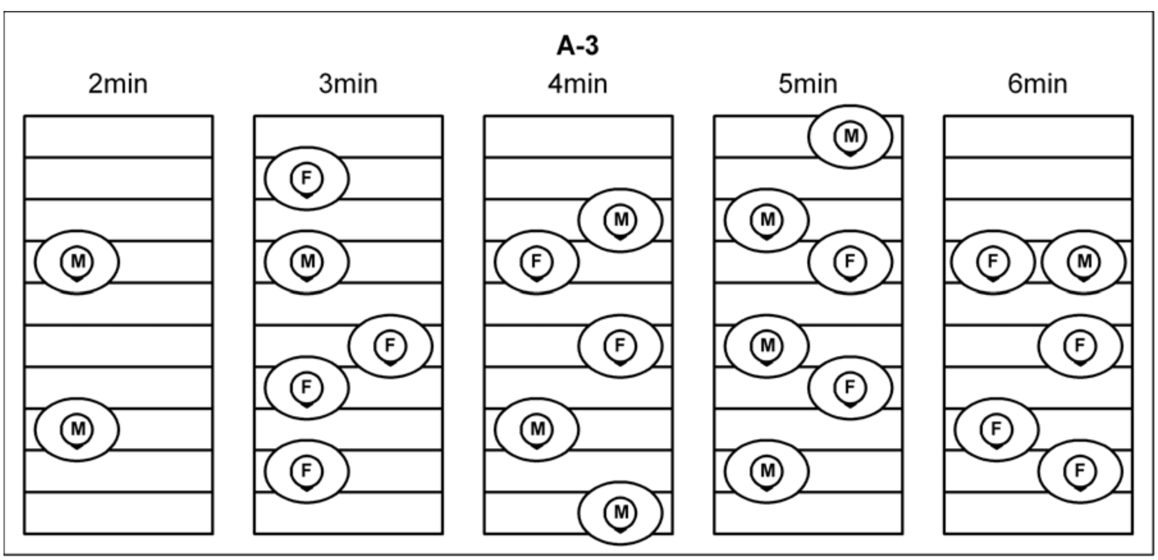

Figure 24: Representation of density on Floor 3, Stairwell A, at 2, 3, 4, 5 and 6 minutes from alarm (not to scale)

Based on observations from the videotapes, most evacuees were at ease and not alarmed by the photoluminescent material. Many comments of awe, such as, “wow” and “this is some lighting” were heard in all three photoluminescent stairwells. One evacuee in Stairwell G commented on the visibility, saying, “you can’t see people, all you can see are the stairs.” Overall, comments about the photoluminescent material were positive. Most occupants did not overtly react to the material and just followed the evacuation flow.

Several questionnaires had handwritten comments which were all analyzed. Among these comments 37 were regarding the fact that evacuees in the photoluminescent stairwells felt uneasy because they were unable to see others around them. Another 15 mentioned colliding into others because of the poor lighting and 3 said they were afraid others would collide with them. Although the videotapes were closely studied it was not possible to identify any of these collisions. Some evacuees commented that carrying coffees should be prohibited as they felt it was an added hazard during a drill. Over 25 people were seen in each stairwell carrying coffee mugs.

5 DISCUSSION AND CONCLUSIONS

The following is a discussion of the general findings of this study and the major conclusions. Finally, future studies that should be undertaken are also briefly described.

5.1 Evacuees' Subjective Assessment of PLM Signage

Overall respondents to the questionnaire provided statistically comparable judgements on several attributes of the 4 tested stairwells. There was, however some systematic evaluation that differentiated the stairwells. It appears that respondents judged Stairwells A (L shape marker) and C (reduced lighting) similar on several questions while these two stairwells appear less appreciated than Stairwells E and G (1” and 2” marking, respectively). In Stairwell A, visibility was judged good by half the respondents and not good by the other half. Two important issues for several evacuees of Stairwell A are that each step in the stair, and the last step of each flight, were difficult to locate. The overall evaluation of Stairwells A and C was not as good as for Stairwells E and G.

The main problem reported for all stairwells during this evacuation, by about half the respondents, was difficulty seeing because of poor lighting. However, 65% to 70% of the respondents said they would feel comfortable moving in the PLM or reduced lighting stairwells if they were faced with an emergency. It is important to reiterate that if photoluminescent material is installed, occupants would have to move in the type of environment experienced during the drill only in case of complete power failure or lighting obscuration.

Stairwell E obtained the best appreciation from the respondents despite the fact that this was also the stairwell that was felt most crowded and that problems such as occupants at the front moving too slowly were identified. Stairwell G also received positive evaluation but somewhat less than Stairwell E on some of the attributes. The larger 2” stair stripes combined with the “L” shaped marking as well as the 2” demarcation line of Stairwell G did not seem to play a role in the respondents’ evaluation. Most respondents judged visibility good to excellent in Stairwells E and G and locating each step appeared to be easier with the photoluminescent marking positioned on each step.

Overall, respondents experienced only the stairwell they used and for which they filled out a questionnaire so their judgement is unbiased by the other installations. As the number of returned questionnaires from each photoluminescent stairwell is comparable, it is concluded that Stairwell E was the stairwell that received the best rating for its features by respondents. Stairwell E is presented in Figure 25 under full lighting and without lighting as experienced during the drill.

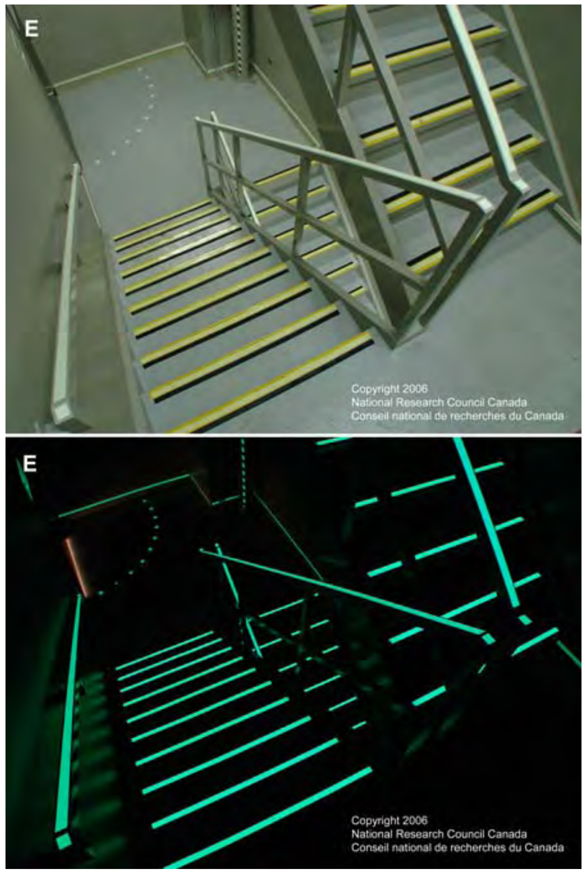

Figure 25: Stairwell E with and without lighting

5.2 Occupant Movement

Video recordings provided a complete account of the movement of occupants who evacuated by the 4 studied stairwells during the evacuation drill. At 10:35:23, the fire alarm bell sounded and rang continuously for 11 min 51 s. During that time, as is the procedure for the building, evacuees on all floors moved to the stairwells and began to descend towards the exit. The average time taken by the first occupants to arrive at each stairwell was 1 min 7 s. A majority of the occupants took on average 1 to 2 min to start their evacuation, which is very consistent with respondents reported pre-movement times from the questionnaire. On average the last person seen entering each stairwell on every floor, entered at 5 min 29 s, usually this last person was a Floor Emergency Officer. Overall, the full evacuation lasted just under 12 min. This finding is interesting in itself as past evacuation drills of the C.D. Howe building usually lasted around 14 min. It seems that the reduced lighting of Stairwell C and the photoluminescent marking without lighting in the other 3 studied stairwells had no impact on the overall time to evacuate that building.

One of the most important findings in an evacuation study is the speed of movement of a natural crowd descending stairwells, and in this case under different lighting conditions. The results show that speed of movement in the 4 stairwells studied ranged from 0.14 m/s to 1.87 m/s. The mean speed of movement for Stairwell A was 0.66 m/s; 0.40 m/s in Stairwell E; 0.57 m/s in Stairwell G and 0.66 in Stairwell C. The results indicate that Stairwell E had significantly slower speed of movement, while the other 3 stairwells shared comparable speeds of movement. It is essential to contrast the speed data to the occupant density to better understand these results. Occupant density was calculated for the 5 busiest minutes of the evacuation. This calculation shows that occupant density on the stairs was very similar for each stairwell from 1.56 to 1.60 p/m^2. When calculating the expected speed of movement, considering the density of occupants, all stairwells have observed speed very close to expected speed, except for Stairwell E, which is substantially slower. More in-depth analysis was needed to understand this discrepancy of Stairwell E.

Close study of the raw data showed that Stairwell E had two individuals with limitations who had a major impact on the evacuation movement. These two persons entered around 2 min after the sound of the alarm: one overweight person entered on E7 and a person using a cane entered on E1. They both negotiated the stairwell with difficulty: essentially one step at a time. Nobody over took these two evacuees who were slower then the rest of the crowd in the stairwell. In front of them a gap opened leaving empty a full flight of stairs. The impact of these two slow evacuees on the descending crowd was substantial. It was noticed that on floor E3 the descending evacuees were stalled for 45 s, on E5 the stall became 1 min 12 s and on E7, 1 min 20 s before the evacuation slowly resumed after the 2 slow evacuees had exited. A complete stop of the evacuation movement longer then 15 s was not noticed in any other stairwell. It is interesting to note that the average density at the busiest times in Stairwell E was 1.60 p/m^2 and the density never increased above 2.30 p/m^2. It appears that occupants refused to increase this density by packing up more closely against others. This observation suggests that it is important to be very careful when using egress models and calculation methods, although some allow calculation of evacuation times on the basis of very high density over 3 p/m^2, these densities appear unrealistic according to the current evacuation study.

Observation of evacuees' behaviour such as crowding, merging, position on stairs and holding the handrail were obtained from the video recordings. One of the most interesting observations is the fact that over 80% of the evacuees were holding the handrail in the stairwell with photoluminescent marking. This fact supports the research team decision to mark the handrail as evacuees seemed to rely considerably on the handrail during movement down as well as during times when the crowd was stopped. The evacuees moved in a scattered fashion on the 1100 mm stairs. Occupants didn't seem at ease travelling on the stairs side by side, as their shoulders and arms might have touched during the descent. Only a limited number of evacuees who were conversing descended side by side.

5.3 Comparison of PLM installations

Although limited statistical differences were found among the 3 photoluminescent stairwells the overall judgement of the respondents favoured the installation of Stairwell

E with the 1” strip marking across each step. It appears that Stairwell A with the L-shaped markers was the least appreciated as it was difficult for evacuees to differentiate each step. Although this installation met the New York City Reference Standard 6-1 for existing high-rise office buildings (and in fact exceeded these requirements with the handrail marking), evacuees evaluated this stairwell as less satisfactory as the other two stairwells with marking across each step.

An interesting finding of this study is that the wider strip of 2” marking each step, L-shaped markers and the 2” landing demarcation lines of Stairwell G did not lead to a better evaluation by the respondents. They judge more favourably the installation of Stairwell E with the 1” marking.

It is not possible to differentiate the impact of the 3 installations tested on the speed of movement observed. The crowd density was the driving factor of the speed of movement as well as the presence of occupants with mobility limitations. As the crowd built up very rapidly with evacuees entering simultaneously on all floors of the stairwells, which became rapidly jammed and slow movement ensued. The photoluminescent installations had no impact on the speed of movement. Consequently, the first hypothesis of this study is not verified.

1. Occupants will be more efficient in terms of movement time with one of the three installations of the PLM wayguidance system. Hypothesis not verified.

The study findings however, confirm the hypothesis that installations with marking across each step are better appreciated by occupants.

2. Installations identifying each step of the stairwell with PLM will receive a higher appreciation by occupants. Hypothesis verified.

Although Stairwell E is the installation that received the best evaluation its better performance is not based on a faster speed of movement on stairs but essentially on the subjective judgement of respondents.

This study’s findings show the interesting potential of photoluminescent 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 smokelogging 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.

5.4 Comparison of PLM with emergency lighting

Stairwell C had reduced lighting to replicate a stairwell with battery-packs or where emergency lighting would be provided with only one luminaire out of three illuminated during an emergency. The COSH and NBC requirement of at least an average of 10 lux was met, as the output was an average of 37 lux. Such a set up supposed that some areas are fully lit while others are almost in total darkness. During the evacuation evacuees moved from brightly lit areas to rather dark areas.

Respondents' evaluation of Stairwell C, with reduced lighting, is comparable to Stairwell A, with L shaped markers. Although these two stairwells were completely different in terms of signage and illumination they were judged similarly on most attributes. Close to half of the respondents who used Stairwell C said that it was difficult to see around because of the poor lighting. Just like the other stairwells around 1 in 5 respondents found it difficult to locate the first step, each step or the last step of each flight. Directional signs with the "running-man" were not provided in that stairwell which was observed by respondents.

Speeds of movement in the 4 studied stairwells were comparable. It is important to state that crowding was similar in the stairwells, which led to similarly slow speeds of movement. Consequently, the third study hypothesis is verified.

3. Occupants who will evacuate in the PLM stairwell will be as fast as occupants travelling under emergency lighting. Hypothesis verified.

Overall the conditions experienced in the 4 studied stairwells were judged as fairly difficult by the evacuees as several considered that the lighting was poor, that steps were difficult to identify and it was crowded and slow. However a majority agreed that they would feel comfortable evacuating under such conditions if there was an emergency.

5.5 Future work

There are a large number of studies that can be conducted in the field of photoluminescent marking. The study reported here is only one of the few researches available. Since each project can only test a small number of factors, it is important to pursue research in this field through many more projects to accumulate a solid body of knowledge. It is important to better understand how to use this most promising technology, which is photoluminescent marking, to improve the safety of building occupants.

Although the large stairwell crowd of this study was a true representation of a small high-rise office full evacuation, it was disappointing for the research team not to observe any difference in the speed of movement in the 4 installations tested. It is possible that one of these installations would have performed better then the others under different conditions. In order to study the impact of different installations on the speed of movement, possibly it would be required to conduct evacuations in a taller building with a lighter crowd. It is possible that conducting a phased evacuation in a 30-storey high building would identify differences in speed of movement. Phased-evacuations are rarely planned for 13-storey high buildings, however in buildings over 25-storeys they are fairly common. It would be beneficial to conduct an evacuation study in a high-rise office building with over 30-storeys to measure the impact of such a descent on the speed of movement under different stairwell markings. It would also be advantageous to consider less crowded movement in stairs with a phased-evacuation.

One of the major findings of this study is the importance of marking across each step. Stairwell E with 1" marking across each step received the best evaluation. It is possible that thinner marking could also obtain positive appreciation. Brighter products with different width should be tested.

The lack of specific marking to differentiate the last step of a flight or the landing was criticised by respondents of the 3 photoluminescent stairwells. The research team did not plan any marking to identify the landing and this seemed to be a missing part according to the evacuees. When descending with a large crowd for evacuees moving close to the inward handrail the landing demarcation line is obstructed by other evacuees. It becomes very difficult to differentiate the last step of the flight and the landing location. Several evacuees mentioned that they felt awkward when stepping onto the landing, because they were not sure if it was the last step or the landing. Means to identify the landing should be studied further and tested in a crowded stairwell.

Identification signs indicating floor number and crossover floors were not useful during the drill conducted since evacuees were not asked to re-enter on a floor or change stairwell. It would be useful to conduct an evacuation drill where a voice communication system is available and provide instructions to the occupants. It would be possible to evaluate the effectiveness of such signage.

During this high-density evacuation, people bumped or were afraid to bump into one another. A continuous demarcation line at 1.5 m could help silhouette other occupants of the stairwell, which could alleviate this problem. More tests are needed to evaluate the performance of such additional marking.

Findings of this study confirmed the importance of the handrail marking. The design of the handrail of the C.D. Howe building was square-shaped, which is rather rare. On a round shaped handrail it could have been more difficult to apply photoluminescent marking that would adhere permanently, as most existing products would tend to curl on the sides. Ideally the handrail should be manufactured with a piece of photoluminescent material encased in the handrail.

This study was conducted in a small high-rise office building, the installations tested were specifically designed for that type of occupancy. Other types of occupancy such as schools, hospitals, residential high-rises, and many assembly buildings could benefit from the installation of photoluminescent marking. These occupancies however, may have different needs in terms of installation and the characteristics of the occupants might require specific components not necessarily needed in office buildings. More research is needed to evaluate the type of installation that would be most effective in different types of occupancy.

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APPENDIX A – Memos to Occupants

Memo Pre-evacuation

MEMORANDUM

Date 2 October 2006

To/Destinataire C.D. Howe Building Employees and Occupants

From/Expéditeur National Research Council Canada

Re/Objet

Evacuation Study at the C.D. Howe Building

The National Research Council of Canada's Institute for Research in Construction (NRC-IRC) in collaboration with the Innovation and Solutions Directorate, Real Property Program Branch of Public Works and Government Services Canada (PWGSC) is conducting a research to study the effectiveness of different photoluminescent wayguidance systems to support occupants' evacuation at the C.D. Howe building, Ottawa, ON.

What is this study?

We have installed photoluminescent material in some of the building stairwells. This material is in the form of stripes, markers and signs, it is meant to glow if electric power is lost and will provide direction to safely evacuate the building in case of a power failure and failure of the emergency lighting.

Why is the study being done?

This project is part of our Fire Research program at NRC, in which we study means to provide the most reliable and cost-effective installations that will ensure your safety.

NOTE DE SERVICE

Le 2 Octobre 2006

Employés et occupants de l'édifice C.D. Howe

Conseil national de recherches du Canada

Étude d'évacuation à l'édifice C.D. Howe

L'Institut de recherche en construction du Conseil national de recherches du Canada (CNRC), en collaboration avec la Direction des innovations et des solutions, Programme des biens immobiliers de Travaux publics et Services gouvernementaux Canada (TPSGC), mène une étude d'évaluation de l'efficacité de divers systèmes d'orientation photoluminescents pour l'évacuation des occupants à l'édifice C.D. Howe, à Ottawa, Ontario.

En quoi consiste l'étude?

Nous avons installé des éléments photoluminescents dans certaines cages d'escalier de l'immeuble. Sous forme de bandes, balises et panneaux de signalisation, le matériau photoluminescent brillera si le courant électrique vient à manquer; il indiquera la voie d'évacuation en cas de panne ou de défaillance de l'éclairage d'urgence.

Pourquoi mener cette étude?

Le projet s'inscrit dans notre programme Recherche en incendie au CNRC. Il s'agit de rechercher les moyens de fournir les installations les plus fiables et les plus efficaces qui soient afin de garantir votre sécurité.

What will you be asked to do?

You will automatically become part of this study by participating in the next evacuation drill. During the drill, the lighting will be turned to emergency lighting and in some stairwells the photoluminescent marking alone will guide your movement. **Follow the instructions, as you would normally do.** Use your designated stairwell to evacuate the structure. Walk at a good speed without rushing and be watchful of your surroundings. For the duration of the drill we will install video cameras in the stairwells to monitor the speed of movement. You will also be handed a questionnaire as you exit the building. Please return the completed questionnaires in the red box in the elevator lobby.

Quel rôle serez-vous appelé à jouer?

Vous prendrez automatiquement part à l'étude en participant au prochain exercice d'évacuation. Au cours de l'exercice étudié, l'éclairage normal sera remplacé par l'éclairage d'urgence et le matériel photoluminescent à lui seul guidera vos déplacements dans certaines cages d'escaliers. **Suivez les directives comme vous le feriez normalement.** Utilisez la cage d'escalier qui vous est assignée. Marchez rapidement sans vous précipiter, et surveillez les alentours. Nous installerons des caméras vidéo dans les cages d'escalier; elles permettront de mesurer les vitesses de déplacements au cours de l'exercice. Vous recevrez également un questionnaire à votre sortie de l'immeuble. S.V.P. déposez le questionnaire complété dans la boîte rouge dans le hall des ascenseurs.

Memo Post-evacuation

MEMORANDUM — **NOTE** DE SERVICE

	MEMORANDUM	NOTE DE SERVICE
Date	6 October 2006	Le 6 Octobre 2006
To/Destinataire	C.D. Howe Building Employees and Occupants	Employés et occupants de l'édifice C.D. Howe
From/Expéditeur	National Research Council Canada	Conseil national de recherches du Canada
Re/Objet	**Evacuation Study at the C.D. Howe Building**	**Étude d'évacuation à l'édifice C.D. Howe**

We would like to thank you for your participation in the annual fire drill. The exercise went very well due to your prompt response to the fire alarm signal and the excellent work of the emergency safety team organisation. It took overall 12 minutes for the towers occupants to evacuate, which is very good. The Ottawa Fire Service as well as the Ottawa Paramedics were on location to ensure your safety during the evacuation. They were totally satisfied with the exercise.

Different installations of photoluminescent material were tested in stairwells A, E and G and stairwell C was under emergency lighting. In the coming weeks we will analyse the data from the video recordings as well as the data from the returned questionnaires to assess which installation worked the best. If you have not yet returned your questionnnaire please drop it at the PWGSC office on level C East Tower. We will advise you when the results of the study will be published.

Nous aimerions vous remercier de votre participation à l'exercice d'évacuation annuel. Cet exercice s'est très bien déroulé grâce à votre réaction rapide à l'alarme incendie et à l'excellent travail de l'organisation des mesures d'urgence. L'évacuation des occupants des tours a été complétée en 12 minutes ce qui est un très bon temps d'évacuation. Le service d'incendie de la ville d'Ottawa ainsi que les services paramédicaux ont pris part à cette évacuation pour assurer votre sécurité. Il se sont aussi montrés très satisfaits de l'exercice.

Pendant l'évacuation nous avons testé du marquage photoluminescent dans les cages d'escaliers A, E et G tandis que la cage d'escaliers C étaient sous éclairage d'urgence. Dans les semaines à venir nous allons analyser les données capturées par les enregistrements vidéo ainsi que les données qui nous viennent des questionnaires retournés pour déterminer qu'elle installation était la meilleure. Si vous n'avez pas encore retourné votre questionnaire complété vous pouvez le déposer au bureau de TPSGC au niveau C Tour est. Nous vous aviserons lorsque les résultats de l'étude seront publiés.

APPENDIX B – Sample Materials MEA

NYC BUILDINGS

NYC Department of Buildings
280 Broadway, New York, NY 10007
Patricia Lancaster, FAIA, Commissioner
(212) 566-5000, TTY: (212) 566-4769

Report of Materials and Equipment Acceptance Division

Pursuant to Administrative Code Section 27-131, the following equipment or material has been found acceptable for use subject to the terms and conditions contained herein.

MEA 241-05-M

Manufacturer: Jessup Manufacturing Company
2815 W. Route 120 – P.O. Box 366
McHenry, IL 60051
Phone: 815-385-6650 Fax: 815-385-0079

Trade Name(s): Glo Brite®

Product: Glo Brite® #7550F – Flexible Film with Adhesive

Pertinent Code Section(s): §27-383(b), Reference Standards RS 6-1 and RS6-1A

Prescribed Test(s):
1. - Brightness Rating - ISO 17398:2004
2. - Washability ASTM D 4828-1994 (2003)
3. - Toxicity Bombardier SMP 800-C
4. - Radioactivity ASTM D 3648-2004
5. - Flame Spread ASTM E 162-2002 or ASTM D 635-2003

Laboratory:
Bodycote Materials Testing NA – Tests: 3 &5
California Institute of Electronics & Material Science – Test 4
DL Labs Inc – Test 2
Intertek Group ETL – Test 1

Test Report(s):
Bodycote Materials Testing NA – Report #05-02-339(A) 5/16/05 and Report #05-02-422(A) Rev. 1 – 6/17/05
California Institute of Electronics & Material Science Report #850950281 – 5/18/05
DL Labs Inc. – Report #DL-14484A-1 – 6/14/05
Intertek Group ETL – Report #3078094-002 – 6/9/05

Description:

Flexible film coated with a high tack pressure sensitive and backed with poly coated release liner. Safety grade photoluminescent material to meet requirements of RS6-1 NYC LL26.

Model Number	Catalogue Description	Size (Approx.)
50F-1SN-F	Directional Sign - Forward	4.5" x 8"
50F-1SN-UR	Directional Sign – Up Right	4.5" x 8"

Accepted August 4, 2005 MEA 241-05-M Page 1 of 3

Model Number	Catalogue Description	Size (Approx.)
50F-1SN-R	Directional Sign – Right	4.5" x 8"
50F-1SN-DR	Directional Sign – Down Right	4.5" x 8"
50F-1SN-D	Directional Sign – Down	4.5" x 8"
50F-1SN-DL	Directional Sign – Down Left	4.5" x 8"
50F-1SN-L	Directional Sign – Left	4.5" x 8"
50F-1SN-UL	Directional Sign – Up Left	4.5" x 8"
50F-2SN-R	Exit Sign- Right	4.5" x 13"
50F-2SN-L	Exit Sign – Left	4.5" x 13"
50F-3SN-R	Final Exit Sign – Right	11" x 8"
50F-3SN-UR	Final Exit Sign – Up Right	11" x 8"
50F-3SN-UL	Final Exit Sign – Up Left	11" x 8"
50F-3SN-L	Final Exit Sign – Left	11" x 8"
50F-3SN-C	Final Exit Sign – Custom Legend	11" x 8"
50F-4SN-R	Exit Through Lobby Sign – Right	7" x 16"
50F-4SN-UR	Exit Through Lobby Sign – Up Right	7" x 16"
50F-4SN-UL	Exit Through Lobby Sign – Up Left	7" x 16"
50F-4SN-L	Exit Through Lobby Sign – Left	7" x 16"
50F-4SN-C	Exit Through Lobby Sign – Custom Legend	7" x 16"
50F-5SN	Not An Exit Sign	6.5" x 5.5"
50F-5SN-C	Not An Exit Sign – Custom Legend	6.5" x 5.5"
50F-6SN-R	Wall Mount Exit Sign – Right	9" x 8"
50F-6SN-UR	Wall Mount Exit Sign – Up Right	9" x 8"
50F-6SN-DR	Wall Mount Exit Sign – Down Right	9" x 8"
50F-6SN-DL	Wall Mount Exit Sign – Down Left	9" x 8"
50F-6SN-UL	Wall Mount Exit Sign – Up Left	9" x 8"
50F-6SN-L	Wall Mount Exit Sign – Left	9" x 8"
50F-6SN-C	Wall Mount Exit Sign – Custom Legend	9" x 8"
50F-7SN-E	Door Handle Markers – Exit	6" x 4"
50F-7SN-P	Door Handle Markers – Push	6" x 4"
50F-7SN-C	Door Handle Markers – Custom Legend	6" x 4"
50F-8SN-C*	Stairwell & Floor Sign – Custom Legend	10" x 10"
50F-DH	4" x 4" Door Marker	4-1/16" x 4-1/16"
50F-DH-C	Custom Door Marker	16 sq. in. min.
50F-L1	1" x 3" x 9" Stair Marker	1" x 3" x 9"
50F-L2	2" x 4" x 9" Stair Marker	2" x 4" x 9"
50F-L1-C	1" x 3" x Custom Stair Marker	1" x 3" x custom
50F-L2-C	2" x 4" x Custom Stair Marker	2" x 4" x custom
50F-1	1" x 100 Ft. Rolls	1" x 100 ft.
50F-2	2" x 100 Ft. Rolls	2" x 100 ft.
50F-1STP	1" x 100 Ft. Rolls Stripe Tape	1" x 100 ft.
50F-2STP	2" x 100 Ft. Rolls Stripe Tape	2" x 100 ft.
50F-3STP	1" x 30 Ft. Rolls Stripe Tape	1" x 30 ft.
50F-4STP	2" x 30 Ft. Rolls Stripe Tape	2" x 30 ft.

Notes:

* The model(s) with asterisks comply with laboratory tests but do not satisfy the design and/or dimensional requirements for mandatory installations under Section 2.1 and 2.2 of RS6-1. These models with asterisks may be installed only as "additional signs and markings" under section 2.5 of RS 6-1.

Terms and Conditions:

1. Pathway markings of green color shall be in compliance with ANSI Z535.1 Safety Color Code.
2. Arrows and egress symbols shall comply with ISO 7010 E001, E002, E003, E004.
3. All approved materials shall be labeled and identified with the model number as well as with MEA No. 241-05-M, BR: 52-12-8 in a minimum of six (6) point type with at least one such identification on each piece of material installed in accordance with RS 6-1.
4. No radioactive materials are used.
5. All signs and markings shall conform to the pictorial representations submitted with this application.
6. All models directing persons to exits are to be installed at a low location so as not to confuse with other required exit signage.
7. No transparent or translucent overlaminates, varnishes, or other coatings shall be applied to the photoluminescent portions of the marking.
8. This acceptance is limited to the materials' use and does not include the installation for compliance with §27-383(b) and Reference Standard 6-1, which is the responsibility of the building owner.

All shipments and deliveries o/f photoluminescent exit path markings shall be provided with a certification from the manufacturer, certifying that the materials shipped or delivered are equivalent to those tested and accepted for use, as provided for in section 27-131 of the Building Code.

Final Acceptance August 4, 2005

Examined By Donald [signature]

APPENDIX C – Questionnaire on the Evacuation Drill

This survey is conducted by the National Research Council of Canada in partnership with Public Works and Government Services Canada to study the effectiveness of the photoluminescent wayguidance system installed in some of the stairwells. Completing this questionnaire is voluntary but we would greatly appreciate your assistance; each questionnaire will be kept confidential. Please return this questionnaire to one of the red boxes located in the elevator lobby.

SECTION 1: Background information

1- On which floor do you normally work? _______

2- In which tower? ☐ West ☐ East

3- Have you taken part in an evacuation in this building before? ☐ Yes ☐ No

4- Do you have limitations that could impede your evacuation?

☐ heart condition ☐ arthritis ☐ overweight ☐ vision impairment

☐ asthma ☐ injury ☐ hearing impairment ☐ mobility impairment

5- Your age: ☐ 20-30 ☐ 31-40 ☐ 41-50 ☐ 50 and over

6- Sex: ☐ F ☐ M

SECTION 2: The last evacuation drill

7- Did you hear the fire alarm? ☐ Yes ☐ No

8- In your opinion, was the alarm: ☐ too loud ☐ loud enough ☐ too quiet

9- Where were you when you heard the alarm or when the drill began?

Tower _________ Floor _________ Area/Room ___________

10- Which of the following actions did you do before starting your evacuation:

	Yes	No		Yes	No
return to your office	☐	☐	gather valuables	☐	☐
continue working	☐	☐	get dressed	☐	☐
seek more information	☐	☐	discuss with a colleague	☐	☐
secure files/information	☐	☐	follow wardens instruction	☐	☐

11- How much time did you spend, from the time the drill started, to the time you decided to leave the floor? ______minutes ________ seconds

12- Which stairwell did you use to evacuate?

☐ A ☐ B ☐ C

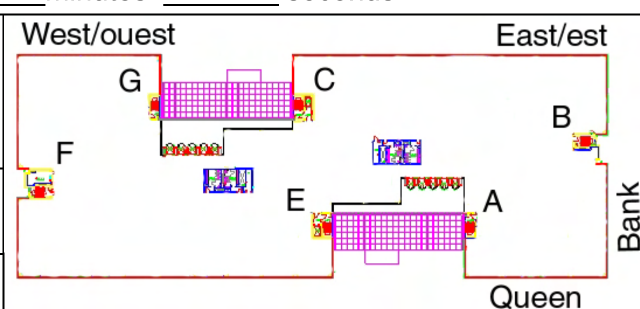
☐ E ☐ F ☐ G ☐ None

13- Was this stairwell your designated exit?

Yes No

14- Was this stairwell your closest exit?

Yes No



SECTION 3: In the stairwell

15- While using the staircase, did you have any of the following problems?

	Yes	No
a· furniture obstructed entry to staircase	☐	☐
b· people crowding around the entry to the staircase	☐	☐
c· difficulty opening the staircase door	☐	☐
d· too many people were coming down the stairs to enter	☐	☐
e· in the staircase, the opening of exit doors hampered movement	☐	☐
f· difficulty finding the handrail	☐	☐
g· difficulty seeing because of poor lighting	☐	☐
h· people from lower floor were coming up	☐	☐
i· people in front of you were moving too slowly	☐	☐
j· people were standing on the landing	☐	☐
k· difficulty finding the exit door at the base of the staircase	☐	☐
l· difficulty opening the exit door at the base of the staircase	☐	☐

16- Assuming you would have to evacuate under emergency lighting conditions, how would you judge the visibility in the stairwell you used?

☐ excellent ☐ good ☐ not very good ☐ poor

17- Indicate your degree of agreement with the following statements:

In the stairwell:	Strongly agree	Somewhat agree	Somewhat disagree	Strongly disagree
a· The handrail was easy to find	1	2	3	4
b· The first step of each flight was easy to locate	1	2	3	4
c· Each step was easy to identify	1	2	3	4
d· The last step of each flight was easy to find	1	2	3	4
e· Directional signs were visible	1	2	3	4
f· Obstructions were well marked	1	2	3	4
g· Re-entry floors were well identified	1	2	3	4
h· The final exit was well marked	1	2	3	4

18- Did you feel comfortable going down the stairs? ☐ Yes ☐ No

If not, explain why:

19- How would you describe the crowd density as you were descending the stairs:

☐ very crowded and slow ☐ few others around

☐ crowded but moving well ☐ I was alone

20- How much time did you take overall to evacuate the building; from the time the drill started to the time you reached the outside? ______minutes ________seconds

Thank you very much for your help.

<u>Please return this questionnaire to the red box by the elevator lobby</u>. If you have any questions or comments regarding this questionnaire or the evacuation drill, please contact Dr. Guylène Proulx of NRC at 613-993-9634 or Guylene.Proulx@nrc-cnrc.gc.ca. Any questions concerning the ethics of this research may be addressed to Diane Fafard, Secretary of the NRC Research Ethics Board at 613-991-9920 or Diane.Fafard@nrc-cnrc.gc.ca, referring to Protocol 2006-20.

Questionnaire sur l'exercice d'évacuation

La présente enquête est effectuée par le Conseil national de recherches du Canada en collaboration avec Travaux publics et Services gouvernementaux Canada pour étudier l'efficacité du système d'orientation photoluminescent installé dans certaines cages d'escalier. Il n'est pas obligatoire de remplir le présent questionnaire, mais nous apprécierions vivement votre collaboration. Chaque questionnaire sera confidentiel. Veuillez déposer le présent questionnaire dans l'une des boîtes rouges situées dans le hall des ascenseurs.

SECTION 1 : Renseignements généraux

1- À quel étage travaillez-vous habituellement? _____

2- Dans quelle tour? ☐ Ouest ☐ Est

3- Avez-vous déjà participé à l'évacuation de cet immeuble auparavant? ☐ Oui ☐ Non

4- Souffrez-vous d'une limitation qui pourrait nuire à votre évacuation?

☐ troubles cardiaques ☐ arthrite ☐ surpoids ☐ trouble de la vue

☐ asthme ☐ blessure ☐ trouble de l'ouïe ☐ trouble de la mobilité

5- Votre âge : ☐ 20-30 ans ☐ 31-40 ans ☐ 41-50 ans ☐ 50 ans ou plus

6- Sexe : ☐ F ☐ H

SECTION 2 : Le dernier exercice d'évacuation

7- Avez-vous entendu l'alarme incendie? ☐ Oui ☐ Non

8- À votre avis, l'alarme était : ☐ trop forte ☐ assez forte ☐ trop faible

9- Où étiez-vous lorsque vous avez entendu l'alarme ou lorsque l'exercice a commencé?

Tour _________ Étage _________ Zone/Pièce ___________

10- Parmi les actions suivantes, lesquelles avez-vous faites avant de commencer l'évacuation :

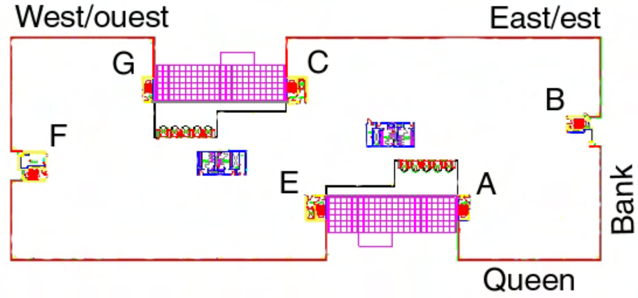
	Oui	Non		Oui	Non
retourner à votre bureau	☐	☐	rassembler vos objets personnels	☐	☐
continuer à travailler	☐	☐	vous vêtir	☐	☐
chercher plus d'information	☐	☐	discuter avec un(e) collègue	☐	☐
mettre vos dossiers en sûreté	☐	☐	suivre les directives des agents d'étage	☐	☐

11- Combien de temps avez-vous mis entre le début de l'exercice et le moment où vous avez décidé de quitter l'étage? ______minutes ________ secondes

12- Quelle cage d'escalier avez-vous empruntée pour l'évacuation??

☐ A ☐ B ☐ C

☐ E ☐ F ☐ G ☐ None



13- Cette cage d'escalier était-elle votre sortie assignée? ☐ Oui ☐ Non

14- Cette cage d'escalier était-elle la sortie la plus proche? ☐ Oui ☐ Non

SECTION 3 : Dans la cage d'escalier		
15- En utilisant la cage d'escalier, avez-vous eu un ou plusieurs des problèmes suivants?	Oui	Non
a· des meubles obstruaient l'accès à la cage d'escalier	☐	☐
b· des gens étaient attroupés à l'entrée de la cage d'escalier	☐	☐
c· la porte de la cage d'escalier était difficile à ouvrir	☐	☐
d· trop de gens descendaient les escaliers pour que vous puissiez entrer	☐	☐
e· dans la cage d'escalier l'ouverture des portes d'accès nuisait aux déplacements	☐	☐
f· difficulté à trouver la main courante	☐	☐
g· difficulté à voir en raison du faible éclairage	☐	☐
h· des gens provenant des étages inférieurs montaient l'escalier	☐	☐
i· des gens devant vous se déplaçaient trop lentement	☐	☐
j· des gens se tenaient sur le palier	☐	☐
k· difficulté à trouver la porte de sortie au bas de l'escalier	☐	☐
l· difficulté à ouvrir la porte de sortie au bas de l'escalier	☐	☐

16- À supposer que vous deviez évacuer l'immeuble avec juste l'éclairage d'urgence, veuillez évaluer la visibilité dans la cage d'escalier que vous avez utilisée.

☐ excellente ☐ bonne ☐ pas très bonne ☐ mauvaise

17- Indiquez à quel point vous êtes d'accord avec les affirmations suivantes :

Dans la cage d'escalier :	Totalement d'accord	Relativement d'accord	Relativement en désaccord	Totalement en désaccord
a· The handrail was easy to find	1	2	3	4
b· The first step of each flight was easy to locate	1	2	3	4
c· Each step was easy to identify	1	2	3	4
d· The last step of each flight was easy to find	1	2	3	4
e· Directional signs were visible	1	2	3	4
f· Obstructions were well marked	1	2	3	4
g· Re-entry floors were well identified	1	2	3	4
h· The final exit was well marked	1	2	3	4

18- Vous sentiez-vous à l'aise en descendant l'escalier? ☐ Oui ☐ Non

Dans la négative, veuillez expliquer pourquoi :

19- Veuillez décrire la densité de la circulation dans l'escalier :

☐ très bondé et lent ☐ quelques personnes

☐ bondé mais fluide ☐ J'étais seul(e)

20- Combien de temps au total avez-vous mis à évacuer l'immeuble (à partir du début de l'exercice jusqu'à ce que vous soyez à l'extérieur)? ______minutes ________secondes

Merci beaucoup de votre collaboration.

<u>Veuillez déposer le questionnaire complété dans la boîte rouge située dans le hall des ascenseurs</u>. Si vous avez des questions à propos du présent questionnaire ou de l'exercice d'évacuation, veuillez communiquer avec M^{me} Guylène Proulx du CNR, au 613-993 9634 ou par courriel à Guylene.Proulx@nrc-cnrc.gc.ca. Vous pouvez adresser vos questions ou vos commentaires concernant l'éthique de cette recherche à M^{me} Diane Fafard, secrétaire du comité, au 613-991-9920 (Diane.Fafard@nrc-cnrc.gc.ca), en mentionnant le protocole 2006-20.

APPENDIX D – Code Book for Questionnaire Analysis

Note: Value '99' for no response
Value '999' for not applicable

Question #	Variable #	Variable Name	Variable Description	Values	Added
	1	Case#	Respondent Number-Write it on top right corner		
	2	Stair_ID	Stairwell letter on the left corner of questionnaire	1= A 2= B 3= C 6= G	
1	3	Flr	Floor number where respondent normally work	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 12= Terrasse 13= Sub-level or S 14= B 15= C 16= Multiple floors 17= All floors	
2	4	Tower	Tower where respondent works	1= West 2= East 3= Both towers	
3	5	EvacBef	Evacuated this building before	1= Yes 2= No	
4	6	Limit	Do you have limitations	1= heart condition 2= arthritis 3= overweight 4= vision impairment 5= asthma 6= injury 7= hearing impairment 8= mobility impairment	
5	7	Age	Age of respondent	1= 20-30 2= 31-40 3= 41-50 4= 50 and over	
6	8	Sex	Sex	1= F 2= M	
7	9	Alm	Hear the fire alarm	1= Yes 2= No	
8	10	Alm_Snd	Sound of alarm	1 = too loud 2= loud enough 3= too quiet	
9	11	Loc_Twr	Where were you: Tower	1= West 2= East	
	12	Loc_Flr	Floor	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 12= terrasse 13= Sub-level or S 14= B 15= C	
	13	Loc_Rm	Area or room	1= a room number 2= office, cubicule 3= meeting room 4= coffee room 5= washroom 6= corridor, elevator 7= others	
10	14	Act_Rtn	Return to office	1= Yes 2= No	

Question #	Variable #	Variable Name	Variable Description	Values	Added
	15	Act_Wrk	Continue working	1= Yes 2= No	
	16	Act_ Info	Seek more information	1= Yes 2= No	
	17	Act_File	Secure files/information	1= Yes 2= No	
	18	Act_Valb	Gather valuables	1= Yes 2= No	
	19	Act_Dres	Get dressed	1= Yes 2= No	
	20	Act_ Disc	Discuss with a colleague	1= Yes 2= No	
	21	Act_Wrdn	Follow warden's instructions	1= Yes 2= No	
11	22	Start_Min	Time you decided to leave the floor- Minutes	0= minute 1= 1 minute 2= 2 minutes 3= 3 minutes 4= 4 minutes 5= 5 mintues 99= no answer to question 11	
	23	Start_Sec	Time you decided to leave the floor – Seconds	1= 0 to 15 seconds 2=16 to 30 seconds 3= 31 to 45 seconds 4= 46 to 60 seconds	
12	24	Str_Use	Stairwell use to evacuate	1= A 2= B 3= C 4= E 5= F 6= G 7= None	
13	25	Str_Dsgn	Stairwell designated exit	1= Yes 2= No	
14	26	Str_Clos	Stairwell closest exit	1= Yes 2= No	
15	27	Furniture	Furniture obstructed entry	1= Yes 2= No	
	28	Crowd	People crowding around entry	1= Yes 2= No	
	29	Diff_Open	Difficulty opening door	1= Yes 2= No	
	30	Ppl_down	People coming down	1= Yes 2= No	
	31	Open_Dor	Opening of exit doors hampered movement	1= Yes 2= No	
	32	Handrl	Finding handrail	1= Yes 2= No	
	33	Seeing	Seeing because of poor lighting	1= Yes 2= No	
	34	Ppl_up	People were coming up	1= Yes 2= No	
	35	Ppl_slow	People in front were moving slowly	1= Yes 2= No	
	36	Ppl_stand	People were standing on landing	1= Yes 2= No	
	37	Find_Dor	Finding the exit door at base	1= Yes 2= No	

Question #	Variable #	Variable Name	Variable Description	Values	Added
	38	Opn_do_b	Opening exit door at base	1= Yes 2= No	
16	39	Visible	Judge visibility	1= excellent 2= good 3= not very good 4= poor	
17	40	Ag_Handr	Handrail was easy to find	1= Strongly agree 2= Somewhat agree 3= Somewhat disagree 4= Strongly disagree	
	41	Step_Fli	First step of each flight was easy to locate	1= Strongly agree 2= Somewhat agree 3= Somewhat disagree 4= Strongly disagree	
	42	Each_Stp	Each step was easy to identify	1= Strongly agree 2= Somewhat agree 3= Somewhat disagree 4= Strongly disagree	
	43	Last_Stp	Last step of each flight easy to find	1= Strongly agree 2= Somewhat agree 3= Somewhat disagree 4= Strongly disagree	
	44	SignVis	Directional signs were visible	1= Strongly agree 2= Somewhat agree 3= Somewhat disagree 4= Strongly disagree	
	45	Obstruc	Obstructions well marked	1= Strongly agree 2= Somewhat agree 3= Somewhat disagree 4= Strongly disagree	
	46	Re_Entry	Re-entry floors well identified	1= Strongly agree 2= Somewhat agree 3= Somewhat disagree 4= Strongly disagree	
	47	FinalExt	Final exit well marked	1= Strongly agree 2= Somewhat agree 3= Somewhat disagree 4= Strongly disagree	
18	48	Feel_Cmf	Feel comfortable going down	1= Yes 2= No	
19	49	Crwd_Ds	Describe crowd density	1= very crowded and slow 2= few others around 3= crowded but moving well 4= I was alone	
20	50	Evac_Min	Time to evacuate the building- Minutes	0= 0 minute 1= 1 minute 2= 2 minutes 3= 3 minutes 4= 4 minutes 5= 5 minutes 6= 6 minutes 7= 7 minutes 8= 8 minutes 9= 9 minutes 10= 10 minutes 11= 11 minutes 12= 12 minutes 50= more than 12 minutes 99= no answer to question 20	
	51	Evac_Sec	Time to evacuate the building- Seconds	1= 0 to 15 seconds 2=16 to 30 seconds	

Question #	Variable #	Variable Name	Variable Description	Values	Added
				3= 31 to 45 seconds 4= 46 to 60 seconds	
	52	Commt	Any handwritten comments of importance	1= Yes 2= No	

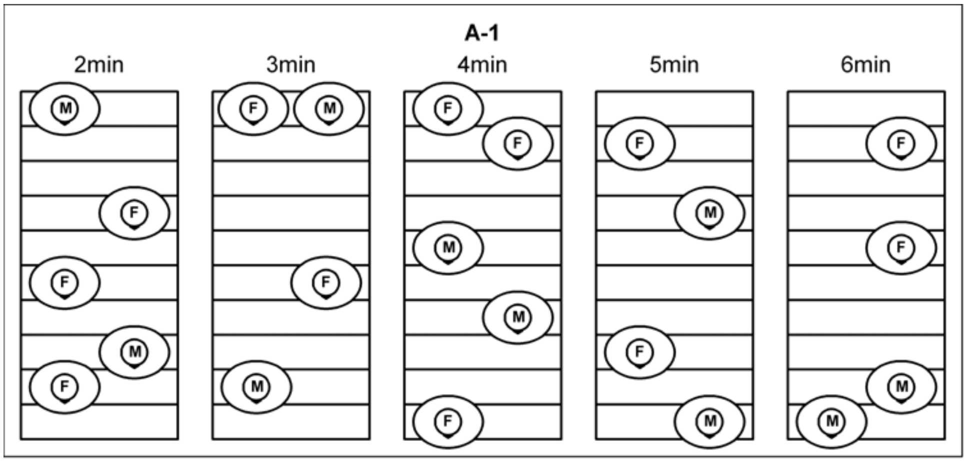
APPENDIX E – PLM Signs Location

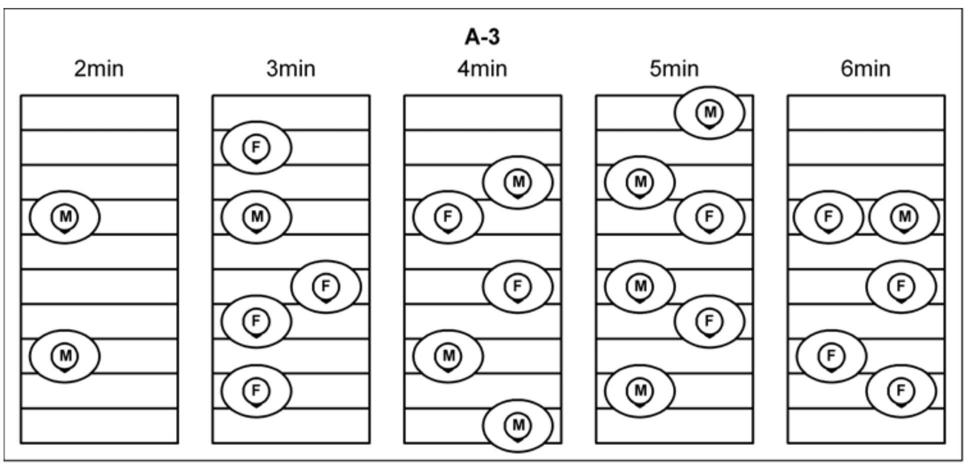
Sizes of Lettering				C.D. Howe PLM Evacuation Study		
	Black Text 5.5"			Building Specific Signage		
	Blue Text 1"					
Floor / Level	**On-door Stairwell**			**Walls @ Floor landing Stairwell**		
	A	**E**	**G**	**A**	**E**	**G**
T	A - T	E - T	G - T			
	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT NO ROOF ACCESS / PAS D'ACCÈS AU TOÎT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT NO ROOF ACCESS / PAS D'ACCÈS AU TOÎT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT
11	A - 11	E - 11	G - 11			
10	A - 10	E - 10	G - 10			
9	A - 9	E - 9	G - 9			
	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT
8	A - 8	E - 8	G - 8			
				NO ROOF ACCESS / PAS D'ACCÈS AU TOÎT	NO ROOF ACCESS / PAS D'ACCÈS AU TOÎT	
7	A - 7	E - 7	G - 7			
6	A - 6	E - 6	G - 6			
5	A - 5	E - 5	G - 5			
	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT			CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT		
4	A – 4	E - 4	G - 4			
		CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT		CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT
3	A – 3	E - 3	G - 3			

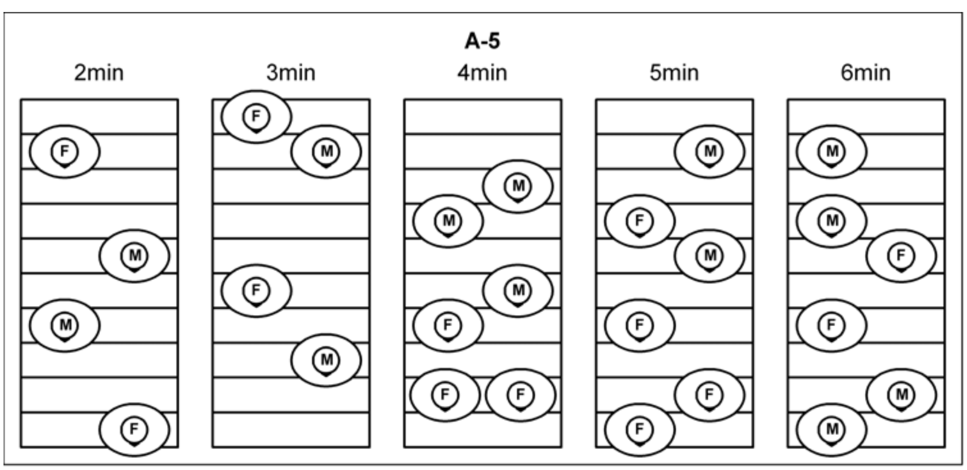
				NO ROOF ACCESS / PAS D'ACCÈS AU TOÎT		NO ROOF ACCESS / PAS D'ACCÈS AU TOÎT
2 **1**	A – 2 A – 1	E - 2 E - 1	G - 2 G - 1			
	CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT			CROSS-OVER FLOOR / ÉTAGE DE TRANSFERT EMERGENCY EXIT AT LEVEL "B" - STREET LEVEL SORTIE D'URGENCE NIVEAU "B" - NIVEAU DE LA RUE	EMERGENCY EXIT AT LEVEL "B" - STREET LEVEL SORTIE D'URGENCE NIVEAU "B" - NIVEAU DE LA RUE	EMERGENCY EXIT AT LEVEL "B" - STREET LEVEL SORTIE D'URGENCE NIVEAU "B" - NIVEAU DE LA RUE
C **B**	A - LEVEL / NIVEAU = C EXIT TO STREET / SORTIE SUR LA RUE	E - LEVEL / NIVEAU = C EXIT TO STREET / SORTIE SUR LA RUE	G - LEVEL / NIVEAU = C EXIT TO STREET / SORTIE SUR LA RUE	3 - EXIT AT LEVEL "B" / SORTIE AU NIVEAU "B"	3 - EXIT AT LEVEL "B" / SORTIE AU NIVEAU "B"	2 - EXIT AT LEVEL "B" / SORTIE AU NIVEAU "B"

APPENDIX F – Density Drawings

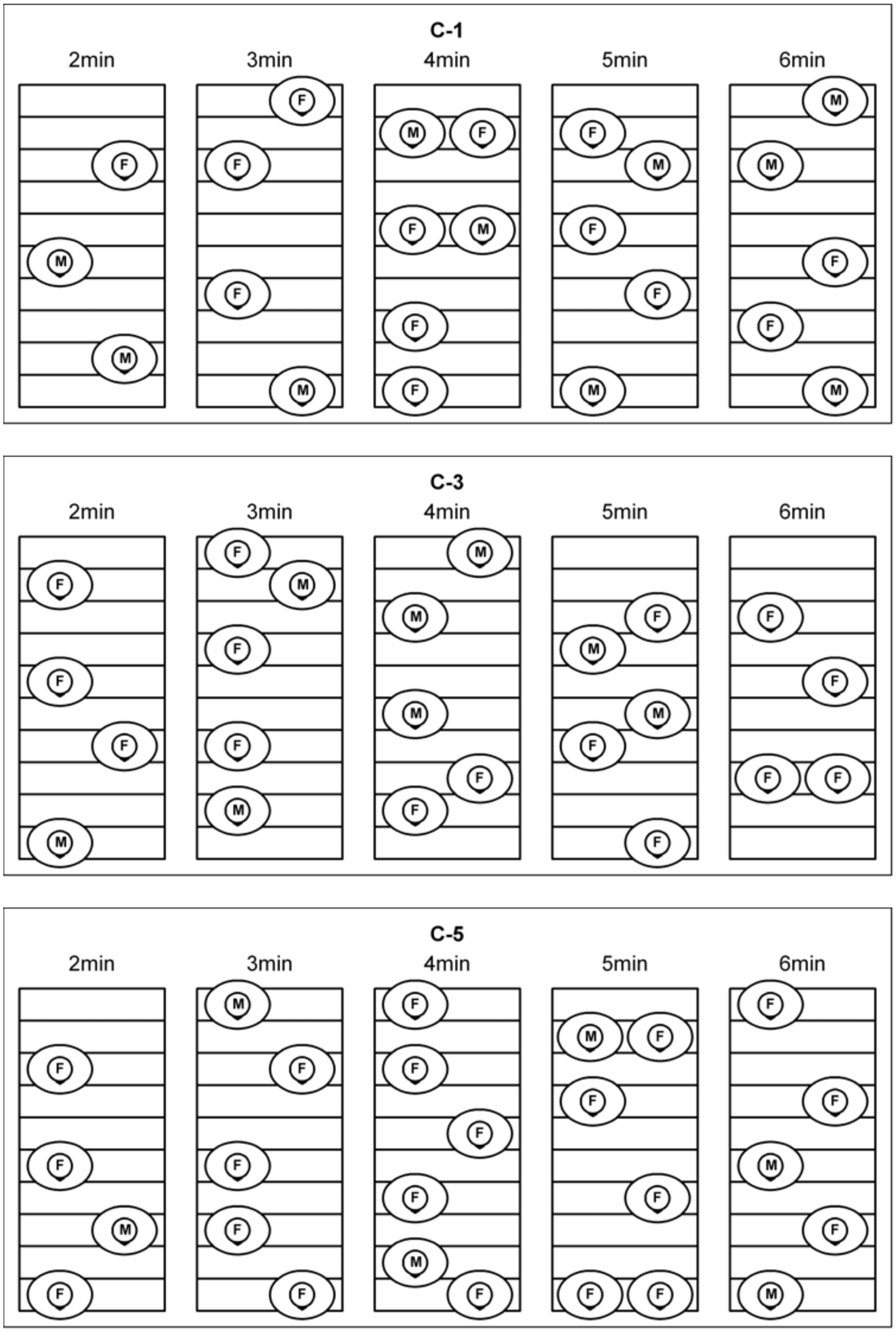
Stairwell A



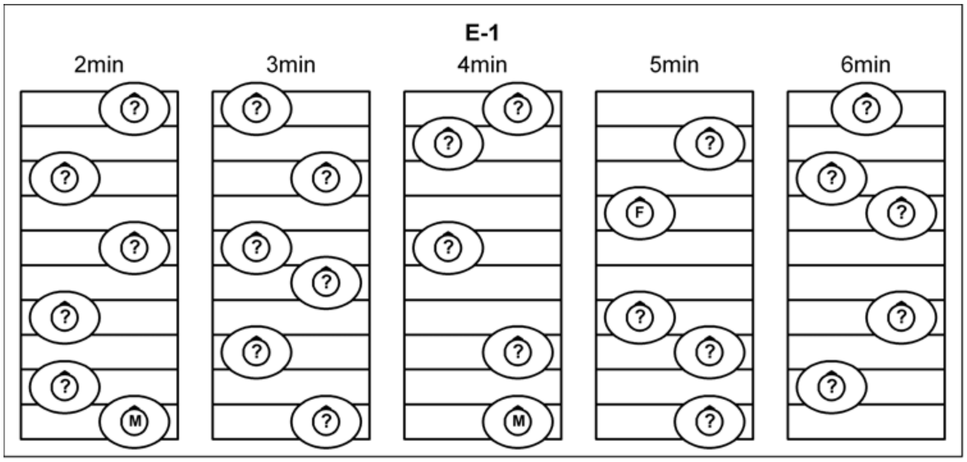




Stairwell C


C-1
2min
3min
4min
5min
6min
C-3
2min
3min
4min
5min
6min
C-5
2min
3min
4min
5min
6min

Stairwell E


E-1
2min
3min
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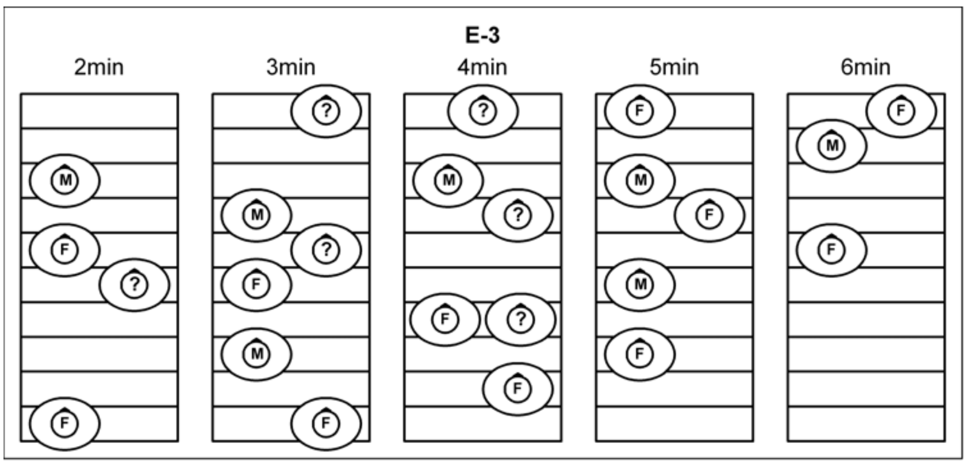
5min
6min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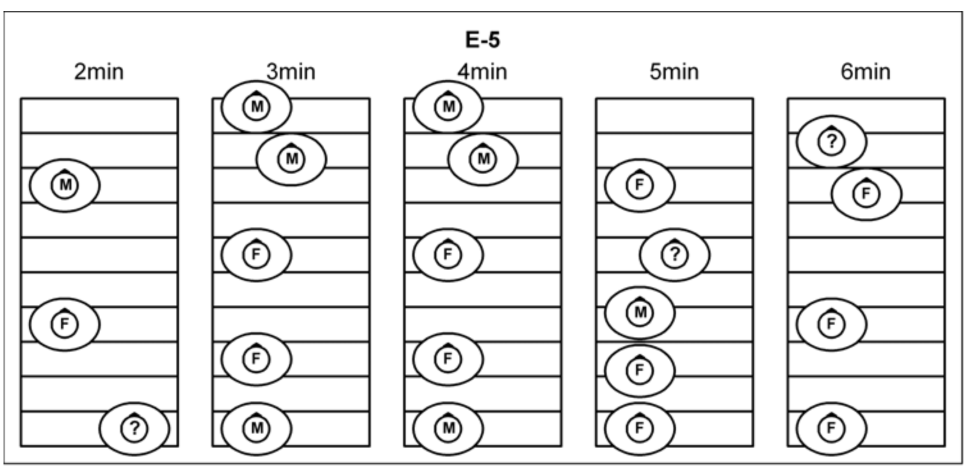
5min
6min


E-5
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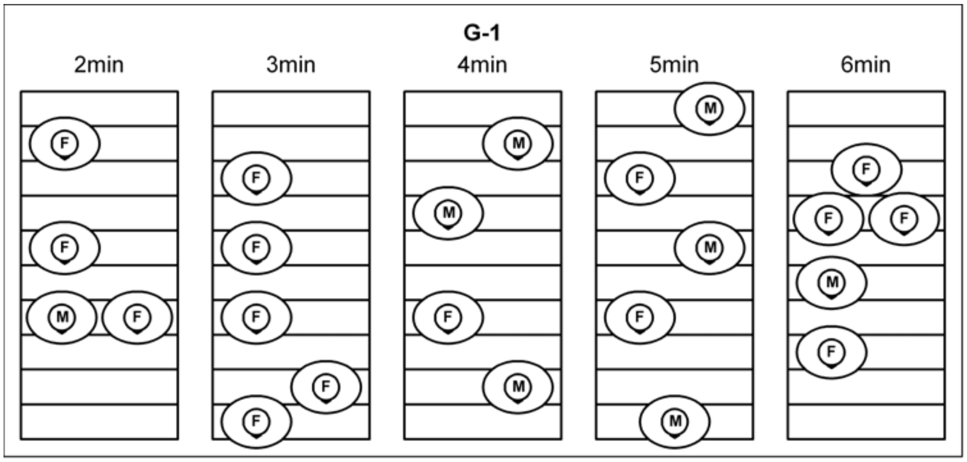
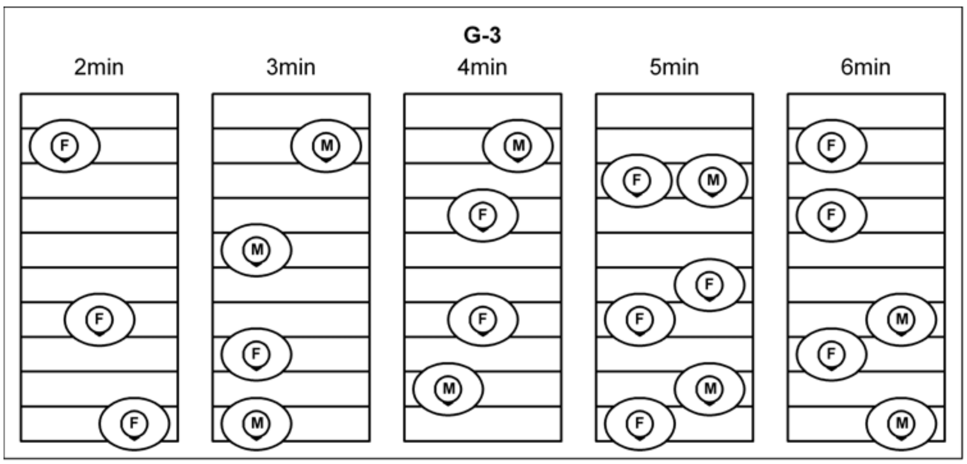
3min
4min
5min
6min

Stairwell G


G-1
2min
3min
4min
5min
6min
F
M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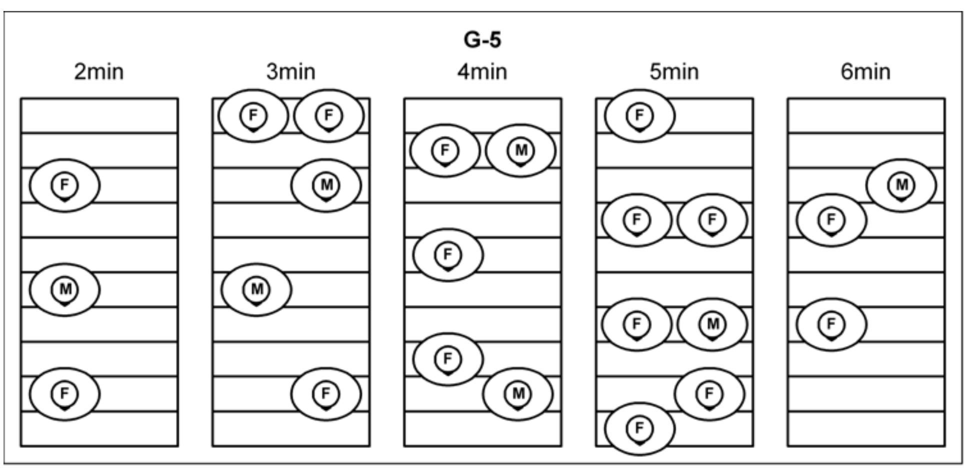
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F
M