Home Office

Research and analysis

Strategies for evacuation of occupants from high-rise residential buildings involved in fire

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Applies to England

Contents

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This publication is available at https://www.gov.uk/government/publications/evacuation-from-high-rise-residential-buildings-involved-in-fire/strategies-for-evacuation-of-occupants-from-high-rise-residential-buildings-involved-in-fire

1. Executive summary

This is a Home Office summary report of live evacuation testing research conducted by the University of Central Lancashire (UCLan) to test the efficiency of evacuation strategies from high-rise residential buildings (HRRBs) using 5 live operational testing strategies. The Home Office derived this summary in its entirety from the original live evacuation testing research conducted by UCLan and reflects UCLan's analysis and interpretation of the original dataset. This summary helps make findings accessible to a wide range of stakeholders in the fire and rescue service sector.

The Home Office derived the following research questions based on the methodology applied:

Research Question 1: Which strategies are likely to lead to the fastest evacuation of a high-rise residential building?

Research Question 2: To what extent do each of the evacuation strategies lead to congestion in stairwells?

Research Question 3: What impact do evacuees with impairments have on evacuations?

Research Question 4: What further factors could affect live evacuations from high-rise residential buildings?

Research Question 5: How accurately can Pathfinder modelling software simulate the live evacuation testing?

The study comprised live operational tests of 5 evacuation strategies between 3 and 6 May 2022, using fire and rescue service (FRS) staff and other volunteers from stakeholder groups to act as residents. The research tested 5 evacuation strategies of a HRRB during a fire incident when it becomes untenable to expect residents to remain in the building, and the FRS Officer in Charge (OIC) initiates a full evacuation.

These results cover one of the 2 tests conducted for each of the following 5 strategies. For each strategy tested, UCLan processed data with the most complete video data. Tests analysed were:

Test 1-1 of Strategy 1: A full simultaneous evacuation using an Evacuation Alert System (single staircase).

Test 2-2 of Strategy 2: A full evacuation with door-knocking alerts from bottom to top of the building, without an Evacuation Alert System (single staircase).

Test 3A-2 of Strategy 3A: A full evacuation using an Evacuation Alert System (single staircase): phased bottom-up from above the fire.

Test 3B-2 of Strategy 3B: A full evacuation using an Evacuation Alert System (single staircase): phased top-down from above the fire.

Test 4-2 of Strategy 4: A full simultaneous evacuation using an Evacuation Alert system with 2 staircases.

In this report, ‘strategy’ refers to the overall evacuation approach, whereas ‘test’ refers to the live trial of a strategy.

The results are limited to the specific conditions of the tests and by the number of tests performed, and so there is uncertainty around how results would be affected if the test conditions changed. The report has made comparisons between tests that are approximately equivalent. However, it should also be noted that while these controls created a degree of consistency between the strategy tests, there were multiple factors which changed between them, including the number of evacuees, which may have influenced the results.

1.1 Research Question 1: Which strategies are likely to lead to the fastest evacuation of a high-rise residential building?

The findings indicate that 2 staircases are likely to support a faster evacuation from a HRRB than one staircase. Where 2 staircases were used (one for evacuation and one for firefighting), evacuation times were shorter than all other evacuation strategies. Strategy 1 and Strategy 4 both tested full evacuations with an Evacuation Alert System (EAS). Test 4-2 (with 2 staircases) was completed in 9 minutes 2 seconds (542 seconds), approximately half the time of Test 1-1 (with single-staircase), which was completed in 19 minutes 15 seconds (1,155 seconds).

For operational decision-makers, the findings suggest that using an EAS (Strategy 1) results in faster evacuation than a door knocking system (Strategy 2). In Test 1-1, the EAS sounded on all floors within 2 minutes and the final evacuee left within 20 minutes. Whereas in Test 2-2, where the test replicated manual floor-by-floor door knocking, it took over 28 minutes to complete.

The findings were not clear in showing whether either a ‘top-down’ or ‘bottom-up’ evacuation strategy is faster and should be preferred during an evacuation. While the ‘top-down’ test was completed in less time than ‘bottom-up’, confounding variables in the tests mean further research would be required to establish robust conclusions. It should also be noted that the effectiveness of such evacuation strategies would also be sensitive to several factors not explored here (for example, different building configurations, fire location)

1.2 Research Question 2: To what extent do each of the evacuation strategies lead to congestion in stairwells?

Findings identified more congestion developed following the EAS signal (Strategy 1) than when firefighters co-ordinated the timing of door-knocking signals on floors (Strategy 2). When the door-knocking strategy was applied, the maximum queue length was 6 people, compared with queues of up to 25 people in stairwells when EAS was used. This was possibly due to the EAS more effectively initiating evacuation movement.

Higher levels of congestion did not necessarily lead to slower evacuation time. While the double-staircase test (Test 4-2) resulted in large queues behind evacuees walking with crutches, the queues did not prevent the 2-staircase firefighting and evacuation completing in far less time (by over 10 minutes) than when firefighting and evacuation combined in a single staircase (Test 1-1). In Test 4-2, the total evacuation time was 9 minutes 2 seconds (542 seconds) with 79 participants, whereas Test 1-1 had a total evacuation time of 19 minutes 15 seconds (1,155 seconds) with 80 participants.

Evacuees moving at a slower pace often caused congestion. Queues formed where evacuees were ‘caught up’ with those moving at a slower pace and occupying additional space in stairwells. This included some who were asked to walk at half pace with crutches, and evacuation chairs guided by one or 2 other people (evacuees or firefighters).

When implementing strategies as part of real evacuation plans, consideration should be given to potential congestion. As well as affecting evacuation time, congestion may have further consequences, such as increased likelihood of slips and delays to access the staircase. It should also be noted that the emotional impact of congestion was not tested, and that this may impact overall evacuation times in a live situation.

1.3 Research Question 3: What impact do evacuees with impairments have on evacuations?

Indicative findings suggest that people evacuating other residents on evacuation chairs can delay the movement of those evacuees behind them. Such delays may also be affected by the degree of familiarity with the evacuation chair equipment and (for firefighters) the cumbersome nature of the equipment worn.

The higher the floor where the residents with impairments were located, the greater the total evacuation time for the evacuees behind them. There was evidence for Tests 1-1, 2-2 and 3A-2 that speeds may be limited for those starting on higher floors, because the transit of evacuees with mobility impairments impacted the speed of those joining stairwells from higher floors.

The appropriate evacuation strategy may also vary depending on the evacuee’s specific needs, but this study did not find consistency in how evacuation needs impacted upon speed. This may be due to the different evacuation needs – for instance, one evacuee was assisted while others were moving under their own volition. In Test 1-1 (Strategy 1), it was observed that evacuation chairs can move at greater speeds than some evacuees walking with crutches, whereas in Test 2-2 (Strategy 2), the opposite was observed.

1.4 Research Question 4: What further factors could affect live evacuations from high-rise residential buildings?

Local movement speed varied by floor. Faster speeds were generally recorded at lower floors, with slower speeds at the top and in the middle floors of the building, close to the fire, where obstacles and congestions were more likely to be present.

For the majority of evacuees, there was no clear effect of having obstacles on the floor, such as hoses. But it was observed that the speed of evacuees with impairments, especially those using crutches, was reduced on those floors.

Evacuees who were instructed to climb stairwells first, rather than immediately evacuate, did not have a demonstrable negative effect on other evacuees. However, the impact of upward movement of evacuees cannot be ruled out when combined with other factors, such as flow density and evacuees with mobility impairments descending.

Similarly, movement of firefighters within the staircase did not appear to have a major impact on evacuation times. However, in some instances where the OIC initiated the activation of the EAS after receiving information that the preceding floor had been cleared, the counter flow of firefighters moving to alert higher floors impacted on movement speed of some evacuees.

1.5 Research Question 5: How accurately can Pathfinder modelling software simulate the live evacuation testing?

The findings suggest that the Pathfinder modelling software, using data from live operational tests, may accurately predict these outcomes via software simulations. This would help reduce the need for full-scale live operational tests to consider changes in evacuation scenario parameters (or might enhance confidence in the test results by allowing replication).

However, it should also be noted that the close match to the live operational tests may be due to an element of over-fitting in the model. This is shown through model variables being tailored to observations from the trial, rather than to expected values from literature. This significantly reduces the extent to which the results can be extrapolated to other strategies.

Overall, the Pathfinder modelling software gave reasonable predictions of results for 4 of the strategies tested (Strategy 1, 2, 3A and 3B), but not for Strategy 4 (which used 2 staircases).

2. Introduction

This is a Home Office summary research report of live evacuation testing conducted by the University of Central Lancashire (UCLan) to test the efficiency of evacuation strategies from high-rise residential buildings (HRRBs) using 5 live operational testing strategies. The Home Office commissioned UCLan to conduct live evacuation testing and follow-up modelling to provide evidence to support the development of national guidelines for carrying out evacuations from HRRBs, which was a recommendation from the Grenfell Tower Inquiry Phase 1 (https://fireengland.uk/quarterly-thematic-update-grenfell-tower-inquiry-phase-1/evacuation). This report summarises key details from a longer paper written by UCLan.

2.1 Acknowledgements

We would like to thank the London Fire Brigade (LFB) for providing access to the building in which UCLan conducted the testing and for the staff who helped run and participate in the live testing. We are also very grateful to all the participants who acted as residents in the evacuation tests. We would like to thank UCLan for managing the study and providing the data and much of the content included within this report (Dr Shephard Ndlovu, James Fowler, Dr Eleni Asimakopoulou, Prof Champika Liyanage, Dr Gabriel Ernesto Castelblanc, Dr Khalid Khan, Dr Howard Parkinson, Daniel Basher and Dr Jianqiang Mai). We would also like to thank DCCH Experts LLP for their technical guidance during the design of the experimental procedure. This summary was edited by Will Dawes, Darrelle Cocozza, Clare Lambley, Amy Butler, Alice Plumridge, and Silviya Gancheva from the Home Office.

2.2 Context and background

This report discusses the findings of live evacuation tests conducted in May 2022 and computer modelling based on evacuation simulations. This research sought to explore the most effective methods of evacuating people from HRRBs. The UCLan research team conducted a scoping study prior to the design of the live testing, comprising a literature review and engagement with over 400 key stakeholders, through semi-structured interviews and questionnaires, to understand their experience and views on evacuation from HRRBs. Stakeholders included professional firefighters, building managers and occupants of HRRBs. The scoping study informed the design and methodology of subsequent live evacuation tests. It was recommended that controls should be incorporated into the design to enable consistency with live evacuation tests. This included exploring the impact that residents with impairments and standard firefighting procedures had on each evacuation strategy.

The British Standard for the application of fire safety engineering, BS7974 (BSI, 2019), states that for complex buildings and HRRBs, the fire alarm system should be a hub of both alerting occupants and of connecting with other building management systems. However, stakeholder consultation revealed a research gap around alarm systems, and that only a minority of residents were aware of an Evacuation Alert System (EAS) in their building. As such, this study examines the use of EASs and how they impact on evacuation times. Using findings from the scoping study, the Home Office and UCLan designed a range of tests to understand efficient evacuation strategies.

2.3 Objective and research questions

The objective of this study was to test a range of evacuation strategies in HRRBs to assess the efficiency of the evacuation procedures. While the Home Office set high-level research questions when commissioning UCLan, through the course of scoping and designing the methodology, these questions were not directly assessed in the live operational testing. The Home Office therefore derived the following research questions based on the methodology applied:

Research Question 1: Which strategies are likely to lead to the fastest evacuation of a high-rise residential building?

Research Question 2: To what extent do each of the evacuation strategies lead to congestion in stairwells?

Research Question 3: What impact do evacuees with impairments have on evacuations?

Research Question 4: What further factors could affect live evacuations from high-rise residential buildings?

Research Question 5: How accurately can Pathfinder modelling software simulate the live evacuation testing?

2.4 Evacuation definitions

Evacuation: the direction of people from a dangerous place to somewhere safe.

Simultaneous evacuation: a strategy in which all occupants vacate the building at the same time regardless of their threat exposure prior to evacuation.

Phased evacuation: a strategy in which only occupants at an elevated risk are initially evacuated (such as those in the immediate vicinity of the fire), while others remain in place for later evacuation.

3. Method

The study comprised live operational tests of 5 evacuation strategies between 3 and 6 May 2022, using fire and rescue service (FRS) staff and other volunteers from stakeholder groups to act as residents. These were tests of potential evacuation strategies for situations in which it becomes untenable to expect residents to remain in the building under 'stay put' (NFCC, 2017), and so the FRS Officer in Charge (OIC) initiates a full evacuation.

3.1 Evacuation strategies

UCLan tested evacuation strategies twice for each of the following 5 tests (as detailed further in Appendix 2) over a 4-day period, based on the HRRB evacuation strategies identified in the project scoping phase:

Strategy 1 (Test 1-1): A full simultaneous evacuation using an Evacuation Alert System (with a single staircase).

Strategy 2 (Test 2-2): A full evacuation using door knocking, without an Evacuation Alert System (with a single staircase).

Strategy 3A (Test 3A-2): A full evacuation using an Evacuation Alert System (with a single staircase): phased bottom-up from above the fire.

Strategy 3B (Test 3B-2): A full evacuation using an Evacuation Alert System (with a single staircase): phased top-down from above the fire.

Strategy 4 (Test 4-2): A full simultaneous evacuation using an Evacuation Alert System (with 2 staircases).

In this report, ‘strategy’ refers to the overall evacuation approach, whereas ‘test’ refers to the live trial of a strategy.

3.2 Overview of tests

A disused 17-storey tower block used by LFB for various exercises was selected for the evacuation tests as an example of a typical UK HRRB.

For each test, the fire started on floor 6 and was assumed to spread upward to floors 7 and 8. FRS Stairwell Protection Teams (SPT) initiated the evacuation tests based on the Standard Operating Procedures (SOPs) and operational techniques appropriate to this incident (LFB, 2021, LFB, 2017 and NFCC, 2022). Important features of each strategy are as follows.

Strategies 2, 3A and 3B involved FRS evacuating each floor in phases replicating either a floor-by-floor EAS (3A and 3B) or door knocking (Strategy 2). The command given to evacuate each floor level was given on the direction of the Incident Commander based on SOPs and the actual operational activity in the strategy being tested. The time intervals depended on the actual operational activity so cannot be given with precision.

Strategies 1 and 4 used an EAS to alert residents on all floors almost immediately, rather than floor by floor. As such, simultaneous evacuation took place once the alert was given.

Other than for Strategy 1, in which everyone evacuated simultaneously, those on the floor of the fire (floor 6) and the 2 floors immediately above the fire (floors 7 and 8) were evacuated first.

For Strategy 3A, after evacuating the floors around the fire as above, the remaining floors were then evacuated at phased intervals working up sequentially from floor 9 to the top floor (floor 12). Strategy 3B used a similar strategy but instead evacuated ‘top-down’ sequentially from floor 12 to floor 9.

Each strategy (other than 4) was tested using the same stairwell in the block, and the lowest floor in which residents were based was floor 4. For Strategy 4, residents evacuated through another staircase from floor 2, while firefighters operated through the staircase used in the other tests.

Strategies 1, 2 and 4 were tested through the evacuation of 10 floors. Strategies 3A and 3B were tested through the evacuation of 9 floors to control for the different number of volunteers.

Timelines and scripts for the strategies tested were displayed on each locked flat door to instruct how volunteers, who were initially stationed outside the flat door at the beginning of the test, should move during evacuations.

Firefighters commenced each test by checking the ‘Secure Information Box’ (SIB) to identify the locations of residents who required the use of an evacuation chair. This helped firefighters to decide whose evacuation they would commence, if possible, with support from other residents during the early stages of the fire incident (that is, within the first 8 minutes). During the tests, these residents were originally positioned on floors 7 and 4.

It is known that movement speed reduces when the density of people in stairwells increases. Therefore, to maintain population density and demand for stairwell space, when volunteer numbers reduced (for example, through variable attendance, drop-outs), the highest floor was removed from the test (left empty). As such, only 9 floors were used for Tests 3A and 3B.

Each test was performed twice to mitigate the risk of problems occurring during the tests, such as unplanned actions of firefighters/volunteers or technical issues. This ensured there was a full set of video capture data suitable for analysis. The purpose of conducting tests twice was not to increase the statistical validity of any data produced. During tests, some cameras and memory cards failed, so UCLan processed video capture data for one version of each test. The version selected for each test was based on data completeness. The final floor coverage captured for each test and number of participants is shown in Appendix 3, table 6 (processed tests) and table 7 (non-processed tests).

3.3 Data collection

Each stairwell within the building was fitted with battery-powered digital video cameras to collect images and data throughout the tests. Video analytics helped assess stair usage, counter flows, flow rate (persons per minute), individual walking speeds (metres per second (m/s)), and total movement times. Additionally, researchers watched the videos to count evacuees, and to identify hold-ups and any resulting queues.

The ’experimental time’ presented throughout this report corresponds to the time elapsed after the switch from ‘stay put’ to each ‘full evacuation’ strategy. In this report, timings are generally presented as minutes and seconds, but may additionally be reported as seconds only, to correspond with the labelling of analytical graph axes.

3.4 Controls

Each evacuation test had the same fire incident conditions (type, location and resident profile) based on London Fire Brigade operational guidance (LFB, 2021 and LFB, 2017). Appendix 2 outlines the controls put in place throughout each test.

Where possible, volunteers participated in one of the 4 days of testing to avoid becoming overly familiarised with the tests. Literature (SFPE, 2019) has suggested that evacuation times could be reduced if the occupants are aware of the location of the closest exit routes and the existence of fire protective lifts, sprinklers and other safety measures. However, this research did not seek to test against occupant awareness of evacuation methods.

3.5 Participants

FRS recruited participants to act as evacuees using a detailed information sheet and consent form. Not all volunteers participated for the full day, meaning each of the 2 tests did not have the same volunteer populations (outlined in Appendix 3, table 4 and table 5). This report refers to residents, participants, volunteers and occupants as ‘individuals who acted as residents’.

The scoping phase found that few previous studies explicitly considered people with impairments. Therefore, all tests were planned to include at least 10% of evacuees briefed to represent residents with impairments. This provided a more realistic spread of evacuee mobility, occupation of space within stairwells and speed. Briefed evacuees with impairments were assigned specific roles, which included:

- individuals with a mobility impairment (all strategies tested), briefed to walk at half pace (including some using elbow crutches)
- mannequins on evacuation chairs assisted by residents and/or firefighters, used to simulate/represent individuals requiring this method of assistance (see evacuation strategy detail in Appendix 2
- an individual with a visual impairment holding a white cane (Strategies 3A and 3B)

It should also be noted that one volunteer took part with a 3-year-old child (Strategy 2).

In each test (except Test 4-2), one or 2 individuals were briefed to commence by moving up 2 floors (to replicate seeking another resident) from floor 10 while other people were going in the opposite direction, before evacuating at their own walking pace.

3.6 Assumptions and limitations

There are a range of assumptions and potential limitations associated with this research (set out in full in Appendix 7).

Key assumptions included that the external hallway EAS would be fully functioning. The research did not control for the impact of the built environment, smoke on visibility, pre-movement time and social interactions.

The UCLan research team planned the tests before the outcome of the 2021 Personal Emergency Evacuation Plans (PEEPs) consultation, using the prevailing terminology at that time.

The results are limited to the specific conditions of the tests and so there is uncertainty around how results would be affected if the test conditions changed. It should also be noted that while these controls created a degree of consistency between the strategy tests (that is, the same evacuation procedures were adopted aside from the differences in strategies tested), there were multiple factors which changed between them (for example, the number of evacuees, type of impairments present, firefighter activity). It is important to note that the tests did not always include the same numbers of floors. For example, Strategy 3A and 3B used 9 floors while the remaining tests used 10 floors). Similarly, Strategy 4 used a different evacuation stairwell to the other strategy tests. There were also large differences in the number of evacuee participants, meaning much caution should be applied when comparing strategies given some differences between the numbers of evacuees used in each test (the most extreme example was Test 3B-2 with 43 evacuees and Test 1-1 used 80 evacuees).

It is also important to note that the evacuation times are partly a function of the method of evacuation alert and not just the movement times of evacuees. For example, all residents were notified at once in Strategy 1, but for Strategy 2, firefighters verbally notified (as a proxy for door-knocking) each floor, taking approximately 23 minutes to notify the final floor in Test 2-2.

Some participants were instructed to simulate evacuees with impairments, such as using crutches at half pace or carrying people in evacuation chairs. While instruction sought to ensure the impact of these impairments was replicated, other factors may have impacted evacuation speed (for example, familiarity of use of crutches).

In addition, although 2 tests were completed for each strategy, the results are based on a single test of each strategy. This introduces some uncertainty around whether the results would be consistent if tested on multiple occasions. It also makes deriving clear conclusions on what is being tested more challenging (that is, assigning outcomes of research to any one specific change in the test conditions) and softens many of the conclusions.

The research is based on the travel times of participants down the building's stairwell. It should be noted that the participant evacuation times did not consider:

- the additional response times for FRS to get onsite, as all tests in the research had the service response starting on site
- the additional response times within flats after an alarm was raised and movement from initial location to doorway, as volunteers did not have access to flats and instead began the test at the doorway
- the additional response times for participants who were in evacuation chairs; by using mannequins in evacuation chairs, reaction times do not consider a wheelchair user's possible exit from a flat, their transfer into an evacuation chair, the likelihood that a person would not weigh the same as a mannequin, nor that a wheelchair may be a possible obstruction in a hallway for other individuals

Although there were limitations, they were present throughout all evacuation strategies and did not affect any individual scenario.

3.7 How the data collected will address the research questions

Research Question 1 (Which strategies are likely to lead to the fastest evacuation of a high-rise residential building?) will be primarily answered through 'building exit curves' (percentage exited by time elapsed). It will also consider flow rate (persons per minute), individual walking speeds (m/s), and total evacuation times. The question will specifically look to compare evacuation times across evacuation strategies, with an emphasis on looking at the effectiveness of EASs, the sequence in which floors above the fire were evacuated and the use of one versus 2 stairwells.

Research Questions 2 (To what extent do each of the evacuation strategies lead to congestion in stairwells?) and **Research Question 3 (What impact do evacuees with impairments have on evacuations?)** will be assessed through video analysis of queues, congestion and individual walking speeds. The questions will also be answered through the assessment of movement of individual evacuees (using person IDs) through each floor of the building by time elapsed and speed. This will allow analysis of flows and bottlenecks to be reviewed to identify potential contributory factors, such as unusual actions (for example, walking upwards) or the presence of evacuees with impairments.

Research Question 4 (What further factors could affect live evacuations from HRRB?) seeks to understand any qualitative factors, not addressed in Research Questions 1 to 3, that were observed during the tests and may impact evacuations (such as those in relation to the evacuation test, the building or behaviour of participants). It will use video analysis to review indicators such as blockages and other factors influencing the outcomes of each strategy tested.

Research Question 5 (How accurately can Pathfinder modelling software simulate the live evacuation testing?) will be addressed through the replication of each of the 5 strategies using Pathfinder simulation software and will use speed and total evacuation times as key metrics.

4. Test results

4.1 Summary of results

These results cover one of the 2 tests conducted for each strategy, which had the most complete video data. Tests analysed were:

Test 1-1 of Strategy 1: A full evacuation using an Evacuation Alert System (single staircase).

Test 2-2 of Strategy 2: A full evacuation using door knocking, without an Evacuation Alert System (single staircase).

Test 3A-2 of Strategy 3A: A full evacuation using an Evacuation Alert System (single staircase): phased bottom-up.

Test 3B-2 of Strategy 3B: A full evacuation using an Evacuation Alert System (single staircase): phased top-down.

Test 4-2 of Strategy 4: A full evacuation using an Evacuation Alert System (2 staircases).

Test 1-1 (Strategy 1) and Test 4-2 (Strategy 4) used simultaneous evacuation on commencement of the EAS. Strategy 2 (2-2) used a door knocking strategy but did not use an EAS.

In Tests 1 and 2, volunteers were originally positioned across 10 floors (floors 13 to 4), while in Test 3A and 3B, volunteers were originally positioned across 9 floors (floors 12 to 4). Test 4 also had volunteers originally positioned across 10 floors, however, they were on floors 2 to 11.

Table 1 presents the evacuation times for all tests at the first camera sighting (when the cameras first pick up movement, indicating that the evacuation has started), and when 25%, 50%, 75% and 100% of participants have evacuated (the total evacuation time).

Any comparisons made between tests should be made with caution, especially where the number of evacuees and floors used were different. This particularly limits comparisons between the tests for strategies 3A/B and the others.

The shortest total evacuation time observed across the different strategies was in Test 4-2, at 9 minutes 2 seconds; whereas the longest total evacuation time was observed in Test 2-2, at 28 minutes 38 seconds.

The first camera sighting in Tests 1-1 and 2-2 was at 6 minutes or above, which is higher than that of Tests 3A, 3B and 4-2, between 2 minutes 47 seconds and 3 minutes 50 seconds.

The times for 25%, 50% and 75% of participants to have evacuated varies across all tests compared to their initial camera sighting. Test 4-2 had comparatively small gaps between these points of around 1 minute. Similarly, Test 1-1 had relatively small gaps of around 2 minutes (ranging from 1 minute 47 seconds to 2 minutes 30 seconds). Test 3A-2 had gaps ranging from 4 minutes 35 seconds to 5 minutes 2 seconds between these evacuation points. Test 3B-2 had gaps ranging from 2 minutes 33 seconds to 5 minutes 44 seconds. Test 2-2 had varying gaps sizes from 2 minutes 38 seconds to 8 minutes 3 seconds.

Table 1: Percentage of persons evacuated and evacuation times for all tests (in minutes and seconds)

Strategy	**1**	**2**	**3A**	**3B**	**4**
Test	Test 1-1 (80 evacuees)	Test 2-2 (68 evacuees)	Test 3A-2 (49 evacuees)	Test 3B-2 (43 evacuees)	Test 4-2 (79 evacuees)
1st camera sighting	6 mins, 30 secs (390 secs)	6 mins (360 secs)	3 mins, 50 secs (230 secs)	2 mins, 47 secs (167 secs)	3 mins, 11 secs (191 secs)
25% exited	8 mins, 17 secs (497 secs)	13 mins, 10 secs (790 secs)	8 mins, 52 secs (532 secs)	7 mins, 31 secs (451 secs)	4 mins, 18 secs (258 secs)
50% exited	10 mins, 47 secs (647 secs)	21 mins, 13 secs (1,273 secs)	13 mins, 27 secs (807 secs)	11 mins, 8 secs (668 secs)	5 mins, 17 secs (317 secs)
75% exited	12 mins, 58 secs (778 secs)	23 mins, 41 secs (1,421 secs)	17 mins, 23 secs (1,043 secs)	13 mins, 41 secs (821 secs)	6 mins, 39 secs (399 secs)
100% exited	19 mins, 15 secs (1,155 secs)	28 mins, 38 secs (1,718 secs)	20 mins, 6 secs (1,206 secs)	18 mins, 1 sec (1,081 secs)	9 mins, 2 secs (542 secs)

Across the tests, it was observed that evacuees without impairments did not appear to be majorly affected by firefighting equipment covering the floors, while the speed of evacuees with impairments (for example, those using crutches, or infants) were reduced when there were obstacles.

Similarly, across the tests, the higher the floor where the residents with impairments were located, the greater the total evacuation time for the evacuees behind them.

Furthermore, it was observed that irregular behaviours, for example, evacuees going up during the evacuation, may be successfully prevented when firefighters stay on specific floors. Notably, firefighters deployed as SPTs could offer guidance to evacuees.

There was inconsistency in the evacuation speeds of some evacuees with mobility impairments. In Test 1-1, it was noted that evacuees using an evacuation chair may take less time than evacuees using crutches but in Test 2-2, the opposite was observed, where it could take twice as long as evacuating residents simulating a mobility impairment using crutches.

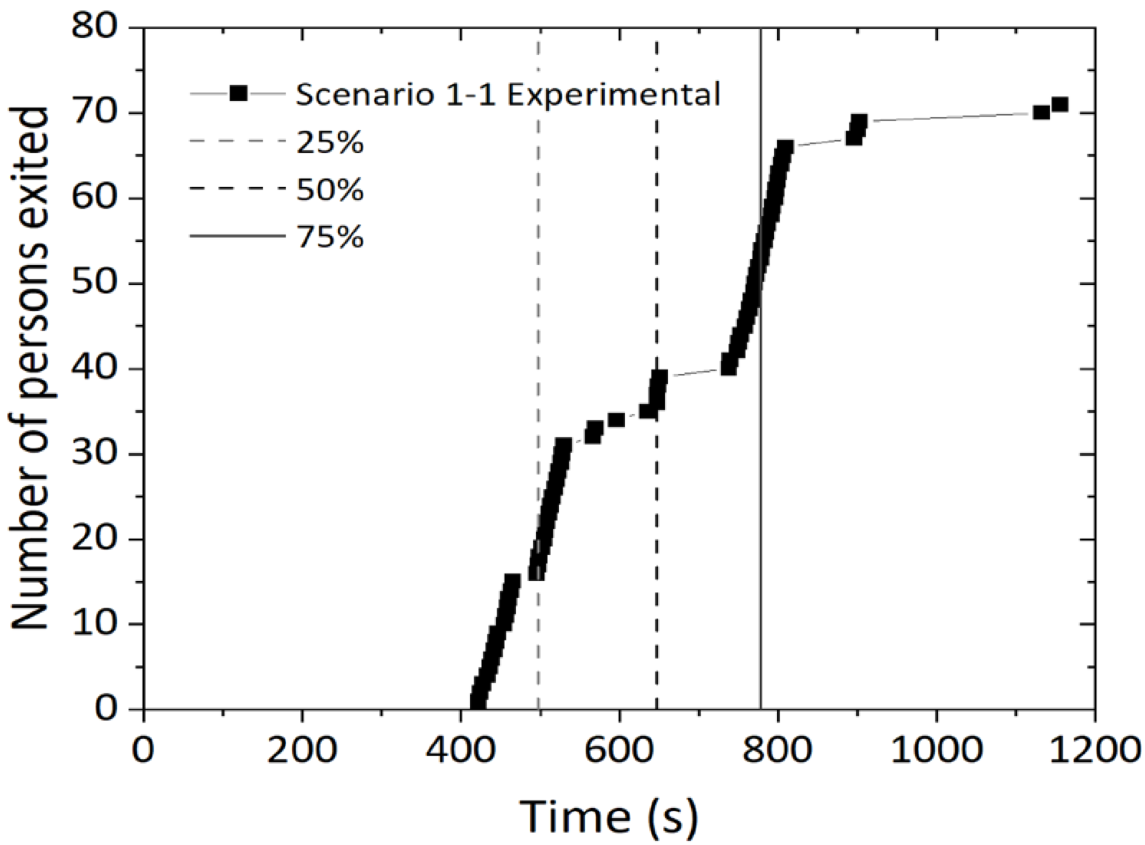
The main findings for each strategy are outlined in sections 4.2 to 4.6. It should be noted that these sections seek to address key features of each strategy tested, but do not always compare tests directly against each other. Equally, the test results make observations about each test, but cannot always explain the causes. Further detail is outlined in Appendix 4.

4.2 Test 1-1 – Full evacuation using Evacuation Alert System

Test 1-1 (Strategy 1) was a simultaneous evacuation of all floors through a single staircase once an EAS was triggered. Figure 1 depicts the number of persons that exited the building during this (Test 1-1), with vertical lines marking the times by which 25%, 50% and 75% of the total number of people evacuated.

It was found that 25% of evacuees had exited at 8 minutes 17 seconds (497 seconds), 50% at 10 minutes 47 seconds (647 seconds), 75% at 12 minutes 58 seconds (778 seconds) and 100% at 19 minutes 15 seconds (1,155 seconds). Congestion was seen throughout Test 1-1, represented by the horizontal lines in figure 1 where the number of evacuees exiting the building remained unchanged.

Figure 1: Number of persons exited by time (seconds) with lines indicating 25%, 50% and 75% evacuated during Test 1-1



Evacuees with impairments took on average 4 to 5 seconds longer to pass each floor than those without impairments. Moreover, evacuees with impairments took 21 seconds longer to pass floor 6, the origin of the fire, than those without impairments. However, evacuees without impairments generally did not appear to be substantially affected by obstacles such as hoses on the floor.

In this test, during the simultaneous evacuation of all floors, there was congestion and delays on the upper floors due to evacuees with reduced speeds, including occupants with impairments, and the presence of firefighting equipment in the staircase. More detail is in Appendix 4.

4.3 Test 2-2 – A full evacuation using door knocking, without an Evacuation Alert System (single staircase)

Test 2-2 (Strategy 2) was an evacuation of all floors through a single staircase using door knocking rather than an EAS. After evacuating floors 6 to 8 (the fire floor and the 2 above it), the remaining floors were evacuated from the lowest floor (4) up. Firefighters verbally notified (as a proxy for door-knocking) each floor, taking approximately 23 minutes to notify the final floor.

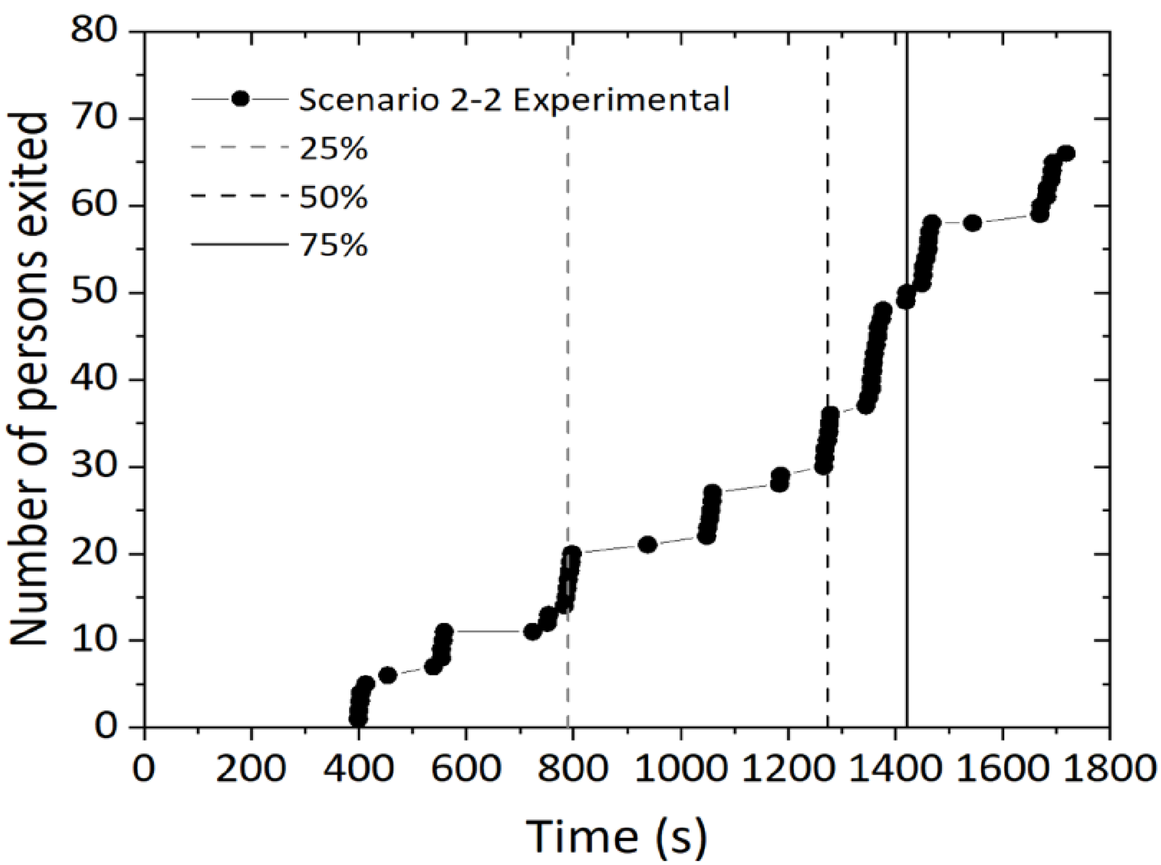
Evacuation was therefore slower in Test 2-2 when firefighters notified evacuees floor by floor than when a simultaneous EAS was used in Test 1-1. This finding is potentially strengthened because Test 1-1 involved more evacuees than Test 2-2 (80 in Test 1-1, compared to 68 in Test 2-2).

Generally, there was little congestion evident in the staircase, although evacuees were occasionally slowed down by firefighters moving up the stairs, resulting in a slight increase in the density of evacuees at floor 6 (involving 2 firefighters wearing breathing apparatus and 4 evacuees). This compared with up to 25 people when floors were alerted simultaneously via EAS (in Strategy 1). The coordination between the firefighters initiating the evacuation on each floor of the test without EAS (effectively implementing phased evacuations at appropriate intervals) resulted in much less congestion in stairwells than when EAS was used.

Figure 2 shows the number of persons that exited the building during Strategy 2, with vertical lines marking the times by which 25%, 50% and 75% of the total number of people evacuated.

It indicates that 25% of evacuees had exited at 13 minutes 10 seconds (790 seconds), 50% at 21 minutes 13 seconds (1,273 seconds) and 75% at 23 minutes 41 seconds (1,421 seconds). Critically, 100% evacuation was achieved at 28 minutes 38 seconds (1,718 seconds) for Test 2-2, compared with 19 minutes 15 seconds (1,155 seconds) when EAS was used in Test 1-1, a difference of 9 minutes 23 seconds (563 seconds) longer than full evacuation using EAS.

Figure 2: Number of persons exited by time (seconds) with lines indicating 25%, 50% and 75% evacuated during Test 2-2



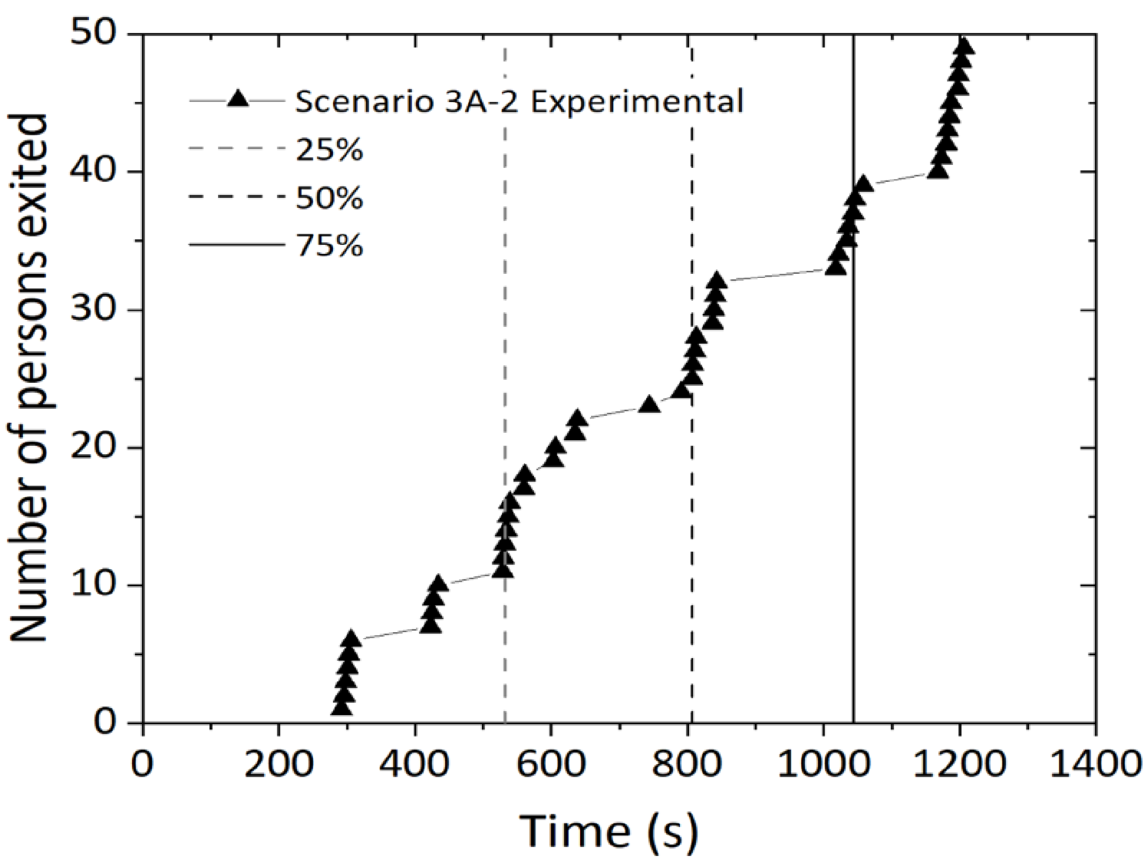
4.4 Test 3A-2 – A full evacuation conducted in phases with an Evacuation Alert System, bottom-up strategy

Test 3A-2 (Strategy 3A) was an evacuation of all floors through a single staircase using an EAS in a top-down phased approach. Once floors 6 to 8 had been evacuated, the 'bottom-up' aspect of the test took place by phased EAS evacuation from floors 9 up to 12. All other occupants on floor 5 and then floor 4 were finally evacuated.

Figure 3 shows the number of persons that exited the building during Test 3A-2 (phased, bottom-up above the fire), with vertical lines marking the times by which 25%, 50% and 75% of the total number of people evacuated. It indicates that 25% of evacuees had exited at 8 minutes 52 seconds (532 seconds), 50% at 13 minutes 27 seconds (807 seconds) and 75% at 17 minutes 23 seconds (1,043 seconds).

Finally, in Test 3A-2, 100% of evacuees had exited after 20 minutes 6 seconds (1,206 seconds) a very similar time compared to the 19 minutes 15 seconds (1,155 seconds) during Test 1-1 (where a full EAS was used in a single staircase).

Figure 3: Number of persons exited by time (seconds) with lines indicating 25%, 50% and 75% evacuated during Test 3A-2



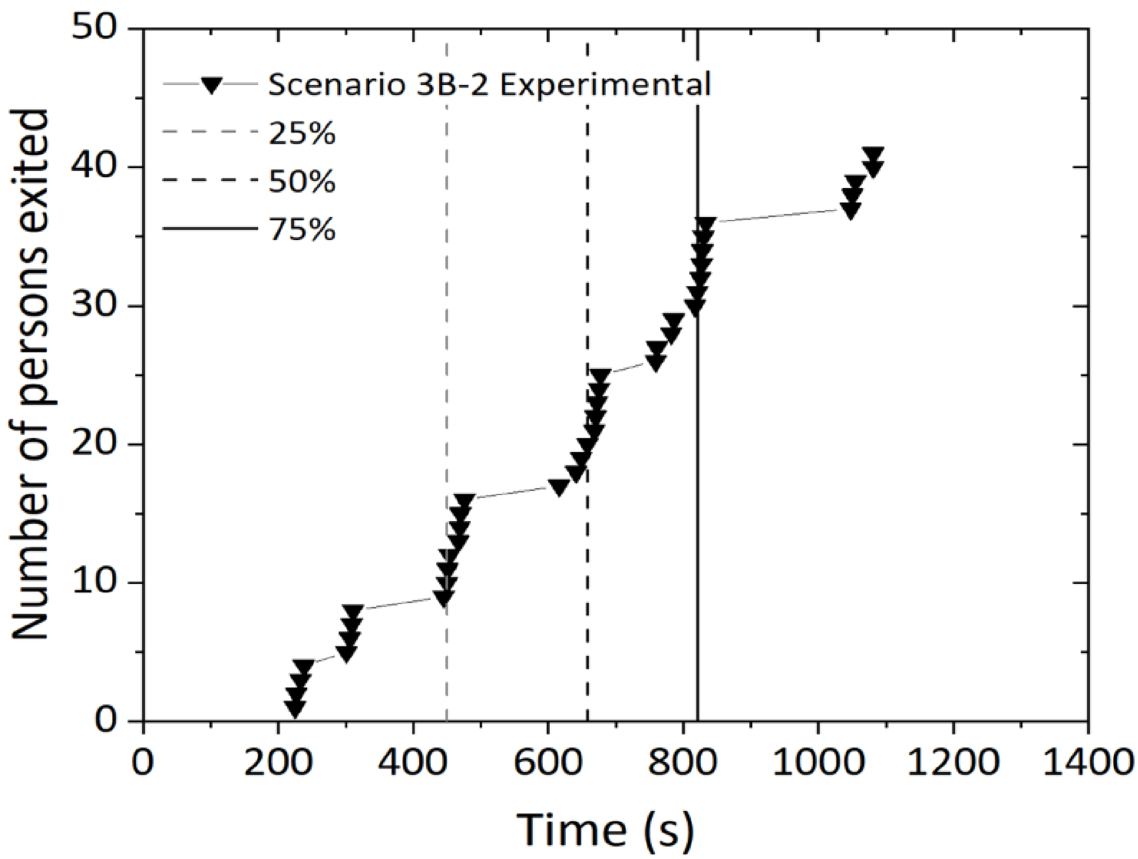
4.5 Test 3B-2 – A full evacuation conducted in phases with an Evacuation Alert System – Top-down strategy

Test 3B-2 (Strategy 3B) was an evacuation of all floors through a single staircase using an EAS in a top-down phased approach. Once floors 6 to 8 had been evacuated, the 'top-down' aspect of the test took place by phased EAS evacuation from floors 12 down to 9. All other occupants in floor 5 and then floor 4 were finally evacuated.

Figure 4 shows the number of persons that exited the building during Test 3B-2 (phased, top-down) with vertical lines marking the times by which 25%, 50% and 75% of the total number of people evacuated.

It indicates that 25% of evacuees had exited at 7 minutes 31 seconds (451 seconds), 50% at 11 minutes 8 seconds (668 seconds) and 75% at 13 minutes 41 seconds (821 seconds), and finally at 100% it was 18 minutes 1 second (1,081 seconds). Top-down phased full evacuation with an EAS (Strategy 3B) resulted in marginally shorter evacuation times compared to bottom-up phased full evacuation with an EAS (Strategy 3A).

Figure 4: Number of persons exited by time (seconds) with lines indicating 25%, 50% and 75% evacuated during Test 3B-2



4.6 Test 4-2 – Two staircases, full evacuation using an Evacuation Alert System

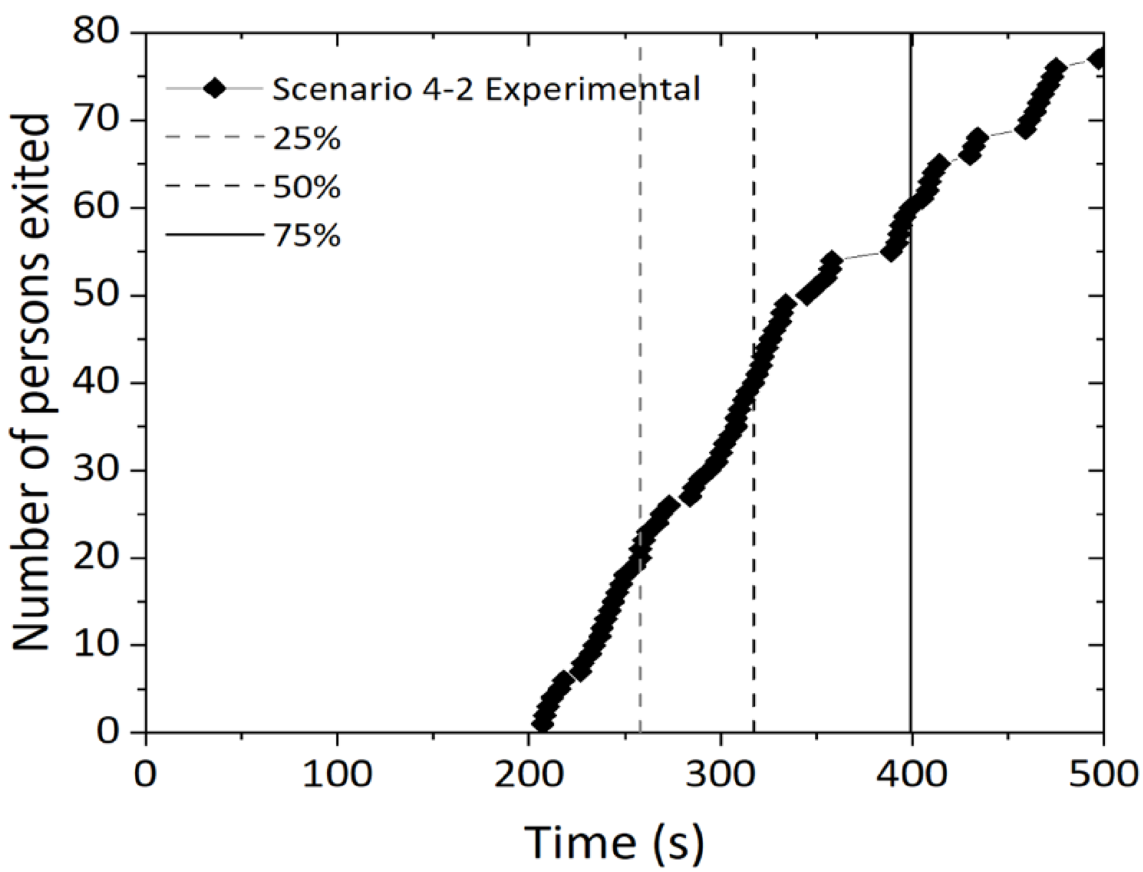
Test 4-2 (Strategy 4) used a simultaneous evacuation of all floors using EAS (replicated Strategy 1). However, residents evacuated through another staircase from floor 2, while firefighters operated through the staircase used in the other tests.

Figure 5 shows the number of persons that exited the building during Test 4-2, with vertical lines marking the times by which 25%, 50% and 75% of the total number of people evacuated. It indicates that 25% of evacuees had exited at 4 minutes 18 seconds (258 seconds), 50% at 5 minutes 17 seconds (317 seconds), 75% at 6 minutes 39 seconds (399 seconds) and 100% at 9 minutes 2 seconds (542 seconds).

The speed of the full evacuation in this 2-staircase strategy was much faster than both the single-staircase evacuation with EAS (Strategy 1), where it took 19 minutes 15 seconds (1,155 seconds), and a single-staircase evacuation without EAS (Strategy 2) where it took 28 minutes 38 seconds (1,718 seconds) for 68 evacuees (with 23 minutes (1,380 seconds) elapsing between the first and last floors being notified to evacuate).

These tests reflect the positive impact of having 2 staircases – one staircase used exclusively for evacuation and the other for firefighter operations, removing obstacles that have been seen in other strategies. The average speed for evacuees in Test 4-2 was 15% faster than in Test 1-1.

Figure 5: Number of persons exited by time (seconds) with lines indicating 25%, 50% and 75% evacuated during Test 4-2



In Test 4-2, there was an increase in the average movement speed. For instance, the average movement speed was higher than in Test 1-1 reflecting the impact of having one staircase used exclusively for evacuation. However, there was also an increase in the length of the queues, possibly due to evacuees with impairments in the staircases. In fact, in Test 4-2, queues caused by evacuees with crutches were longer than the queues with evacuation chairs guided by firefighters.

4.7 Evacuation speed analysis

Evacuation speed analysis calculates the distance in metres that the individual had to travel (using 7.5m as the distance between each floor/camera location) divided by the time an individual takes to move from the first stairwell camera to the last. This analysis provides evidence relevant to Research Question 1 (Which strategies are likely to lead to the fastest stairwell evacuation of a high-rise residential building?). It is also related to the performance of those with impairments and therefore is relevant to Research Question 3 (What impact do evacuees with impairments have on evacuations?).

Table 2 presents the average speeds of all occupants while they descend for all tests and the movement speed range (min to max) for the processed tests of this study. The table includes stair descent speeds for 2 other studies conducted by (Proulx et al., 1995) and (Proulx, 1995). These studies collected data on evacuation times in high-rise and mid-rise apartment buildings, respectively. This included the time taken to start the evacuation (since all occupants were in their home when the fire alarm sounded); the time to move, the time to evacuate and the speed of movement in the staircase. While there are observable differences between the tests conducted and the external studies, it is important to note that there are differences in the methodology, such as the buildings were occupied buildings, the number of occupants taking part in the study and their level of familiarity with the layout of the buildings.

Table 2: Stair descent speeds for each test

Study / test	Average movement speed (m/s)	Movement speed range (m/s)
Test 1-1	0.39	0.19 – 0.71
Test 2-2	0.62	0.20 – 0.82
Test 3A-2	0.48	0.19 – 0.78
Test 3B-2	0.59	0.15 – 0.83
Test 4-2	0.45	0.18 – 0.89
Proulx et al. (1995a)	-	0.95 – 1.07
Proulx (1995)	-	0.52 – 0.62

Faster speeds were generally recorded on lower floors, slow speeds on top floors, and even slower speeds in the middle floors in the building (close to the fire where it was assumed to start on floor 6 and spread to floors 7 and 8) where obstacles were more likely to be present. For example, in Test 1-1, slower speeds were recorded on floors 6, 7, 8, 9, 10 and 11.

Evacuation chairs guided by 2 evacuees were typically faster than those guided by one evacuee and one firefighter. The mannequin in the evacuation chair guided by 2 evacuees in Test 1-1 had an average speed of 0.29m/s and evacuated quicker than the mannequin in the evacuation chair led by one firefighter and one evacuee in Test 3B-2, with an average speed of 0.15m/s (although it is important to note that these speeds were observed under the different test conditions including the strategy, the number of participants, and the number of participants with impairments). Similarly, the evacuation chair guided by 2 evacuees in Test 3B-2 reached an average speed of 0.31m/s. It is possible that this finding may partly be a function firefighting equipment slowing evacuation speeds, but also that firefighters may replicate more accurately carrying a person in an evacuation chair.

Movement speeds derived in the single-staircase strategies where there was specialist evacuation, firefighting equipment and FRS personnel in the staircase was relatively slower when compared to movement speeds recorded by (Proulx, 1995 and Proulx et al., 1995), where such equipment was not in the staircase during evacuation.

Appendix 4 describes this data further with figures outlining the minimum, mean and maximum stairs descend speeds.

5. Evacuation modelling

The aim of the modelling was to test whether modelling may reduce the need for full-scale live tests and to answer Research Question 5: How accurately can Pathfinder modelling software simulate the live evacuation testing?

Pathfinder evacuation modelling software (https://www.thunderheadeng.com/pathfinder) was used to perform evacuation simulations. Pathfinder is a software tool that simulates evacuations that use steering behaviours to model occupant motion. It comprises 3 modules:

- a graphical user interface
- the simulator
- a 3D results viewer (more details are in Appendix 5)

5.1. Design and inputs

The building (including corridors, habitable rooms and staircases) was constructed in the Pathfinder software using the floor plans and elevations. The models were built up to the 13th floor (the highest used in the tests) though the building is taller. All doors were assumed to be fully open during the evacuation; however, for strategies 1, 2, 3A and 3B where a single-staircase strategy was taken, the cross-corridor doors were locked and all occupants were in one half of the building, with access to only one stairwell. Both stairwells were modelled to discharge into a corridor on the ground floor, leading to a final exit lobby.

The primary data input parameter is the evacuation speed (m/s), which is taken from the test video data, and set to be constant throughout.

Population flow rates through doors were assumed to be the maximum suitable for the widths of the doors. Wheelchairs within the software were used to simulate the evacuation chairs used in the tests, with sizes adjusted to pass through the stair doors, but no smaller, as observations showed evacuees did not overtake evacuation chairs within stairwells.

The modelling simulation set-up mirrored the parameters of the live tests, with all occupants positioned at the apartment doors and evacuation chair users positioned on floors 4 and 7. The full interpretation of strategies into models to represent the experiments are in Appendix 5.

5.2. Modelling analysis

Experimental and simulation results were similar for Tests 1-1, 2-2, 3A-2 and 3B-2.

As can be seen from the difference, ε (%) in Table 3, differences between experimental and numerically modelled results were below 5%. We calculated this difference using the following expression as depicted in the equation below:

> $\varepsilon = ((M-E) / M) \times 100$

Where:

M : is the numerical value (modelled time seconds).

E : is the experimental evacuation time (seconds).

Numerical data on the building exit curves and how the model compares with the experimental data is presented in figure 11 to figure 15 in Appendix 6. The shape of the modelled exit curve generally follows that of the corresponding experimental exit curve.

The total time to exit the building varied between tests. Other than in Test 3A-2, the modelled exit time was greater than the actual times observed in the tests.

However, the greatest differences between experimental observation and numerical modelling occurred for Test 4-2, where there was a 23% over-prediction of evacuation time by the modelling.

Table 3: Evacuation times as recorded in the tests, simulation times, and difference

	Test 1-1	Test 2-2	Test 3A-2	Test 3B-2	Test 4-2
Experimental evacuation time(s)	19 mins, 15 secs (1,155 secs)	28 mins, 38 secs (1,718 secs)	20 mins, 6 secs (1,206 secs)	18 mins, 1 sec (1,081 secs)	9 mins, 2 secs (542 secs)
Modelled evacuation time(s)	19 mins, 19 secs (1,159 secs)	28 mins, 43 secs (1,723 secs)	19 mins, 19 secs (1,159 secs)	18 mins, 5 secs (1,085 secs)	11 mins, 50 secs (710 secs)
Difference, ε	0.35%	0.29%	-4.06%	0.37%	23.7%

Overall, the Pathfinder modelling software gave reasonable predictions of experimental results for Tests 1-1, 2-2, 3A-2 and 3B-2. However, Pathfinder modelling for Test 4-2 (full evacuation using EAS and 2 staircases), which resulted in the fastest overall evacuation time in the experimental results, gave a much longer predicted evacuation time. Hence, further testing and modelling comparisons would be required before using Pathfinder modelling to replicate evacuations with 2 staircases in use.

It should also be noted that the close match to the live tests may be due to an element of over-fitting in the model. This is shown through model variables being tailored to observations from the trial, rather than to expected values from literature. For example, in Test 1-1, the evacuees on higher floors were programmed to move slower than occupants on lower floors, instead of necessarily recreating the conditions that resulted in slower movement. This was based on average speeds measured during the trial and would be consistent with congestion slowing people on higher floors while their counterparts below moved more freely. The impact of this is that the exit times from the modelling closely replicate the trial, but only because they have been programmed to do so. This significantly reduces the extent to which the results can be extrapolated to other strategies.

6. Key findings

This section addresses the 5 research questions derived by the Home Office from the research methodology.

6.1 Research Question 1: Which strategies are likely to lead to the fastest evacuation of a high-rise residential building?

The findings indicate that 2 staircases are likely to support a faster evacuation from a HRRB than one staircase. When using 2 staircases (one for evacuation and one for firefighting), evacuation times were shorter than for all other evacuation strategies. Strategy 1 and Strategy 4 both tested full evacuations with an EAS. However, Test 4-2 (with 2 staircases) was completed in 9 minutes 2 seconds (542 seconds), approximately half the time of Test 1-1 (with single-staircase exercise) which completed in 19 minutes 15 seconds (1,155 seconds).

For operational decision-makers, the findings indicate that using an EAS (Strategy 1) results in faster evacuation than a door-knocking system (Strategy 2). In Test 1-1, the final evacuee left in under 20 minutes (1,155 seconds). Whereas in the Test 2-2, where the test replicated manual floor-by-floor door-knocking, it took over 28 minutes (1,718 seconds) to complete. Future research could look to understand the impact of resident awareness of EAS on evacuation effectiveness, as this study's scoping found that this is an important feature of it working well.

The findings were not clear in showing whether either a 'top-down' or 'bottom-up' evacuation strategy is faster and which should be preferred during an evacuation. In these tests, evacuation starting from the highest floor above the fire ('top-down') completed in less time than 'bottom-up', where evacuation began from the first feasible floor above the fire. However, due to the confounding variables in participants' profiles (such as the number of participants and the amount instructed to walk at half pace), further testing would be required to establish robust conclusions.

6.2 Research Question 2: To what extent do each of the evacuation strategies lead to congestion in stairwells?

The findings identified more congestion developed following the EAS signal (Strategy 1) than when firefighters co-ordinated the timing of door-knocking signals on floors (Strategy 2). This was despite the use of an EAS resulting in a faster evacuation than door-knocking. When the door-knocking strategy was applied, the maximum queue length was 6 people, compared with queues of up to 25 people in stairwells when EAS was used.

Evacuees moving at a slower pace often caused congestion. Queues formed where evacuees were ‘caught up’ with those moving at a slower pace and occupying additional space in stairwells. This included some of those walking with crutches, and evacuation chairs guided by one or 2 other people (evacuees or firefighters). Though it should be noted that in some instances evacuees passed others that were walking more slowly.

Higher levels of congestion did not necessarily lead to slower evacuation time. While the double-staircase test (Test 4-2) resulted in large queues behind evacuees walking with crutches, the queues did not prevent the 2-staircase firefighting and evacuation completing in far less time (by over 10 minutes) than when firefighting and evacuation combined in a single staircase (Test 1-1). In Test 4-2, the total evacuation time was 9 minutes 2 seconds (542 seconds) with 79 participants, whereas Test 1-1 had a total evacuation time of 19 minutes 15 seconds (1,155 seconds) with 80 participants.

When implementing strategies as part of real evacuation plans, consideration should be given to potential congestion. As well as influencing evacuation times, there may be further consequences that congestion could cause, such as slips and obstruction to operational response. It should also be noted that the emotional impact of congestion was not tested, and that this may impact overall evacuation times in a live situation.

6.3 Research Question 3: What impact do evacuees with impairments have on evacuations?

Indicative findings suggest that people evacuating other residents on evacuation can delay the movement of those evacuees behind them. Such delays may also be affected by the degree of familiarity with the evacuation chair equipment and (for firefighters) the cumbersome nature of the equipment worn.

The higher the floor where residents with impairments live, the greater the potential detrimental effect on the evacuation speeds from following evacuees with impairments. There was evidence for Tests 1-1, 2-2 and 3A-2 that evacuation speeds may be limited for those starting on higher floors. This is because the transit of evacuees with a mobility impairment appeared to affect the evacuation speed of those joining stairwells from higher floors.

The appropriate evacuation strategy may also vary depending on the evacuee's specific needs, but this study did not find consistency in how evacuation needs affected speed. In Test 1-1 (Strategy 1), it was observed that evacuation chairs can move at greater speeds than some evacuees walking with crutches, whereas in Test 2-2 (Strategy 2), the opposite was observed. Therefore, it is important to note uncertainty in these findings, given the number of limitations in assessing the impact of participants with impairments.

6.4 Research Question 4: What further factors could affect live evacuations from high-rise residential buildings?

There were several key observations from the testing that should be considered as factors affecting evacuation and may need to be considered in planning the strategies for evacuation.

Local movement speed varied by floor. Faster speeds were generally recorded at lower floors, with slower speeds at the top and in the middle floors of the building, close to the fire, where obstacles were more likely to be present.

For most evacuees, there was no clear effect of having obstacles on the floor, such as hoses. But it was observed that the speed of evacuees with impairments was reduced on those floors.

Evacuees instructed to climb stairwells first, rather than immediately evacuate, did not have a demonstrable negative effect on other evacuees. However, the impact of upward movement of evacuees cannot be ruled out when combined with other factors such as flow density, evacuees with a mobility impairment descending and when occurring on other floors (not just the highest floors).

Similarly, movement of firefighters within the staircase did not have a major impact on the evacuation. However, in some instances where the OIC initiated the activation of the EAS after receiving information that the preceding floor had been cleared, the counter flow of firefighters moving to alert higher floors impacted on movement speed of evacuees who waited in the staircase landing to allow firefighters to pass.

6.5 Research Question 5: How accurately can Pathfinder modelling software simulate the live evacuation testing?

The findings suggest that the Pathfinder modelling software, using data from live operational tests, may accurately predict these outcomes via software simulations. This would help reduce the need for full-scale live operational tests to consider changes in evacuation scenario parameters (or might enhance confidence in the test results by allowing replication).

However, it should also be noted that the close match to the live operational tests may be due to an element of over-fitting in the model. This is shown through model variables being tailored to outcome observations from the trial (for example, the speed was based on what was seen in the trials rather than wider physiological evidence about movement speeds). This significantly reduces the extent to which the results can be extrapolated to other strategies.

Overall, the Pathfinder modelling software gave reasonable predictions of experimental results for Test 1-1, 2-2, 3A-2 and 3B-2.

However, Pathfinder modelling for Test 4-2 (full evacuation using EAS and 2 staircases), which resulted in the fastest overall evacuation time in the experimental results, gave a much longer predicted evacuation time by 23.7%. Hence, further testing and modelling comparisons would be required before using Pathfinder modelling to replicate evacuations with 2 staircases in use.

7. Considerations for future research

This study unearthed valuable insights that can be useful for evacuation planning and strategy. However, in the process of conducting the live evacuation strategy tests, this study has identified opportunities that can serve as a springboard for future enhancements in both the methodology and how similar tests could be conducted.

While field experiments are challenging to conduct, maintaining control over key experimental conditions (for example, population size) is imperative for comparison between results and inferring implications. Future research can explore ways to address whether the same outcomes from the evacuation strategies would hold outside of the context of the experiment.

The research highlighted the importance of the participant population in enabling like-for-like repetition. This was borne out in this study because of limitations in participation due to conducting the study while COVID-19 risks had to be managed.

The small number of tests for each strategy limited confidence in the results produced. Future research could run more tests or include participants with impairments to improve the robustness of the findings. Future research may also include tests with participants without the simulation of their impairments to examine the impact of them on the evacuation performance.

Scenario-specific conditions may also be improved in future research. There was limited access to apartments which affected the initial pre-evacuation/pre-movement delays of participants who were initially position at apartment entrances. Evacuees had prior warning that an evacuation would take place. This may have had an impact on their evacuation behaviour, precluding the assessment of participant response. Future research may explore avenues to improve the degree of similarity of scenario-specific conditions to everyday experiences before and during evacuation.

The Pathfinder modelling software used in the study may in future be applied to explore and test the conditions in this research in different contexts and situations. For instance, the modelling software can include data on building designs and population sizes, which will improve the applicability of the research in new and emerging evacuation strategies.

8. Appendix 1: Supplementary methodological detail

8.1 Building description and layout

The UCLan research team selected a disused 17-storey tower block (Hereford House in Carlton Vale, NW6) for the experiments in this study. The building represents a common UK HRRB and is comparable to other buildings used to conduct evacuation studies in HRRBs (Lovreglio et al., 2019) and was deemed particularly relevant for the questions posed in this work. LFB uses the site (within a gated perimeter wall) for multi-flat fire training, fire survival guidance and evacuation exercises. While LFB train at the venue, Brent Council maintain the lifts and power supplies to the communal area's electrical sockets.

The building had 2 staircases: a firefighting staircase (right-hand side), where the dry riser outlets were located; and an evacuation staircase (left-hand side). The building was divided horizontally into equal compartments at every level with a cross-corridor fire door and could simulate a single-staircase HRRB. The cross-corridor fire doors were locked, and approximately only half the building was used to simulate the single-stair evacuation tests. All flats were inaccessible, meaning that volunteers representing residents commenced exercises from flat entrance doors, following specifically assigned scripts. Each volunteer was told that they have been allocated a floor and a flat number and they would be expected to stand outside the flat entrance. The notice on the flat door indicated how they should move during the exercise.

Therefore, experimental times did not include simulation of response within flats, only within communal corridors and staircases.

The briefing covered the following:

- the purpose of the tests
- that the tests are based on prior research
- which test the participant will take part in
- their floor and flat number (told to stand outside the flat entrance and not to enter any flats)
- the notice on the flat door informed them on how to move during the exercise; for example, the action to take during each test, for Strategy 1 for example, "On hearing the Evacuation Alert System start to move towards the stairs and evacuate"
- told that "When (they) enter the staircase to evacuate in a safe manner taking into consideration events that are happening in your surroundings"

An EAS installed within the building provided audible alerts and evacuation signals in the communal corridors of each floor and had manual controls operated by FRS. The EAS was purely used to enable an evacuation signal and initiate the experiments – its functionality was not tested during the experiments.

8.2 Building occupancy levels and volunteer arrangements

The study measured the building occupancy in accordance with the work of Hopkin et al. (2019) drawing on the English Housing Survey (MHCLG, 2019), which estimated the mean number of occupants per bedroom in high-rise apartments as 1.19. Hereford House had 215 bedrooms across 143 flats on 17 floors, so using the mean value of 1.19 residents per bedroom, the total number of residents expected to reside in the building was 256. However, the tests placed residents in parts of 9 or 10 floors, reducing the number of volunteers required to replicate the expected level of occupancy. In response to the number of volunteers available, only half of each floor was used, allowing access to evacuate through a single staircase.

Volunteers received a project aims information sheet and were debriefed and allocated a Person ID number and directed to the individual start position for that ID number.

Research indicated that people with mobility impairments were likely to move more slowly through buildings (Boyce et al., 1999). Tests were planned to include a prescribed number of volunteers (from specific floors and flats) scripted to act as residents with mobility impairments, such as simulating walking at half speed with an elbow crutch, slow walkers, and residents using evacuation chairs (containing mannequins for safety). A small sample of volunteers (at least 10%, consistent with ONS, 2021) were identified to act with mobility impairments scripted for specific flats (consistent throughout each test). The experiments did not account for future demographic changes between mobility, cognitive and sensory impairments, so the results may need to account for this aspect when informing future policy.

Residents requiring assistance with evacuation chairs were simulated by mannequins on evacuation chairs outside flats on floors 4 and 7. These chairs were assisted by a pair of volunteers, a volunteer with a firefighter, or solely by firefighters (detailed in the test descriptions in Appendix 2).

The flat associated with the scripted impairment had the relevant instructions placed on a notice at the entrance. The test timelines and scripts (displayed on each flat door) were used to direct volunteer movements.

The number of volunteers for each test is detailed in Table 4 (in Appendix 3).

8.3 Planning and preparation

A week ahead of the experiment, the project team (UCLan) met with all subcontractors. They developed the evacuation procedure (including floor plans highlighting planned start positions of participants) and undertook risk assessments.

Pre-project scoping work identified that many FRSs were either using, or piloting the use of, smoke curtains to protect staircases from the spread of smoke. Therefore, such equipment was incorporated into the exercises, in line with the expected operational procedure at this type of incident, and in line with the SOP by which curtains are fitted by SPT (Williams, 2019).

LFB service personnel including an Area Manager, a Station Manager (as Evacuation Officer) and an Evacuation Command Vehicle plus a support fire appliance (to support the Evacuation Officer) supported the experiments. A Fire Safety Enforcement Officer advised on the building’s fire protection features and over 40 FRS staff participated in the tests. Existing LFB operational techniques for HRRB emergency evacuation procedures, communication strategies and firefighting equipment were used in all tests. The testing required the resources (personnel, firefighting equipment and fire appliances) associated with the normal predetermined attendance (PDA) for a HRRB fire incident. This figure varies across the UK; however, 8 fire appliances were required with additional personnel resources to supplement the evacuation procedures being tested. The fire control room on site supported the tests. Actions resulting from mobilising control handling and communicating the information to the Incident Command Unit was simulated at specific times during each of the tests, at 5, 10 and 20 minutes.

The day before the tests, extended life digital video camera batteries were charged, camera memories cleared, and all equipment was checked. For each test day, time was allotted for setting up and testing cameras and monitoring equipment.

The 2 evacuation chairs and 2 mannequins (both standard FRS training models) were used in the experiments (these are ‘GBRH’, with a green body ‘GB’, and red head and ‘RB’, with a red body and red head). In all tests, mannequins were placed on evacuation chairs prior to commencement of the evacuation. The chair from flat 47 (floor 4) was assisted by 2 residents that were specially briefed and flat 77 (floor 7) was assisted by firefighters.

8.4 Data collection

In total, 17 digital cameras were used to collect the video data during the experiments, positioned in each stairwell landing at a height of 2 metres. The digital cameras covered each staircase and each floor.

Digital Transit Limited (DTL) vision system processed video feeds that were recorded during the evacuation testing. The vision system collated multiple video inputs, detected the number of people within each frame of the footage and could detect whether a person was travelling up or down the stairs. The system tracked people as they moved up and down staircases and allowed the manual identification of evacuation chairs (GBRH and RB) within video footage from digital cameras throughout the HRRB’s staircase. Within videos, evacuees were identified by a sequential number; however, each volunteer wore a separate pre-allocated ID number linked to their individual ‘resident’ script.

Data processing was carried out off-site. A video technique called optical flow detected speed and behaviour, such as hesitation or stumbling. Resulting data allowed for comparison with Pathfinder evacuation modelling software.

Records were kept of the incident command communication directed towards participants during the tests, and the video system recorded evacuation times floor by floor. Fire Service Guidance calls were included in the experiments at an operationally appropriate time in the evacuation. These calls were straightforward and designed to imitate additional movements of FRS resources and residents, but they did not seek to test control operator techniques.

9. Appendix 2: Tests

The test plan schedule determined the firefighters’ actions. The volunteers on each level reacted within a timeframe according to a predetermined script describing how residents were to respond.

FRS staff taking part in the tests were briefed on the key parameters and objectives of the experiments and their own role in the test.

Each test commenced as follows:

1. A fire was reported on floor 6, in a flat directly adjacent to the stairwell entry point.

2. On arrival, the Officer in Charge (OIC) recognised the severity of the incident and immediately increased the available resource to 8 pumps.
3. Firefighters entered the building to set up and fight the fire internally (hose deployment, breathing apparatus procedures and command structures, and initial SPTs were in position before each experiment).
4. Subsequently, the fire developed, spreading to the 2 floors above.
5. The OIC recognised the implications of the fire development and took the decision to implement the strategy being tested.
6. The ‘Secure Information Box’ (SIB) provided information on residents who needed evacuation chairs. They were located on floors 4 and 7. These residents were evacuated by chair (however, during these experiments, mannequins were used to represent these residents).

Typical obstructions seen during firefighting operations, such as firefighting hoses and other firefighting equipment within the staircase, were also used in each test.

During the experiments, FRS used the functioning EAS manual controls on each floor (for all except Test 2-2), allowing simultaneous (Test 1-1 and 4-2) or phased (3A-2 or 3B-2) evacuation signals. Throughout the tests, the Incident Commander considered control measures, and FRS staff communicated as per standard command procedures. This included the exact timing of alerts (EAS simultaneous, EAS phased or door knocking), checking the SIB for residents with a mobility impairment who require an evacuation chair, and then assisting with the evacuation of these residents.

Features of the control measures as per SOPs included:

- withdrawing
- use of breathing apparatus
- LFB-standard firefighting equipment
- ventilation
- patrolling the staircase(s) continuously to ensure that exit routes were safe and free of obstructions
- searching floors, staircase(s), hallways and lifts for residents who may have been trapped
- identifying residents who may be a priority or may need specialist assistance during evacuation
- reporting back to the Incident Commander – reporting conditions at each floor to the Fire Sector Commander or, when in place, the Search Sector Commander
- deploying to Fire Survival Guidance calls
- managing resident evacuation; and ensuring the stairs were clear of smoke where possible

During all tests, the SPT simulated the requirement to deploy breathing apparatus. SPTs were deployed on each floor of the building, adopting the SOPs and techniques for this incident type (LFB, 2021 and LFB, 2017). SPT duties included:

- fitting smoke curtains
- supervising the entry into the staircase to minimise the spread of smoke
- keeping the exit routes clear of obstructions
- warning others if they noticed significant fire development

9.1 Strategy 1 – A full evacuation using an Evacuation Alert System

Both tests of Strategy 1 took place on Wednesday 4 May 2022. The experiment involved the evacuation of 80 residents distributed across 10 floors (4 to 13).

Impairments simulated:

- nine volunteers were briefed to walk at half pace
- four volunteers were briefed as evacuation chair assistants
- two volunteers on floor 10 were briefed to move up 2 floors and then evacuate down the staircase at their own walking pace

The residents on each level reacted within a time frame according to their predetermined script. The EAS signalled residents to evacuate simultaneously.

9.2 Strategy 2 – A full evacuation without an Evacuation Alert System

This method of manual alert (door knocking) of residents is most common operationally, due to the scarcity of HRRB currently fitted with an EAS.

Both tests of Strategy 2 took place on Tuesday 3 May 2022. The experiment involved the evacuation of 68 residents distributed across 10 floors (across floors 4 to 13).

Impairments simulated:

- eight volunteers were identified to walk at half pace
- three volunteers and 2 firefighters were briefed as evacuation chair assistants
- two volunteers on floor 10 were briefed to move up 2 floors and then evacuate down the staircase at their own walking pace

One volunteer was a 3-year-old child (attending with a parent).

Firefighters physically alerted residents by knocking on flat doors. The residents were positioned outside the flat doors and reacted on each level within a timeframe according to a predetermined script on the flat door.

9.3 Strategy 3 – A full evacuation conducted in phases (that is, certain floors) with an Evacuation Alert System

Strategy 3A: Bottom-up

The first test of Strategy 3A took place on Wednesday 4 May 2022 and the second attempt on Thursday 5 May 2022. Test 3A-2 involved the evacuation of 49 residents distributed across 9 floors (4 to 12).

Impairments simulated:

- four volunteers were briefed to walk at half pace
- three volunteers and 2 firefighters were briefed as evacuation chair assistants
- one volunteer on floor 10 was briefed to move up 2 floors and then evacuate down the staircase at their own walking pace

One volunteer had a visual impairment and used a cane to assist navigation.

Evacuation started from the floor immediately above the fire at-risk area, and worked up sequentially, floor by floor, to the top of the building.

Strategy 3B: Top-down

Both tests of Strategy 3B took place on Thursday 5 May 2022. Test 3B-2 involved the evacuation of 43 residents distributed across 9 floors (4 to 12).

Impairments simulated:

- three volunteers were identified to walk at half pace
- three volunteers and 2 firefighters were briefed as evacuation chair assistants
- one volunteer on floor 10 was briefed to move up 2 floors and then evacuate down the staircase at their own walking pace

One volunteer had a visual impairment and used a cane to assist navigation.

Evacuation started from the floor immediately above the fire at-risk area, and worked down sequentially, floor by floor, to the bottom of the building.

9.4 Strategy 4 – Two staircases, full evacuation using an Evacuation Alert System

Both tests of Strategy 4 took place on Friday 6 May 2022. The experiment involved the evacuation of 79 residents distributed across 10 floors.

Impairments simulated:

- seven volunteers were briefed to walk at half pace
- two volunteers and 3 firefighters were briefed as evacuation chair assistants

The residents on each level reacted within a timeframe according to their predetermined script. The EAS signalled residents to evacuate simultaneously.

10. Appendix 3: Data capture

Table 4 shows the tests that were processed along with the number of participants in total and starting on each floor. Table 5 shows the tests that were unprocessed along with the number of participants.

Table 4: Total number of volunteers per floor for tests (processed)

Processed and analysed					
Experiment	1-1	2-2	3A-2	3B-2	4-2
Total volunteers	80	68	49	43	79
Floor 16	-	-	-	-	-
Floor 15	-	-	-	-	-
Floor 14	-	-	-	-	-
Floor 13	9	4	0	0	0
Floor 12	8	5	4	3	0
Floor 11	8	8	4	4	6
Floor 10	8	8	4	4	8
Floor 9	8	8	4	4	7
Floor 8	8	7	5	5	8
Floor 7	9	6	6	6	8
Floor 6	6	6	6	4	7
Floor 5	9	8	8	7	8
Floor 4	7	8	8	6	14
Floor 3	-	-	-	-	6
Floor 2	-	-	-	-	7
Floor 1	-	-	-	-	-

Table 5: Total number of volunteers per floor for reserve tests (unprocessed)

Unprocessed					
Experiment	1-2	2-1	3A-1	3B-1	4-1
Total volunteers	64	69	64	49	86

Unprocessed					
Floor 16	-	-	-	-	-
Floor 15	-	-	-	-	-
Floor 14	-	-	-	-	-
Floor 13	8	4	8	0	0
Floor 12	5	5	5	4	0
Floor 11	7	8	7	4	8
Floor 10	8	8	8	4	8
Floor 9	3	8	3	4	8
Floor 8	7	8	7	5	8
Floor 7	6	6	6	6	8
Floor 6	5	6	5	6	7
Floor 5	7	8	7	8	8
Floor 4	8	8	8	8	15
Floor 3	-	-	-	-	8
Floor 2	-	-	-	-	8
Floor 1	-	-	-	-	-

Where a camera failed, it was sometimes possible to extrapolate its data accurately by looking at the camera data from the floors above and below. However, where there were continuous camera failures (see table 6 and table 7), there was an unacceptable level of uncertainty. For each test, the footage with the lowest number of continuous camera failures was selected to be processed and analysed. If no continuous failures occurred in either run of the test, then the run with lowest total number of failures was chosen, or the higher number of volunteers (as in Test 1-1).

For each of the processed and analysed experiments, detailed second-by-second data was reviewed on the number of evacuees on each floor, and the movement of individual evacuees (using person IDs) through each floor of the building by time elapsed and speed. This allowed the analysis of flows and bottlenecks to be reviewed to identify potential contributory factors, such as unusual actions (for example, walking upwards) or the presence of evacuees with impairments.

Table 6: Camera failures in processed experiments

Experiment					
	1-1	**2-2**	**3A-2**	**3B-2**	**4-2**
Floor 0			BM		
Floor 1		CF			
Floor 2			SD		
Floor 3					
Floor 4					
Floor 5				SD	
Floor 6					
Floor 7					
Floor 8					
Floor 9				CF	
Floor 10					
Floor 11					
Floor 12					
Floor 13					

DB = Drained Battery; BM = Battery Malfunction; SD = SD Data Corrupt; CF = Camera Failure

Table 7: Camera failures in non-processed experiments

Experiment					
	1-2	**2-1**	**3A-1**	**3B-1**	**4-1**
Floor 0					
Floor 1					
Floor 2			BM		
Floor 3					
Floor 4			BM		

Experiment				
Floor 5				
Floor 6		BM		
Floor 7		BM		
Floor 8				
Floor 9				CF
Floor 10			SD	
Floor 11			SD	
Floor 12	DB			
Floor 13				

DB = Drained Battery; BM = Battery Malfunction; SD = SD Data Corrupt; CF = Camera Failure

11. Appendix 4: Further observations from tests

11.1 Further observations from analysis of Test 1-1 (a full evacuation with an EAS)

Although the evacuation signal was sounded simultaneously across all floors, variations in evacuees' readiness and reaction time resulted in evacuees from higher floors being blocked on the staircase while lower floor evacuees were still leaving their initial floor. Up to 9 evacuees could be seen within the stairwell of a single floor. Contributing to the congestion were 2 evacuees who used crutches to walk downstairs – their speed was slow, particularly where firefighting equipment covered the floor, causing queues above. There was a relationship between the floor level where evacuees using crutches entered stairwells and the length of queue they produced as they descended. A queue of 15 evacuees formed behind a crutch user from floor 5, while 25 people were observed queuing behind the evacuee using crutches from floor 8.

While the firefighters ascended the stairs in the first 3 minutes of the experiment, before volumes of evacuees built up, congestion occurred due to evacuees descending from higher floors merging with those emerging from lower floors.

It was observed that evacuating an individual in an evacuation chair may take less time than the evacuation of an individual using crutches (average speeds of 0.3m/s and 0.32m/s for those using crutches compared with averages of 0.2m/s and 0.4m/s for evacuation chairs).

11.2 Further observations from analysis of Strategy 2 (full evacuation without an EAS)

Congestion was seen for several short periods during Strategy 2, for example at around 9 minutes 10 seconds to 11 minutes 40 seconds (550 to 700 seconds). Furthermore, just a few evacuees left the building between 13 minutes 20 seconds to 17 minutes 30 seconds (800 and 1,050 seconds), and between 17 minutes 55 seconds to 21 minutes 15 seconds (1,075 to 1,275 seconds), after which, several people left in quick succession. A few short gaps were then seen between exits, until another pause around 24 minutes 10 seconds to 27 minutes 30 seconds (1,450 to 1,650 seconds).

The plateau in evacuees exiting the building from 13 minutes 54 seconds (834 seconds) corresponds with the movement of an evacuation chair guided by 2 firefighters. Analysis found 2 firefighters wearing breathing apparatus were delayed by 4 evacuees going down the stairs on floor 6, and an interaction of 1 minute 30 seconds (90 seconds) between 2 evacuees aiming to ascend from floor 10 were prevented by 2 firefighters, which also created brief congestion.

Within this experiment, video analysis showed that evacuating an evacuation chair (assisted by firefighters) could take longer than evacuating using crutches. This is different to that observed in Test 1-1, but each evacuee with a mobility impairment (or simulating a mobility impairment through the use of cutches) will be different. For instance, in Test 2-2 the evacuation chair guided by 2 firefighters went down from floor 3 to floor 1 in 1 minute 16 seconds (76 seconds), while the evacuation chair guided by evacuees (in Test 2-2) covered the same floors in 59 seconds.

Except when navigating hoses at floor 6, the participation of a 3-year-old child in this test did not greatly reduce the walking speed of the adult holding their hand (average time per floor of 15 seconds, compared to 13 seconds for adults without impairments). However, it is important to note that this may not reflect the actual time it takes for parents to evacuate because it is possible that there will be both more parents and children in the event of a real evacuation, which may impact the overall evacuation time.

11.3 Further observations from analysis of Strategy 3A (full evacuation conducted in phases with an EAS, bottom-up)

It was observed that 2 firefighters wearing breathing apparatus had to wait at the landing of floor 5 to give priority to one firefighter and one evacuee guiding an evacuation chair, creating congestion. Firefighters engaged in the evacuation of an occupant in an evacuation chair were also delayed by 2 evacuees in the landing of the staircase at floor 3; the congestion was due to narrowness of the stairs and firefighters trying to accommodate the evacuation chair.

Observations show that the evacuee with a visual impairment had little effect on movement speed, as an evacuee walking at half pace was setting the pace of that group of evacuees.

11.4 Further observations from analysis of Strategy 3B (full evacuation conducted in phases with an EAS, top-down)

This evacuation test resulted in less congestion between floors than in the simultaneous evacuation (Test 1-1). The mannequin in the evacuation chair guided by 2 residents evacuated more quickly than the mannequin in the evacuation chair led by one firefighter and one evacuee, potentially due to the firefighting equipment that might have contributed to slower movement of the firefighters.

Video observations showed that an evacuation chair guided by an evacuee and 2 firefighters blocked the path of another evacuee from floor 4 to the exit.

When the firefighters co-ordinated the evacuation via door knocking (as in Strategy 2), there was less congestion compared to Strategy 1 (full evacuation with EAS).

11.5 Further observation from analysis of Strategy 4 (2 staircases, full evacuation using an EAS)

Within this test, there was a notable reduction in visibility in the staircase of floor 5 due to less illumination when an evacuee closed the door from the corridor of that floor. This impacted the average speed of evacuees. When there was reduced visibility, the average speed of the 9 evacuees affected by the decrease in visibility was 0.33m/s, which was 12% slower when compared to the average speed of the 35 evacuees that passed the floor before the door was closed and light reduced (0.37m/s).

11.6. Average movement analysis

The following figures (figure 6 for Test 1-1, figure 7 for Test 2-2, figure 8 for Test 3A-2, figure 9 for Test 3B-2 and figure 10 for Test 4-2) demonstrate the average movement speeds per person per floor during each test.

The diamond symbols represent each of the volunteers' speed per floor. Each box plot shows the distribution of data, that is, the speeds of volunteers per floor based on 5 quantities. Each box shows the minimum data value, lower quartile (25%), mean (50%), upper quartile (75%) and maximum data value within 2 standard deviations above and below the median movement speed.

The cameras used to record the data in these charts were placed in stairwells. Therefore, the floor number on the charts corresponds to the camera in the stairwell between that floor and the floor above. For example, evacuees recorded as they descended from floor 13 to 12 are represented on floor 12 in the charts.

Figure 6 represents the speed of each of the 80 residents during the evacuation on each floor, starting from their original position on floors 4 to 13 and moving down to evacuate. Higher speeds were recorded on floors 12, 2 and 1 (the highest on floor 12 at 1.25m/s) whereas the slowest speeds were recorded on floors 9, 8, 7 and 6 (between 0.078m/s and 0.11 m/s).

Figure 6: Average movement speeds per person per floor for Test 1-1

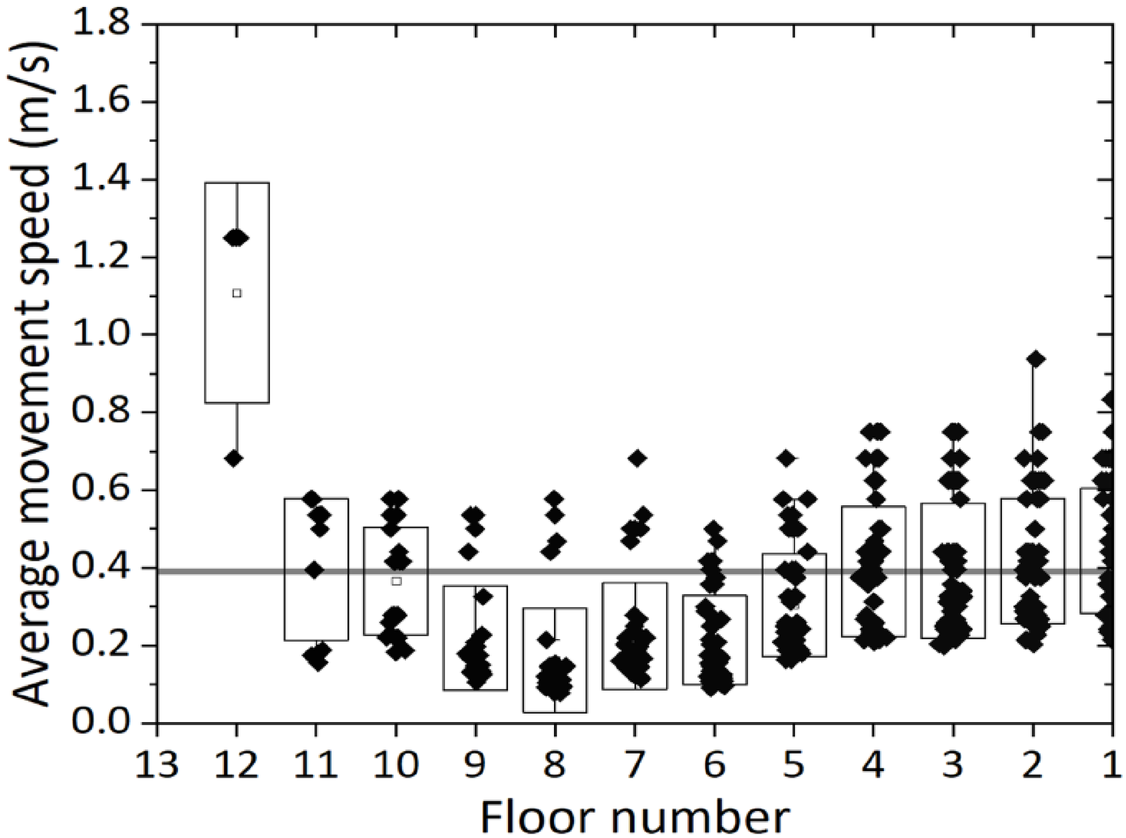


Figure 7 represents the speed of each of the 68 residents during the evacuation on each floor for Test 2-2, starting from their original position on floors 4 to 13 and moving down to evacuate. The slowest speeds were recorded between floors 3 to 8 with speeds of approximately 0.15m/s to 0.23m/s while the fastest speeds were recorded on floors 8 and 2 (at speeds of 1.071m/s). It is important to note that due to a camera failure in Test 2-2, there is no recording of average movement speeds on floor 1, hence the chart is blank for floor 1.

Figure 7: Average movement speeds per person per floor for Test 2-2

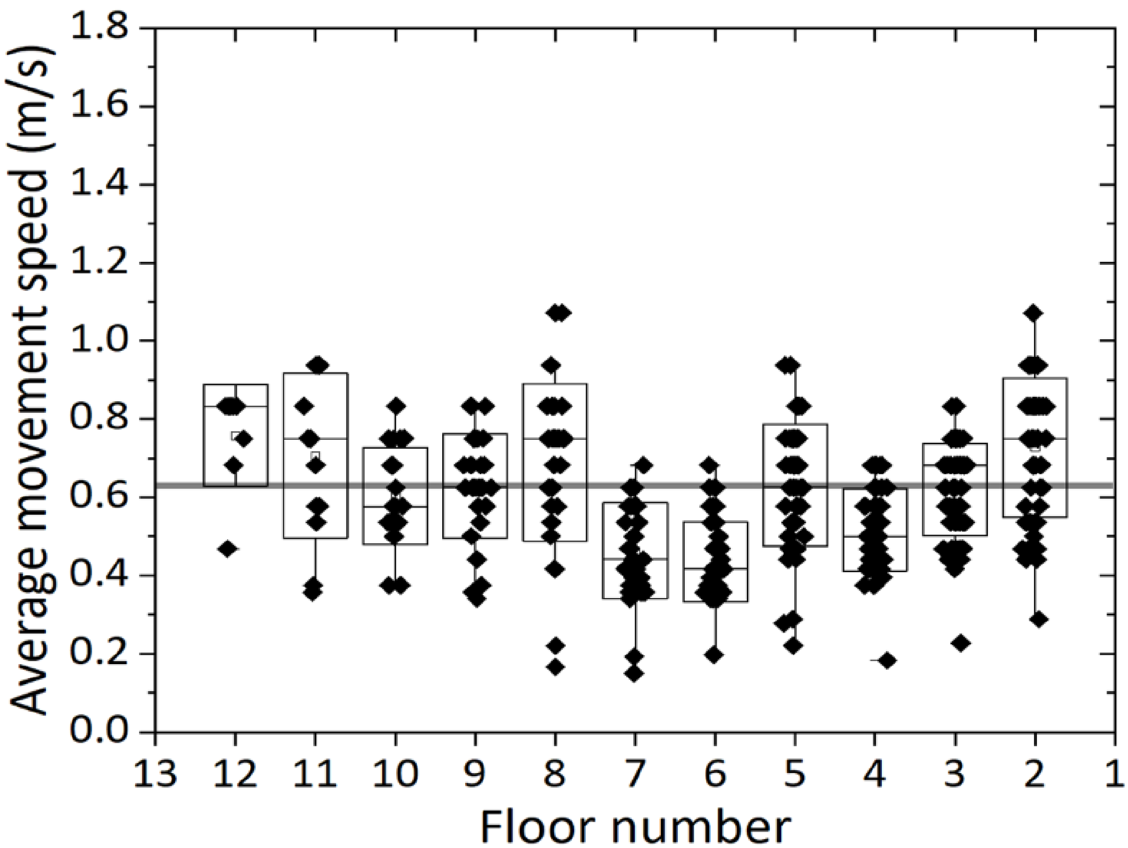


Figure 8 represents the speed of each of the 49 residents during the evacuation on each floor for Test 3A-2, starting from their original position on floors 12 to 4 and moving down to evacuate. The fastest speeds were recorded on floor 3 at around 1.5m/s and the slowest speeds were recorded on floors 11 and 10, both of which were at around 0.1m/s.

Figure 8: Average movement speeds per person per floor for Test 3A-2

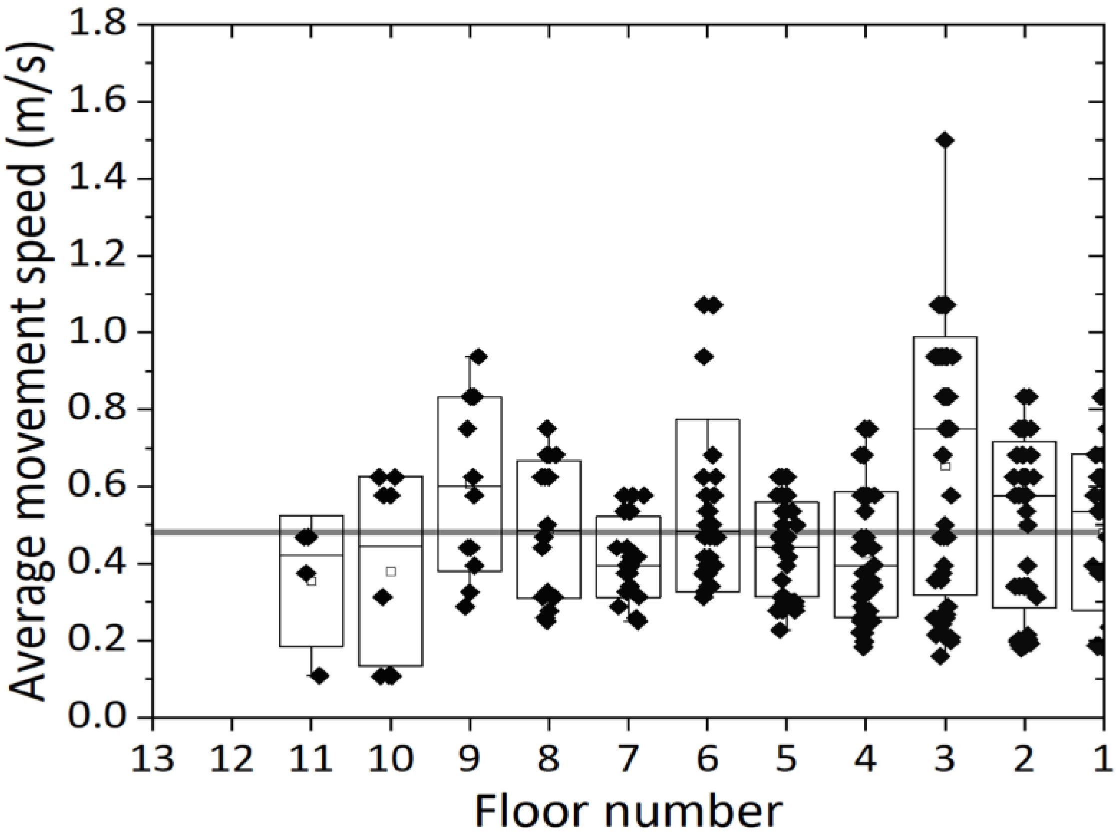


Figure 9 represents the speed of each of the 43 residents during the evacuation on each floor for Test 3B-2, starting from their original position on floors 12 to 4 and moving down to evacuate. The fastest speed was on floor 6 at around 1.5m/s while the slowest speed was recorded on floor 1 at below 0.08m/s.

Figure 9: Average movement speeds per person per floor for Test 3B-2

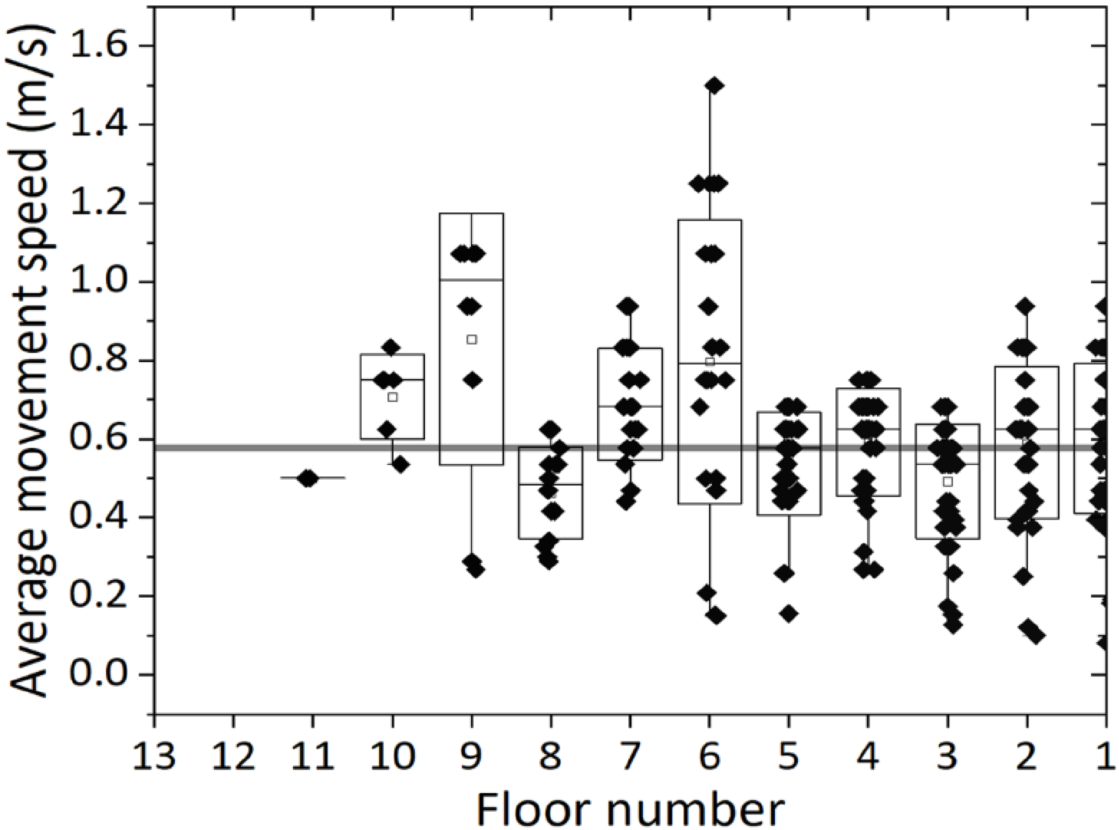
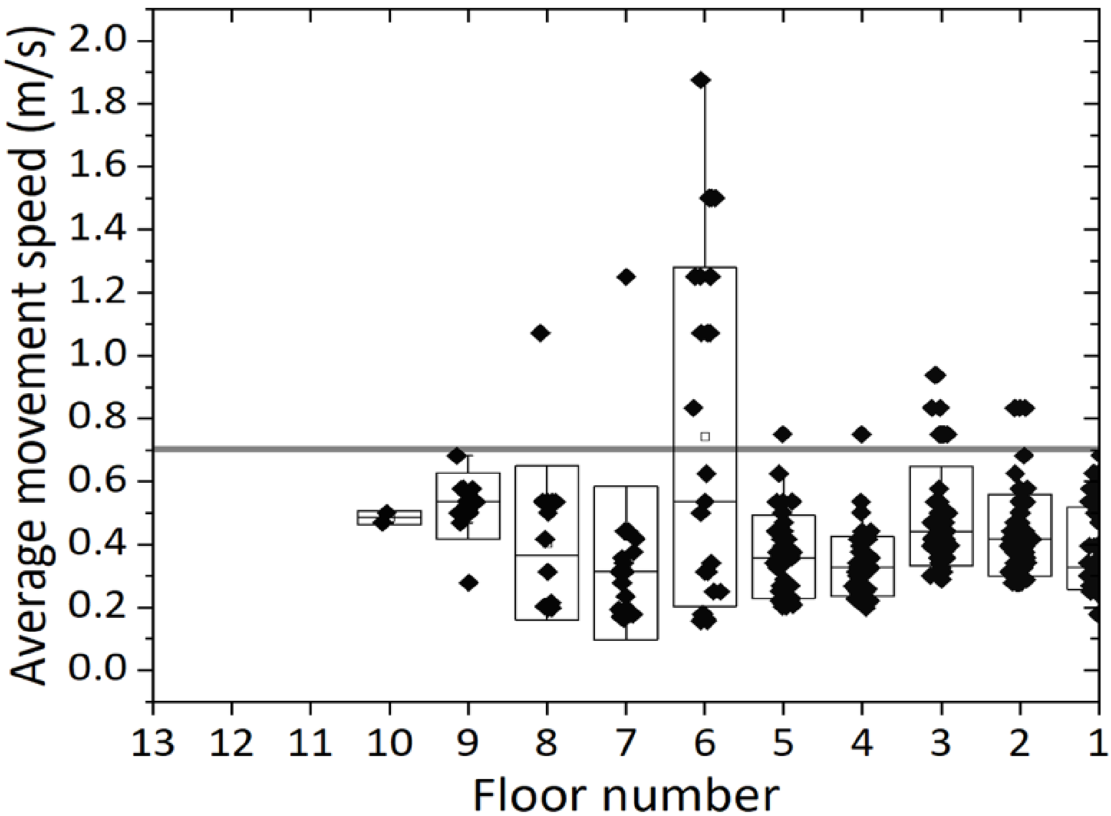


Figure 10 represents the speed of each of the 79 residents during the evacuation on each floor for Test 4-2, starting from their original position on floors 11 to 2 and moving down to evacuate. The fastest speeds recorded were on floor 6 at 1.87m/s while the slowest speeds were recorded on floors 8, 7, 6 and 1, at around 0.16m/s to 0.2m/s.

Figure 10: Average movement speed per person per floor for Test 4-2



12. Appendix 5: Additional modelling information

For Pathfinder simulation of Strategies 1, 2, 3A and 3B, the model used one staircase with agents distributed across test floors, all on the left-hand side of the simulated building. For Strategy 4 (2 staircases), the Pathfinder simulation used a different distribution of start locations for the agents, with agents distributed across the breadth of simulated floors, on each side of both staircases.

When describing the modelling information, this research refers to agents and simulations to distinguish between tests and simulation models.

12.1 Modelling of Strategy 1 – A full simultaneous evacuation with EAS

To mirror the live operational test, 2 agents were instructed to move up 2 floors (10 to 12) before evacuating. In the test, there were 69 participants (with 2 mannequins in the evacuation chairs.), hence the model included 71 agents.

The model runs from 0 seconds, EAS was triggered at 6 minutes 30 seconds (390 seconds) to reflect the conditions in Test 1-1, and all agents had evacuated at 19 minutes 19.3 seconds

(1,159.3 seconds).

12.2 Modelling of Strategy 2 – A full evacuation without EAS

In the modelling of Strategy 2, 2 agents were instructed to move up from floor 10 to floor 12, before evacuating. In the experiment, there were 64 participants (with 2 mannequins in the evacuation chairs, and 3 firefighters assisting), hence the model included 66 agents.

Modelling of Strategy 2 examined a phased evacuation. In the live test, firefighters notified participants floor by floor (at approximately 2-minute per floor intervals). However, the phased evacuation examined in the modelling generally used 2-minute intervals between evacuation of floors, starting with floor 6 (the seat of the fire) and working upwards to floor 13 (top floor in use) before re-commencing at floor 5, then working downwards.

The model runs from 0 seconds, EAS was triggered at 6 minutes (360 seconds) to reflect the conditions in Test 2-2, and all agents had evacuated at 28 minutes 42.5 seconds (1,722.5 seconds).

12.3 Modelling of Strategy 3A – Full phased evacuation with EAS, bottom-up

In Test 3A-2, there were 49 participants with 2 mannequins in the evacuation chairs, hence this model included 51 agents.

This model operated using the same phased sequence as in the model of Strategy 2 but reduced the time intervals to approximately 1-minute between floors.

The model runs from 0 seconds, EAS was triggered at 3 minutes 50 seconds (230 seconds) to reflect the conditions in Test 3A-2, and all agents had evacuated at 19 minutes 18.8 seconds (1,158.8 seconds).

12.4 Modelling of Strategy 3B – Full phased evacuation with EAS, top-down

In Test 3B-2, there were 43 participants with 2 mannequins in the evacuation chairs, hence this model included 45 agents.

This model also operated similarly to models 2 and 3A, but instead of a constant time interval, slightly random time intervals were used to reflect the conditions in Test 3B-2.

The model runs from 0 seconds, EAS was triggered at 2 minutes 47 seconds (167 seconds), and all agents had evacuated at 18 minutes 5 seconds (1,085 seconds).

12.5 Modelling of Strategy 4 – Full simultaneous evacuation with EAS, 2 staircases

Test 4-2 used a 2-staircase approach, with all firefighting apparatus located to the second stairwell, and all evacuation taking place through the first stairwell. Therefore, all the cross-corridor doors were opened, and participants' start positions distributed across the whole floor area, with access to both staircases (and in contrast to the live testing experiment, modelled evacuation used both staircases). Other settings of this model are the same as in Test 4-2.

In Test 4-2, there were 79 participants with 2 mannequins in the evacuation chairs, hence the model included 81 agents.

The model runs from 0 seconds, EAS was triggered at 3 minutes 11 seconds (191 seconds) to reflect the conditions in Test 4-2, a simultaneous evacuation of the building was modelled using both the stairwells converging at a single exit at the ground floor level, and all agents had evacuated at 11 minutes 49 seconds (709 seconds).

13. Appendix 6: Building exit curves

Numerical data on the building exit curves and how the model compares with the live operational test data are presented in figure 11 for Test 1-1, figure 12 for Test 2-2, figure 13 for Test 3A-2, figure 14 for Test 3B-2 and figure 15 for Test 4-2. The following 5 figures use labels, such as 'Scenario 1-1', which refers to the experimental activity Test 1-1, and 'PF1', which refers to the Pathfinder modelling applied to the corresponding strategy.

Figure 11 shows that the simulated results over-predicted the evacuation times in all stages of Test 1-1. Nevertheless, the total evacuation time predicted for Test 1-1 was 19 minutes 19 seconds (1,159 seconds), compared with 19 minutes 15 seconds (1,155 seconds) during the experiments. This resulted in an error of 0.35%. Also, the first person evacuating the building was relatively accurately predicted, as they were shown to exit the building approximately 50 seconds later than the test data.

Figure 11: Building exit curve for Test 1-1

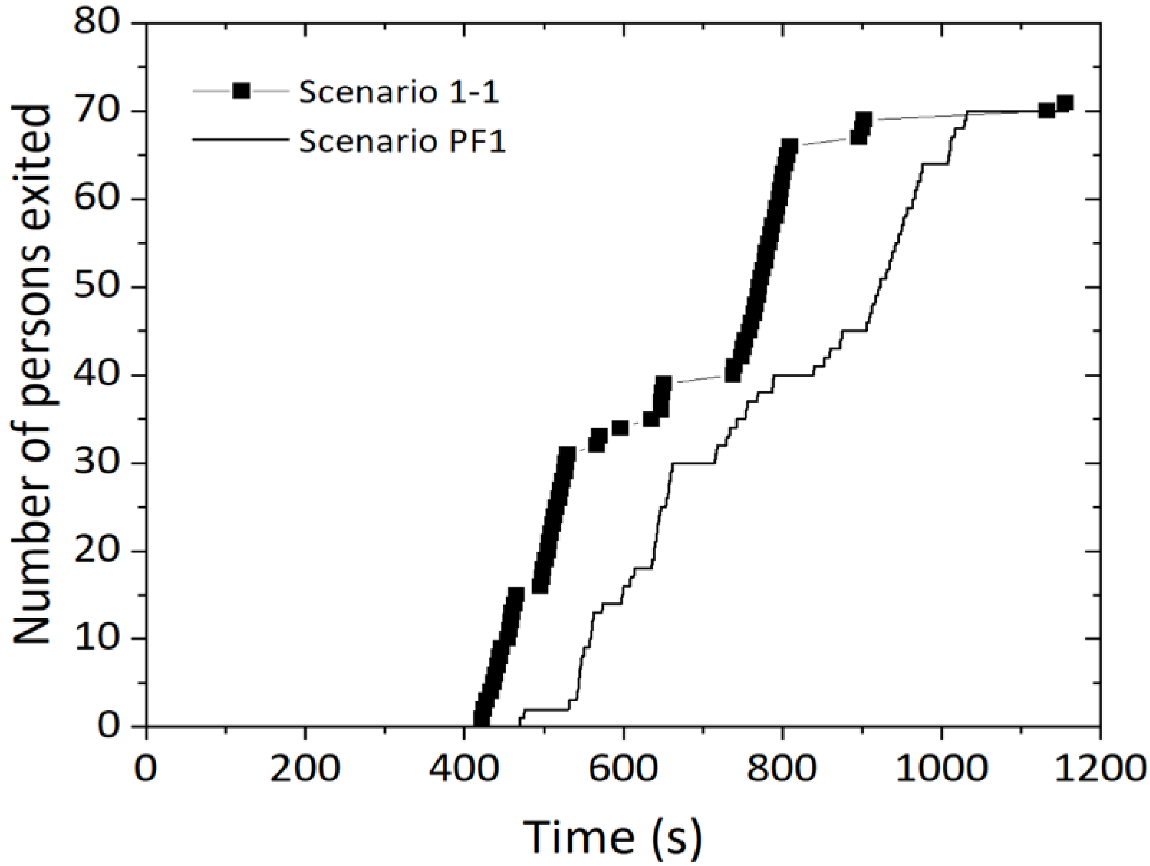


Figure 12 shows that the simulated results were close to the experimental evacuation times in all stages of the evacuation. Also, the total evacuation time predicted for Test 2-2 was 28 minutes 43 seconds (1,723 seconds), compared with 28 minutes 38 seconds (1,718 seconds) during the experiments. This resulted in a very low error of 0.29%. The first person evacuating the buildings was relatively accurately predicted, as they were shown to exit the building approximately 30 seconds later than the test data.

Figure 12: Building exit curve for Test 2-2

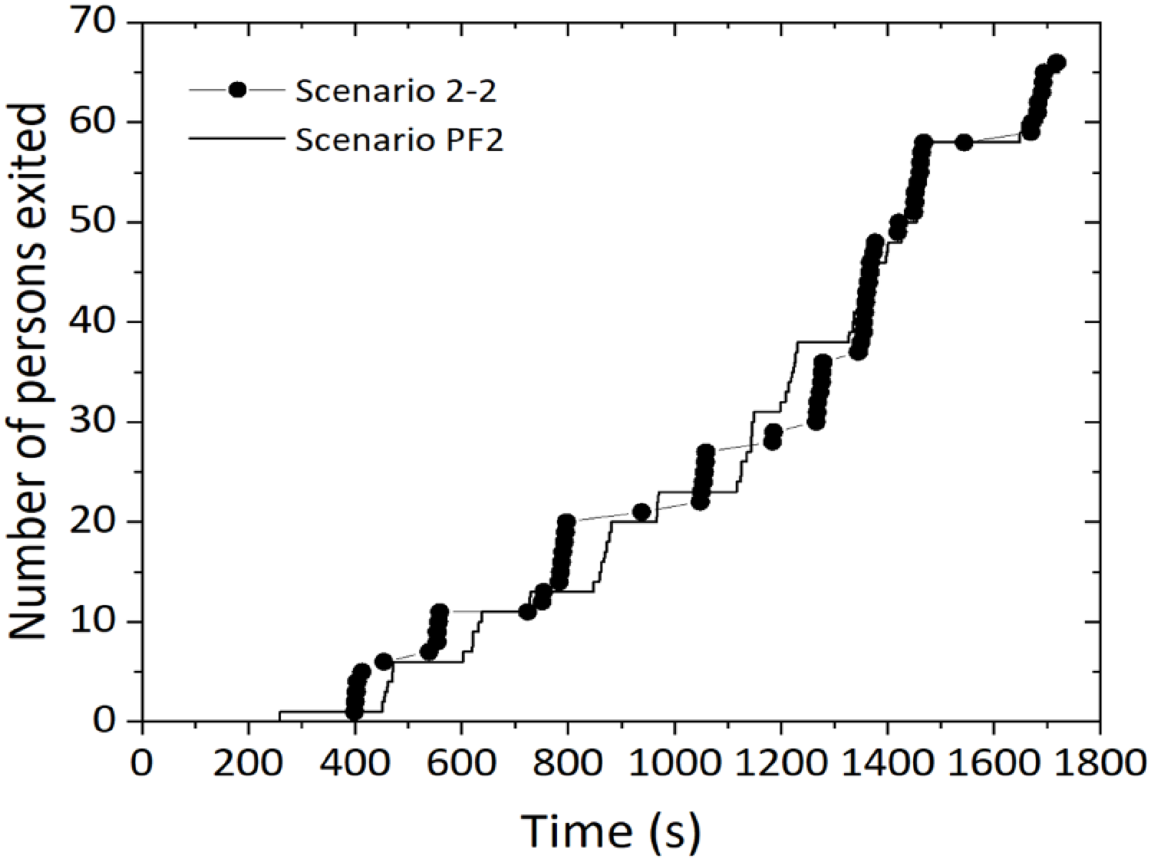


Figure 13 shows that the simulated results were close to the test evacuation 3A-2. The total evacuation time predicted for Test 3A-2 was 19 minutes 19 seconds (1,159 seconds), compared to 20 minutes 6 seconds (1,206 seconds) during the experiments. This resulted in an error of -4.06%. In this case, the first person evacuating the buildings was relatively accurately predicted as they were shown to exit the building approximately 50 seconds later than the test data.

Figure 13: Building exit curve for Test 3A-2

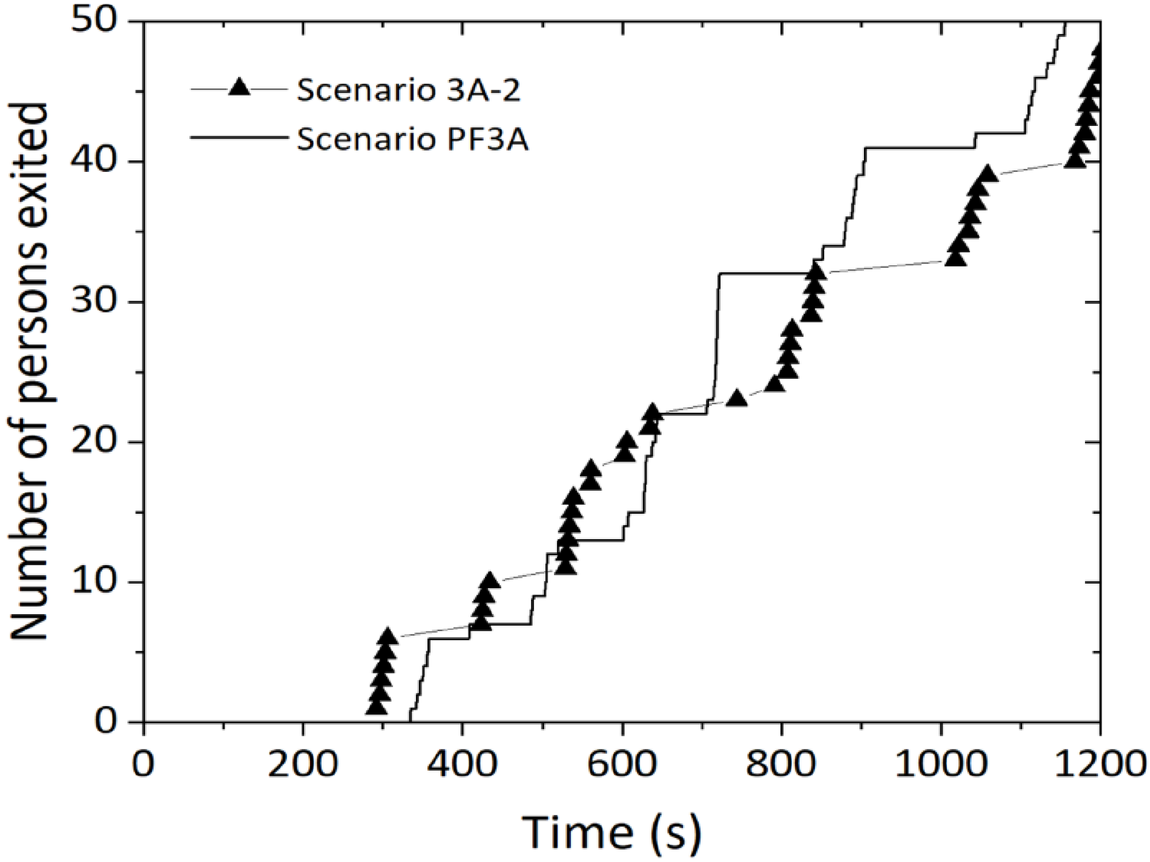


Figure 14 shows that the simulated results were close to the experimental evacuation times in all stages of the evacuation. The total evacuation time predicted for Test 3B-2 was 18 minutes 5 seconds (1,085 seconds), compared to 18 minutes 1 second (1,081 seconds) during the experiments. This resulted in an error of 0.37%. The first person evacuating the buildings was relatively accurately predicted as they were shown to exit the building approximately 60 seconds later than the experimental data.

Figure 14: Building exit curve for Test 3B-2

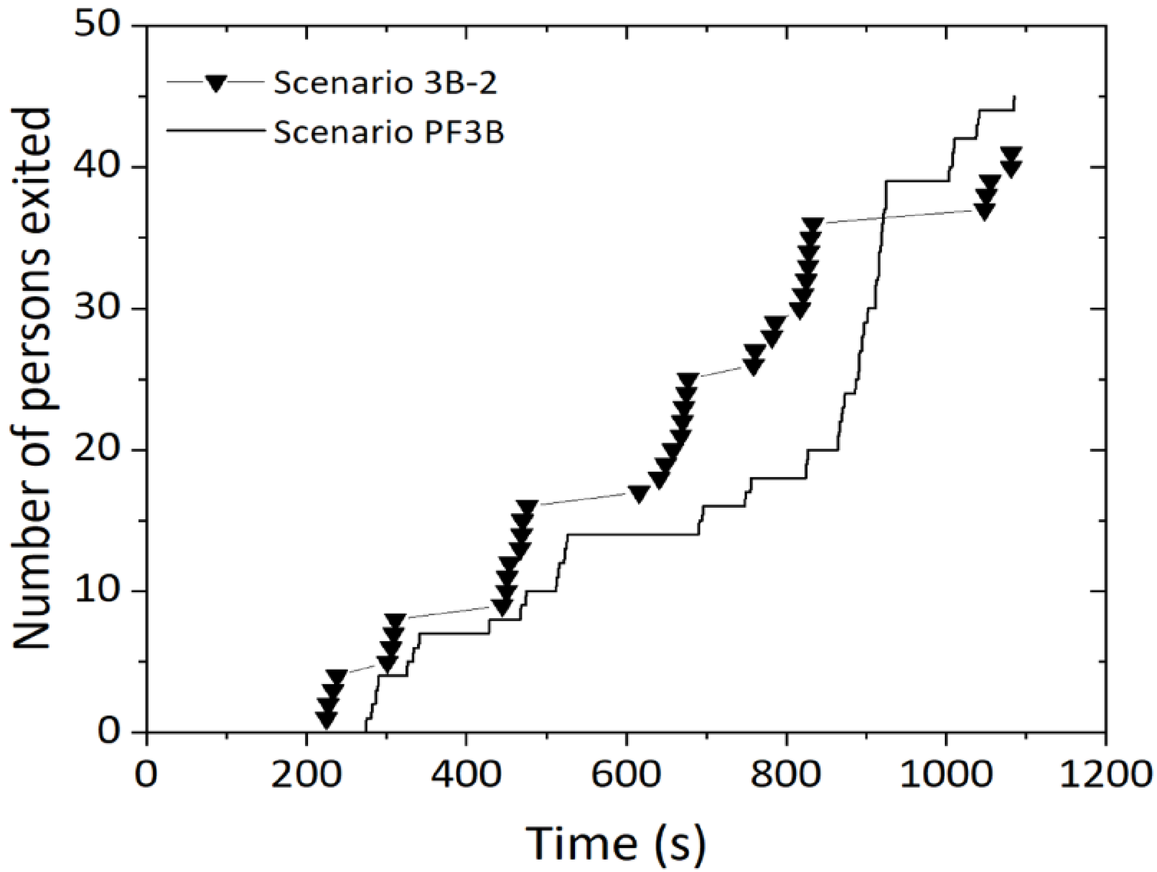
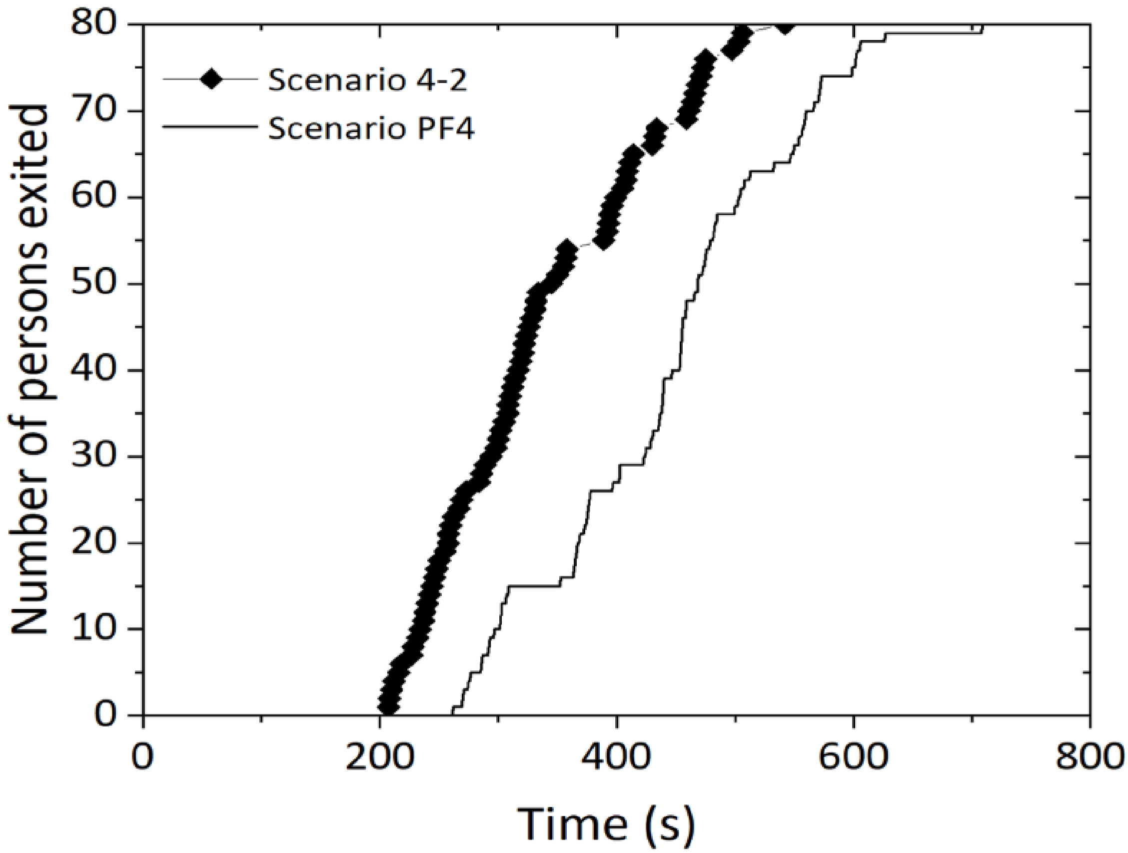


Figure 15 shows that the simulated results were fairly close to the test evacuation times in all stages of the evacuation. The total evacuation time predicted for Test 4-2 was 11 minutes 50 seconds (710 seconds), compared to 9 minutes 2 seconds (542 seconds) during the experiments. This resulted in an error of 23.7%. The first person evacuating the buildings was over-predicted as they were shown to exit the building approximately 80 seconds later than the experimental data. However, it must be noted that the model allowed evacuation through 2 staircases, whereas during the live tests, firefighting operations took place in the original staircase and evacuation was only carried out in the second staircase.

Figure 15: Building exit curve for Test 4-2



14. Appendix 7: Further assumptions and limitations

Experiment repetition: Each of the 5 live evacuation tests was repeated twice. Only data from Tests 1-1, 2-2, 3A-2, 3B-2 and 4-2 (the most complete dataset from each pair) were used in the analysis. The strategies tested were limited to the different HRRB evacuation strategies identified in the pre-project scoping work. Ideally, additional evacuation trials could have been conducted with different fire scenarios, evacuation routes and fire spread assumption mechanisms.

Experimental announcement: This research followed the announced approach, using non-resident volunteers, as opposed to monitoring unannounced evacuations of genuine residents. Experimental evacuation studies have been criticised for not representing valid human behaviour and evacuation in fires, as perhaps they were not representative of the situation occupants will face in a real fire (Gwynne et al., 1999; Kuligowski, 2003); However, these studies can still capture the data related to movement speed (m/s) and flow rates.

Signalling full evacuation after lifting a 'stay put' position: This research focused on the emergency evacuation of a HRRB with a 'stay put' position, instigated by FRS when the 'stay put' position is becoming unsustainable due to a failing building. Although the incidence of an EAS in HRRBs is relatively low as identified in the project scoping, all but one test assumed an EAS was available, allowing either a truly simultaneous or phased evacuation signal. The research did not evaluate the effectiveness of the EAS system, nor did it investigate alternative evacuation strategies that may be adopted at building design stage.

Pre-movement time in residential buildings (the time between the alarm or evacuation signal being given and occupants starting to evacuate) is widely reported in guidance documents and studies (SFPE, 2016; Gwynne & Boyce (2016); BSI, 2019).

Pre-movement time can be a major component of the total evacuation time; it can vary and be difficult to quantify. This study included participants who started evacuation at the flat entrance doors, were awake and were informed about their expected behaviour and initial response. Gwynne and Boyce (2016) reported that in HRRBs, pre-movement time can range from 0.3 to >20 minutes. This could increase the overall evacuation time if pre-movement time was considered. However, the aim of this research was to conduct a comparative study of evacuation scenarios, not to determine the total evacuation time for the building experiments. Therefore, this study did not investigate pre-movement times in HRRB as the flats within the building used were inaccessible. Future non-announced evacuations could allow for accurate capture of pre-movement time.

Volunteer evacuees were used, therefore the number available varied between tests. Numbers (between 43 and 80 per experiment) were comparable with other evacuation tests in residential buildings (Lovreglio et al., 2019). Scripts (with timeframes) were provided, but the actual actions of volunteers may have differed from the plan.

Building familiarity may assist evacuation speeds for HRRB residents, but in the event of an evacuation, there may be several visitors or new residents who might not be familiar with it (Sime, 1985), (Canter et al., 1980). During the tests, the factor of place affiliation (ibid) was minimised as different volunteers participated each day. Non-announced evacuations would allow consideration of the impact of evacuees' familiarity with the building. However, it is important to note that 3 live tests were conducted on the Wednesday and Thursday, which means some volunteers may have become increasingly familiar with the building.

Building environment parameters were controlled and matching for each strategy (except Strategy 4, in which dividing doors were opened to allow access to the second staircase). The internal staircase light levels would be the same during night-time as during the daytime experiments, but for other buildings, lighting levels may reduce at night and impact walking speed (Frantzich & Nilsson, 2004).

Firefighting operations were assumed to follow the SOPs and existing LFB Operational Techniques appropriate to this HRRB incident (LFB, 2021; LFB, 2017; NFCC, 2022). During all tests, the SPTs simulated the requirement to deploy breathing apparatus above the bridgehead, which is a safe base from which to commence firefighting operations. Firefighting operations took place within the same single staircase as evacuations in all, apart from Strategy 4, where firefighting operations continued to take place in the same staircase, but the second staircase was utilised for evacuation. Trends in response times and procedures of the first responders were limited to the building tested and data could be different for different geometries and floor heights.

Smoke was not present during the experiments, although smoke curtains were installed on each floor. Smoke reduces visibility, impacts on ability to identify escape routes and reduces movement speed. Jin and Yamada (1989) have shown that both irritant smoke and increased smoke density further reduce movement speed. Smoke is likely to be hot, and this radiant heat can influence evacuees (for example, respiratory tract burns, body surface burns or hyperthermia). Smoke also reduces oxygen concentration, which can impair movement, judgement and even cause loss of consciousness (Stensaas, 1991), depending on the level of oxygen loss.

Fatigue was also not accounted for in the live operational tests. Although some participants were instructed to move slower than the average movement speed, the research does not account for the impact of fatigue on all participants, including those who may need to help others evacuate. Fatigue can impact evacuation time and movement speed and can further complicate the impact of smoke on movement and evacuation time.

The impact of smoke on visibility may reduce movement during fire evacuation. For example, Fridolf et al. (2018) suggested where visibility levels are ≤3m, occupants' walking speeds reduce by as much as 0.34m/s. The experiments did not evaluate the impact of fire products, such as smoke or heat, on movement speeds or on reaction to the alarm.

Public access/intervention was excluded from the experiment as the experimental building was not publicly accessible and evacuees were gathering into the assembly point after each exercise as instructed during the briefing. Due to this, the live testing did not need to consider any requirements for members of the public.

The number of evacuees was similar for the simultaneous evacuations using EAS – Test 1-1 with single staircase (80 participants) and Test 4-2 with 2 staircases (79 participants). However, evacuee numbers were lower for Test 2-2 full evacuation without EAS (68 participants) and lower still for the pair of phased evacuations, Tests 3A-2 and 3B-2 (with 49 and 43 participants, respectively).

Movement speed depends upon the density of people on the stairs (Kuligowski, et al., 2015; Hoskins & Milke, 2013). Occupied floors had an average of 1.8 to 1.9 people per flat, which is similar to the average (mean) size household of 1.9 people in HRRBs (MHCLG, 2019). Although the number of occupants varied slightly between tests, FRS controlled the movement down the stairs (apart from in simultaneous exits in Test 1-1 and Test 4-2). Further experiments could be carried out with larger samples than the ones used in this study to better understand the dependency of movement speed on density and the impact on firefighting activities.

The location of residents with impairments was on the same 2 floors during all the tests to ensure consistency. Volunteers acted to represent residents with mobility impairments as per scripts provided, and FRS standard training mannequins were placed in evacuation chairs to represent those unable to walk to the ground floor unaided. However, while the location of residents with impairments is unsupported by data from real fires, we can assume that residents may be on any floor within the building.

14.1 Further limitations of the modelling

Various sources of randomness in real incidents were eliminated as each occupant was assigned starting positions and walking speeds within the model. However, further sensitivity analysis could be performed to evaluate the impact of pre-movement time and initial position of the occupants on the efficiency of evacuation. Typical occupants were generated to serve as a template for evacuee profiles and would not follow unexpected evacuation behaviours such as jumping.

Pathfinder simulated the walking speed for each evacuee as a constant value, using average evacuation speeds observed in experiments. However, the experiments have shown that constant speeds were not realistic, as speeds varied on each floor. In addition, evacuees with a visual impairment could not be defined in the model.

The dimensions of the wheelchairs simulated did not directly match the evacuation chairs. Simulations of the evacuation chair times should therefore be further validated.

Simulations could not consider the obstacles on the floor and staircases. Consideration should be given to further evacuation software that can simulate obstructions, such as firefighting hoses and smoke curtains.

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Human behaviour in fire: Knowledge foundation and temporal evolution

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ABSTRACT

Understanding human behaviour in fires (HBiF), whether in building or wildland fire contexts, is crucial for saving lives and managing evacuations. However, existing research lacks a comprehensive analysis of HBiF knowledge from both perspectives. To address this issue, we examined nearly 1900 HBiF-related research papers and their references, identifying around 6600 frequently cited references as the HBiF knowledge foundation. We focused on highly prominent items using metrics like citation frequency, burst, and centrality. By analysing co-citation patterns among these references, we unveiled current trends and waning areas of HBiF research. This study identifies knowledge gaps and potential future directions for the field, enabling both mapping of the research concerning our fundamental understanding of behavioural decision-making in fires as well as developing more effective life-saving strategies.

1. Introduction

Human Behaviour in Fire (HBiF) is a critical area of research that holds important implications for life safety, evacuation management, and disaster preparedness [1,2]. The term HBiF, in this context, refers to the behaviour of people *during* fire scenarios, which can include fires that occur in buildings and fires that occur in larger outdoor contexts (e.g., wildfires affecting communities). Climate change contributes to the intensification of wildfire seasons [3], posing significant challenges to land management and firefighting efforts. Simultaneously, urbanisation continues unabated, further increasing the potential impact of building fires on occupants. In both scenarios, understanding human behaviour in fire assumes an ever more pressing significance.

Whether occurring within buildings [4–6] or in wildland-urban interface environments [7–9], fires pose significant risks to human lives and infrastructure and the human response plays a great role in mitigating such risks [10]. Understanding how individuals respond to fires, make decisions during emergencies, and navigate evacuation processes is pivotal for formulating effective safety measures and devising comprehensive evacuation strategies.

The urgency of this topic is irrefutable, as fire-related incidents continue to pose serious threats worldwide. Building fires, wildfire outbreaks, and fires involving transportation infrastructure can escalate rapidly, leaving limited time for safe evacuation. Each event underscores the need for a deeper understanding of human behaviour under such circumstances. The multidimensional nature of HBiF requires attention to various factors, such as psychological responses, cultural influences, cognitive processes, and societal dynamics. People's behaviour during a fire is influenced by factors like mental and physiological stress, familiarity with escape routes, perception of risks, and their past experiences [6]. Additionally, cultural norms, age, and functional limitations can significantly affect evacuation decisions and outcomes (Bukvic et al., 2020; Galea et al., 2010).

Despite the evident importance of HBiF, scholarly exploration of this field has not been fully comprehensive. Studies often focus on specific aspects, such as evacuation modelling or human psychology, resulting in a fragmented understanding of the topic. A holistic approach is necessary to bridge the gaps between these various dimensions and create a unified knowledge framework that can inform future research as well as policies, procedures, and safety measures.

The foundational knowledge in any field forms the bedrock on which future advancements are built. In the context of HBiF, identifying and

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consolidating this knowledge foundation is crucial for informed decision-making and the formulation of evidence-based policies/ research agendas. The multitude of research papers and references in the field necessitates a systematic and objective analysis to pinpoint key references that provide enduring insights and influence subsequent research. Additionally, tracking trends and temporal shifts within the field is important in its own right. The evolution of research streams sheds light on emerging priorities, areas of intensification, and topics that have lost traction. Understanding these trends equips researchers, practitioners, and policymakers with the ability to anticipate challenges, adapt strategies, and allocate resources effectively.

In the multifaceted landscape of HBiF research, the analysis of authorship and co-authorship also assumes a crucial role. Collaborative efforts often drive innovative research, allowing for the fusion of diverse expertise and perspectives. Examining authorship patterns provides insights into the interdisciplinary nature of HBiF, where experts from fields such as psychology, engineering, sociology, and emergency management converge to tackle complex challenges. Co-authorship patterns unveil networks of knowledge exchange and collaboration, shedding light on influential hubs within the field. Understanding the dynamics of authorship and collaboration not only acknowledges the collaborative nature of advancing knowledge but also identifies thought leaders and research clusters that are actively shaping the trajectory of HBiF research landscape. This analysis contributes to a holistic comprehension of the field, enabling the identification of collaborative trends, emerging research alliances, and areas where interdisciplinary collaboration can be intensified to drive impactful advancements in fire safety and evacuation management.

To address the issues mentioned above, the Human Behaviour in Fires Working group of the International Association for Fire Safety Science initiated a set of coordinated efforts to map the knowledge in this domain and subsequently define a research agenda. This study represents the first step in this process and seeks to address these existing gaps in the understanding of HBiF. This is achieved by offering a comprehensive analysis of its knowledge foundation and temporal evolution. By examining nearly 1900 research papers and identifying a core set of around 6600 frequently cited references, this research aims to create a consolidated repository of this knowledge domain. The analysis of prominence using citation frequency, bursts, and centrality metrics will unveil references that have significantly influenced the field. This not only aids in identifying seminal works but also highlights the trajectory of the most impactful research directions. Furthermore, the investigation into co-citation patterns within this core set will uncover evolving trends in HBiF research. Identifying clusters of references that are cited together frequently provides insight into current focal areas, emerging concerns, and declining interests. This empowers stakeholders to align their efforts with the evolving landscape of HBiF, ensuring that research and innovations remain effective and relevant.

2. Data acquisition

In order to extract relevant literature on HBiF from the Web of Science, an extensive search query was constructed. The query encompassed a wide range of search terms and combinations to ensure the inclusion of relevant studies related to fire incidents and evacuation behaviours. The search terms were organised into logical groupings to capture the multidimensional aspects of HBiF research. The query employed title (TI), abstract (AB), author keywords (AK), and topic (TS) fields to maximise the scope of the search. A complex combination of logical operators (AND, OR, NOT) was applied to refine the search results.

The search query included terms related to fire, evacuation, human behaviours, building types (e.g., shopping malls, hotels, hospitals), and various related disciplines and contexts. The query also considered specific aspects such as evacuation drills, wildland-urban interface fires, and disaster response. To enhance specificity, terms associated with other types of disasters such as earthquakes, tsunamis, cyclones, floods, and chemical spills were excluded from the results using the NOT operator.

The resulting query was designed to comprehensively capture a wide array of literature on HBiF, spanning research articles as well as literature reviews, surveys, and systematic analyses. The utilisation of multiple fields (TI, AB, AK, TS) and logical operators ensured a comprehensive search that targeted various dimensions of the topic. The search query was constructed with the goal of yielding a representative sample of literature relevant to the study's objectives, thereby providing a robust foundation for subsequent analyses and discussions. The full search query string is accessible in the Appendix of this article.

3. Temporal analysis

In this section, we undertake a comprehensive examination of key themes within the field, coupled with their temporal dynamics and a specific focus on citation patterns. Our analytical approach centres on the premise that co-cited references—those frequently cited together within the same papers—can effectively delineate the foundational knowledge underpinning distinct research streams [11]. By identifying clusters of references frequently co-cited, we define these research streams. Subsequently, we probe the referencing patterns in the articles associated with these clusters to determine the evolving intensity of different research avenues over time.

In our study, we identified 20 clusters, each emblematic of a significant facet of HBiF research (see Table A1 in the Appendix). The clusters exhibit varying sizes and degrees of significance within the field. A visualisation (Fig. 1) showcases these references as nodes within a document co-citation framework. The nodes align along the timeline of the publication year of the references they represent, with their size proportionate to the number of localised citations, i.e., citations originating solely from the HBiF literature. An alternate depiction (Fig. 2) employs a network view to map these clusters, positioning conceptually akin clusters in closer proximity. Nodes circumscribed by red rings denote references experiencing a sudden burst of local citations, signifying a rapid surge of citations from HBiF articles within a specific timeframe. Burst attributes encompass the onset, culmination, and intensity of the citation surge. Both visualisations are tied by co-citation connections, highlighting instances of interrelated references.

Initially, each cluster was assigned a descriptor through algorithmic analysis of titles from articles citing the respective cluster. The algorithm extracts noun phrases, assigning a log-likelihood ratio score based on frequency and coverage within the citing article. The highest-scored noun phrase is represented as the algorithmic label. While algorithmic labels offer objectivity, they sometimes fall short as descriptors. To address this limitation, alternative labels were manually determined, informed by both algorithmic outcomes and the actual content of each cluster. To succinctly present the content of the document, co-citation network and the pivotal references identified in our analysis, an informative data is included in Table A1 in the Appendix. Notably, the table does not exhaustively list all cited and citing references for each cluster, given the extensive scope—the entire network encompasses nearly 6500 frequently cited references—rendering complete listing impractical. Instead, the table highlights a subset of the most locally cited references per cluster, along with the articles that achieve the highest coverage within each cluster. This selective inclusion aims to provide a representative snapshot of the diverse network while navigating the constraints of presentation space. Fig. 3 quantifies the research activities of these research streams by quantifying cluster-level local citation indicators, including the total number of citations and the number of citing articles on a year-by-year basis. Those that did not exhibit any distinct patterns have been omitted from this visualisation. As such, Fig. 3 is essentially to appreciate the temporal trends behind the formation of the document co-citation network, which is not necessarily observable in the maps in Figs. 1 and 2.

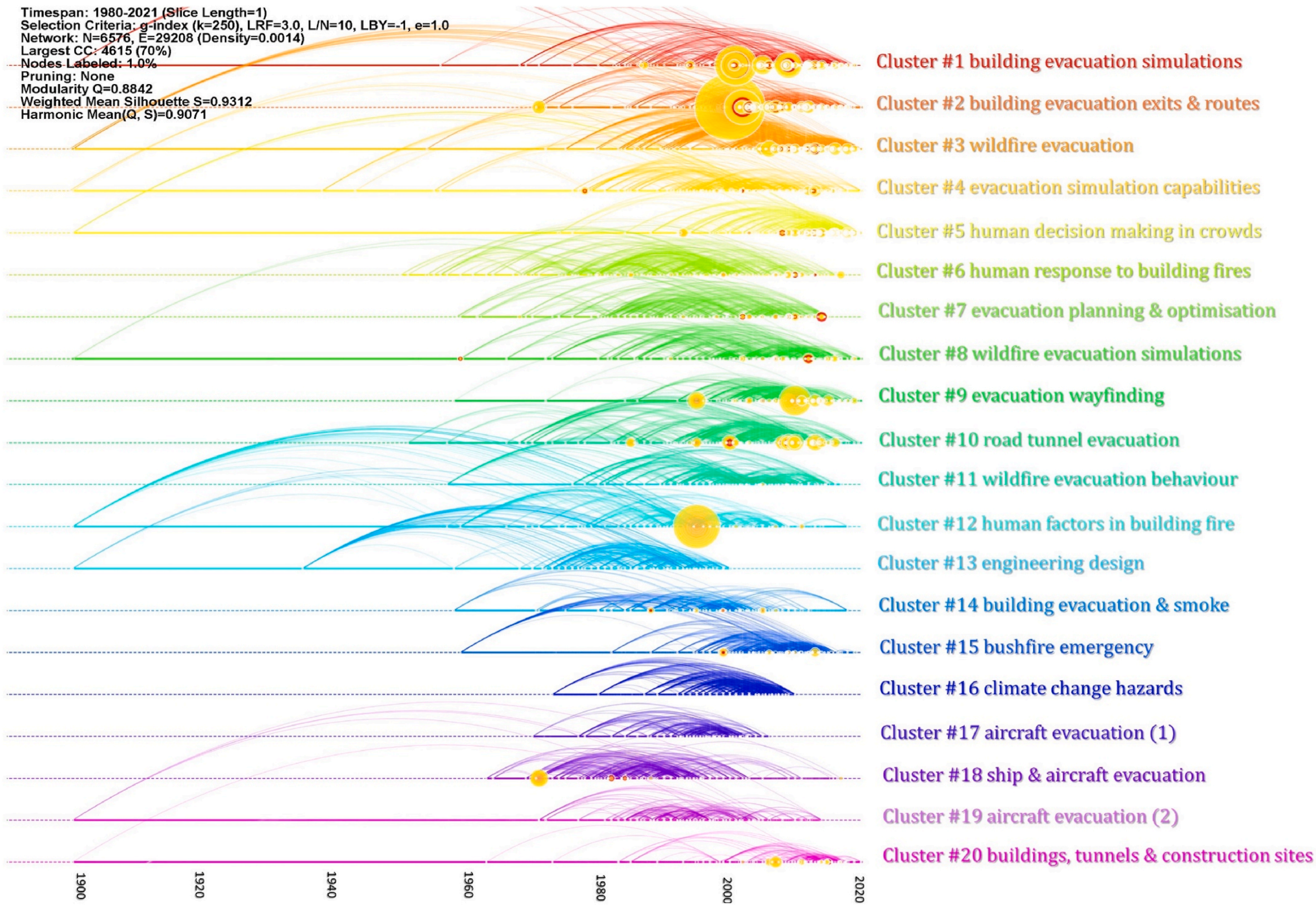

Fig. 1. Timeline view of document co-citations in HbiF literature.

Below we provide a short description of the 10 most significant clusters.

Cluster #01, *building evacuation simulations*, represents a broad stream of research focusing on the simulation of building fire evacuations using different modelling solutions. The majority of the papers belonging to this stream apply evacuation models to high-rise buildings using modelling solutions such as cellular automata approaches, see, for instance, Ding et al. [12] and Ma et al. [13]. The most cited article in this cluster is Burstedde et al. [14], which is one of the core papers in the field proposing the use of floor field cellular automation modelling to simulate building evacuations. As shown in Fig. 3, this stream started being relatively active after 2010, and it is still very active today.

Cluster #02, *building evacuation exits and routes*, represents a broad stream of research mainly focusing on exit and route choice and the impact of exit features on the evacuation process. As such, this stream includes a mix of experimental and simulation studies. The most cited works here are Helbing et al. [15] and Kirchner et al. [16], which are two key references for the social force model and floor field cellular automation model, respectively. This stream significantly started its activity after 2005 and it is showing a substantial drop after 2020.

Cluster #03, *wildfire evacuation*, relates to the wildfire research focusing on different key human behaviour topics combining review studies [17,18], theoretical studies [19] and case studies [20]. One of the recurrent subjects in this cluster is the decision to evacuate and the factors affecting this decision; see, for instance, Strahan et al. [21] Lovreglio et al. [20] and McLennan et al. (2019). This stream had a significant increment after 2010, and it shows a growing trend.

Cluster #04, *evacuation simulation capabilities and validity*, focuses on the capabilities of evacuation models in predicting different evacuation scenarios. This stream includes several pieces of research comparing the capabilities of different building evacuation models [22] as well as papers on how to assess the validity of existing evacuation models accounting for behavioural uncertainty [23]. This stream started in 2000, and it has had fluctuations in activities in the last 20 years.

Cluster #05, is predominantly about *human decision making in crowds*. It is considered a relatively young cluster and one of the emerging trends of HBiF. Sustained activities of this cluster are detectable since 2017 and have been on the rise since. The emergence of a number of review articles in 2020 and 2021 (e.g., Haghani [24], Yan et al. (2020) and Ding et al. [12]) have been instrumental in creating this specific cluster of references and pinning them as the knowledge foundation of this stream. The cluster primarily consists of empirical references. Studies by Zhang et al. [25] and Kinateder et al [26,27] are amongst the highest cited references of this cluster.

Cluster #06, *human response to building fires*, represents a broad stream of research mainly focusing on how humans respond to building fires. This stream combines several reviews [28–32] on how people behave in a building fire as well as work focusing on how to integrate known behaviours and theories in evacuation simulations ([20]; Kuligowski et al., 2017; Gwynne et al., 2016). This stream started in 1985, and it has reached different peaks and drops in the last 40 years, as shown in Fig. 3, and it shows a substantial drop in the last years.

Cluster #07, *evacuation planning and optimiszation*, represents a broad stream of research focusing on how to make evacuations faster or more effective. This stream combines both building fire case studies [33,34] and wildfire evacuation optimisation [35], and it investigates different routing algorithms [36]. This steam started after 2000, and it shows substantial ups and downs over the last 20 years.

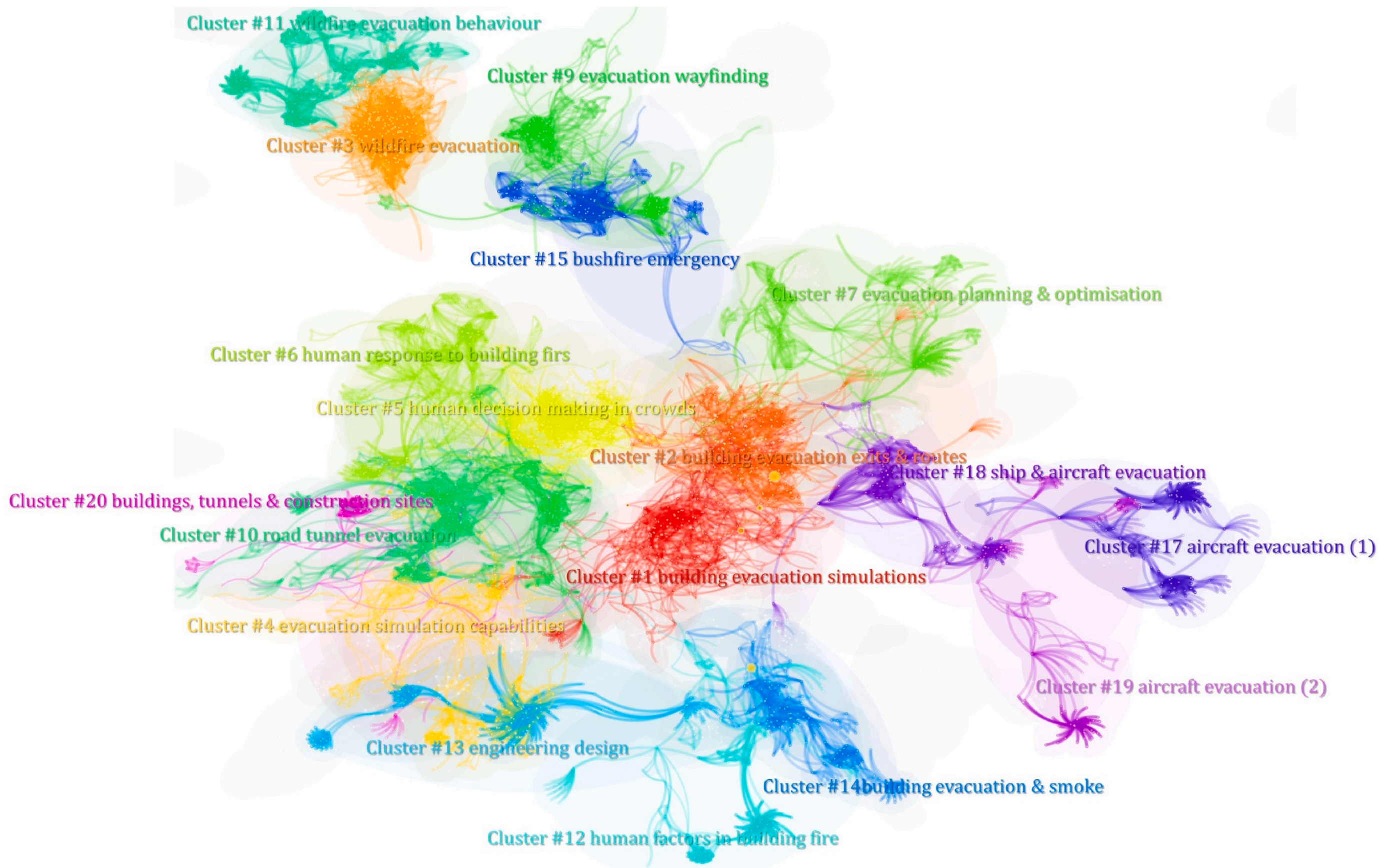

Fig. 2. Network of document co-citation in HBiF literature.

Cluster #08, *wildfire evacuation simulations*, is a stream of large-scale evacuation studies mainly focused on wildfire disasters. Several of the works belonging to this stream focus on wildfire evacuation triggers ([37]; Cova et al., 2017). Fig. 3 shows that this stream was established after 2005. It shows substantial ups and downs over the last 20 years.

Cluster #09, *evacuation wayfinding*, is a stream which collects papers proposing and testing different wayfinding systems. The stream includes both physical experiments [38,39] and virtual reality experiments [26,27,40,41]. This stream has shown steady growth since 2010.

Cluster #10, *road tunnel evacuation*, is a stream that includes multiple works on road tunnel evacuation experiments and simulations. In fact, this stream includes several papers investigating how people respond in virtual road tunnel evacuations (Kinateder et al., 2013; [26,27]) and different simulation solutions for road tunnel simulations [42–44]. This steam started after 1995, and it had peaks and troughs in terms of citations until 2010. Since 2010, this stream has had a steady increment, as shown in Fig. 3.

Note that in this objective determination, using document co-citation patterns and clusters as indicators of research trends and divisions, several clusters could often share similar themes. For example, in our analysis, four clusters emerged on wildfire evacuation: Clusters 3, 8, 11 and 15. What tells them apart, however, is the set of references (i.e., the knowledge foundation) that they employ. This could be a reflection of differential methodologies that these research streams might have employed (e.g., mathematical optimisation and algorithmic analysis versus quantitative and behavioural studies). In the wildfire example, the set of references (i.e., citing articles in Table A1) of Cluster 3 includes review studies, theoretical studies, and case studies focusing on different human behaviours in wildfires. On the other hand, the set of references of Cluster 8 includes a group of large-scale evacuation simulations mainly focused on wildfire disasters (see Table A1).

The clustering solution based on citing articles could also reflect paradigm shifts within sub-topics of the field. If a set of traditional references on wildland fire, for example, suddenly get abandoned by the researchers of the field and a new set emerge or get adopted (e.g., as a result of the paradigm shift in thinking), then two distinguishable clusters on the same topic could emerge in a document co-citation network. This differentiation may not manifest at the lexical aspects of the papers, but the document co-citation analysis has adequate levels of granularity to unmask such distinctions, including paradigm shifts or variations in methodological approaches.

4. Authorship and collaboration analysis

Patterns of collaboration between authors are investigated in this paper. This analysis was carried out using data from over 800 authors who have published at least one work in the HBiF literature. The network of collaboration is shown in Fig. 4 where each node represents an author. Fig. 4 also shows links connecting pairs of nodes. These links represent co-authorship between authors, while the thickness of each link is proportional to the number of articles on which the two authors are listed jointly (i.e., as co-authors). This metric is known in the literature as *link strength*. Using the link strengths of all the links generated by a single node, it is possible to measure the *total link strength* for each author. This second metric provides an indication of the overall extent of co-authorship activities of an author with other authors in the proposed network. The total link strength is visualised in Fig. 4 through the size of the nodes. As such, bigger nodes represent authors who have co-authored more with other authors of this network.

Using patterns shown in Fig. 4, it is possible to carry out a cluster analysis to identify groups of authors who have frequently co-authored their publications. This analysis identifies 53 clusters; the 18 biggest

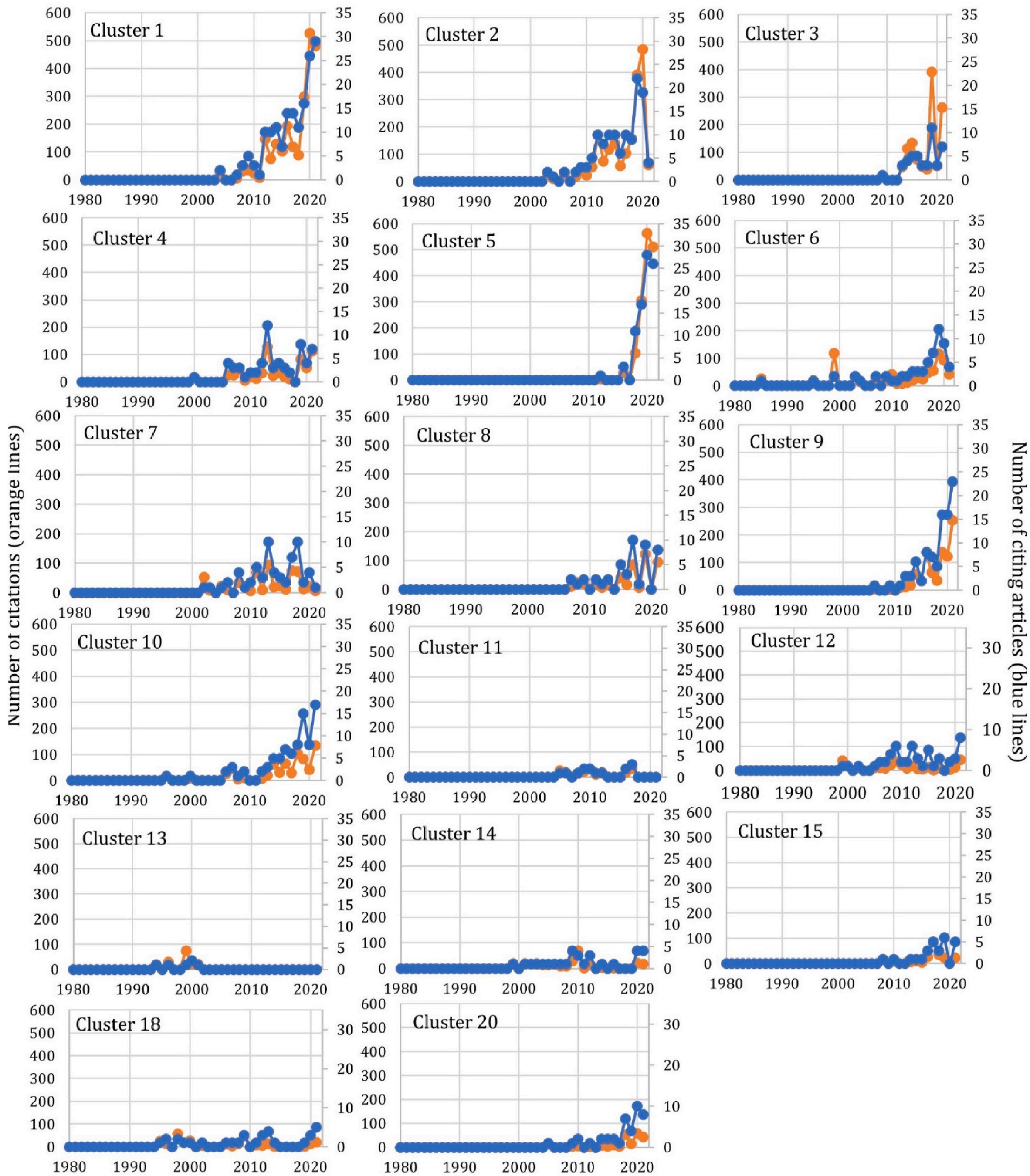

Fig. 3. Cluster-level citation activity in HBiF literature.

clusters from this analysis are visualised in Fig. 4 using different colours, while the remaining 35 smaller clusters are visualised in grey. The cluster dimensions of the top five clusters and the main three nodes in these clusters are reported in Table 1. Many of the strongest links reflect a combination of collaborations within a single university or government agency and mentoring relationships (e.g., a postdoctoral fellow and their supervisor/mentor).

5. Discussion

Understanding human behaviour in fire (HBiF) holds significance for safeguarding lives and effectively managing evacuation scenarios, both in building and wildland fire contexts. In addition, knowledge of the fundamental understanding of human behaviour in fire could be useful to understand human behaviour in other hazards or in general. For instance, it is exemplary that some of the most known classical studies in social psychology relate to the emergency context ([45]; Latané & Darley, 1970).

In our paper, we undertook a comprehensive examination of the HBiF domain to bridge existing gaps in knowledge and provide insights that can steer future research, policies, and practices. By analysing nearly 1900 research papers and their corresponding references, we uncovered a knowledge foundation comprising approximately 6600 frequently cited references that underscore the bedrock of HBiF science.

In this context, we note that the domain of human behaviour in building fires has, in recent years, primarily been approached from an engineering perspective, i.e., how behavioural understanding can be embedded into fire safety engineering and used to improve building

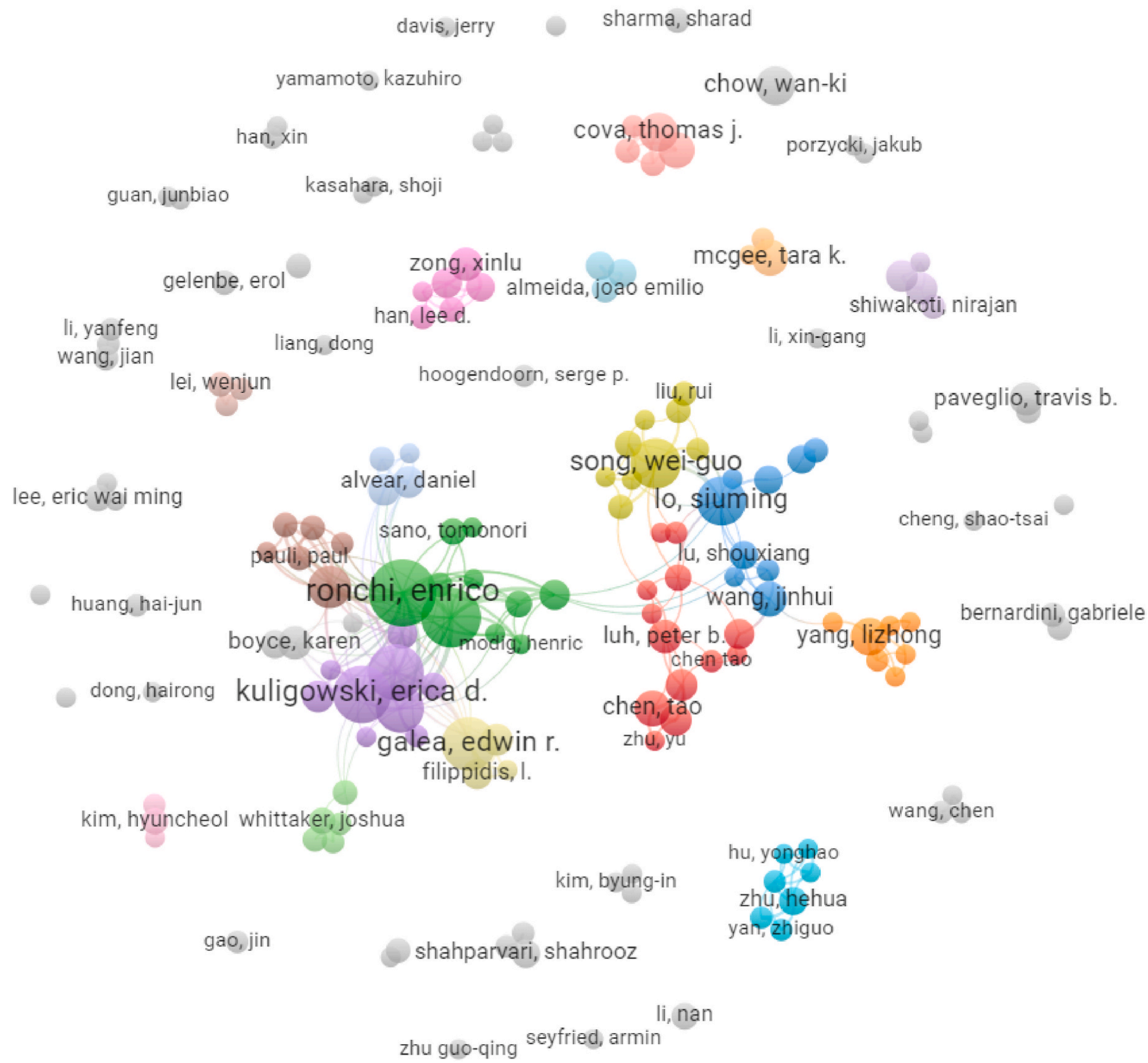

Fig. 4. Network of author collaborations in the HBiF literature. An interactive version of this map can be accessed through this link.

Table 1
Details of the 5 biggest clusters (TLS: Total Link Strength; D: Number of documents).

Cluster #	Cluster size	Node 1	Node 2	Node 3
1	13	Chen Tao (TLS:23, D:13)	Ding Ning (TLS:22, D:10)	Zhang Hui (TLS:18, D:10)
2	10	Ronchi Enrico (TLS:106, D:45)	Nilsson Daniel (TLS:78, D:35)	Frantzich Hakan (TLS:25, D:9)
3	9	Lo Siuming (TLS:26, D:24)	Wang Jinhui (TLS:16, D:12)	Lu Shouxiang (TLS:14, D:8)
4	9	Song Wei-Guo (TLS:38, D:25)	Lv Wei (TLS:13, D:7)	Cao Shu-Chao (TLS:10, D:6)
5	9	Kuligowski Erica (TLS:64, D:33)	Gwynne Steven (TLS:85, D:31)	Lovreglio Ruggiero (TLS:46, D:23)

evacuation design. Nevertheless, its knowledge foundation relies on a set of core experimental and theoretical work which is largely based in the social sciences ([46]; Darley & Latane, 1968; Deutsch & Gerard, 1955; Latané & Darley, 1970 [47]; Tajfel et al., 1979) and human factors and ergonomics fields [48–50]. In fact, seminal reviews were conducted by Bryan [28] and Shields and Proulx [51] that highlight key studies upon which the field of human behaviour in building fires was built. Such fundamental studies may not be visible in full in scientific databases (as some of them were published in the form of books or government reports that are not indexed in Web of Science); even so, they represent a significant portion of the knowledge foundation in the field. Another important set of references is the list of publications from the Human Behaviour in Fire Symposia series. This conference series started in 1998 (with the latest conference in 2015), and over the years, only a selection of papers ended up being published in journals special issues associated with the conference. This means that a significant portion of the scientific contributions of the conference are not fully visible in our review, although the HBiF Symposia series has represented for years the meeting point for researchers in this field.

While this review focuses only on human behaviour *during* fires, we should acknowledge that the domain of human behaviour in outdoor fires, and more specifically, wildfire events, encompasses a wealth of social science literature on other important topics, including homeowner mitigation, public acceptance of fuels treatments on government-owned lands and perceptions of fire management practices (e.g., prescribed burns), the social impacts of fire, post-fire recovery, and wildland fire planning and policy [52]. Much of the early work in wildfire evacuation originated from the fields of environmental science (e.g., ecology, resource management), geography, and psychology. This includes work in the U.S. as early as 2006 [53] to understand the factors that influence homeowners' decisions to evacuate, and in Australia (2005) and the U.S. (2009) to discuss the safest approaches for protection during bushfires [54]. The 2009 Black Saturday fires in Australia, which resulted in the deaths of 173 people, provided the impetus for increased focus on and funding for evacuation research, some of which was published in trade journals or as organisation reports and, therefore, may not be captured by our systematic review [55–57].

As we steer the trajectory of future HBiF research, several avenues emerge from our analysis that warrant further exploration. (i) With rapid urbanisation, the complexities of wildfire (and even building) evacuations intensify. Research should delve into the influence of urban layouts, community knowledge and experiences, and transport infrastructural elements on evacuation efficiency, particularly under scenarios of high population density and limited building and community egress options. (ii) Deeper exploration of how cultural norms, socioeconomic disparities, and the needs of vulnerable populations influence evacuation behaviours can guide the development of tailored evacuation strategies that are inclusive and equitable. (iii) Furthermore, harnessing the potential of emerging technologies and approaches beyond the existing levels—such as virtual reality, augmented reality, machine learning, and sensor-based monitoring systems—can contribute to the dynamic evolvement of fire safety and evacuation research. (iv) Building on the growing interest in decision support systems, future research can focus on the development of real-time tools that aid decision-makers during fire emergencies. These tools could leverage real-time data to offer tailored evacuation recommendations and enhance the efficiency of disaster management. This is also associated with data-driven approaches that can be coupled with traditional theory-based approaches to deepen our understanding in this domain.

In the pursuit of these directions, interdisciplinary collaboration remains paramount. The ensemble of expertise from fields including psychology, engineering, urban and regional planning, geography, computing technologies, sociology, and emergency management must converge to address the multifaceted challenges that arise from the interplay between human behaviours and fire incidents. Recent research efforts tend to go in the direction of more and more collaborative cross-disciplinary collaborations, highlighting how research siloing is an issue that can be overcome.

An important aspect to highlight is how the HBiF field is closely interconnected with the related fields of fire safety engineering and pedestrian and evacuation dynamics. This allows researchers and practitioners to take advantage of research in related fields to establish new research directions and agendas. In this context, a particular challenge is linked to the use of controversial terminology (e.g., panic, herding, stampede, etc.). This is an issue which has been discussed in several HBiF-related fora [58,59], where several misconceptions appear to still be present [60–62]. Attempts to harmonize and advise on the appropriate use of terminology have been conducted (Adrian et al., 2019). This is likely going to facilitate a dialogue across disciplines.

6. Conclusions

Our analysis delved into the core references, identifying highly prominent items based on a range of metrics, including citation frequency, bursts of local citations, and centrality. These metrics allowed us to discern references that have profoundly influenced the field and have contributed significantly to shaping its contours. This method of discerning prominence brings forward a refined understanding of the most impactful works, thereby facilitating a focused exploration of human behaviour in fire (HBiF) essential components.

The exploration of co-citation patterns among these references unveiled the trends and dynamics within the realm of HBiF research. Our analysis highlighted the emergent streams that are currently shaping the field, as well as the areas that have shown diminishing prominence over time. This dual perspective—of active trends and waning interests—empowers stakeholders to adapt their strategies, allocate resources, and align their endeavours with the ever-evolving landscape of HBiF.

The collaborative nature of HBiF research is a hallmark of its complexity and interdisciplinary scope. Co-authorship analysis uncovers the vibrant networks that underpin this field, where experts from diverse domains coalesce to tackle multifaceted challenges. The visualisation of co-authorship networks reveals hubs of collaboration, highlighting influencers and areas of collective strength.

In conclusion, our study contributes to the holistic understanding of HBiF by not only consolidating existing knowledge but also paving the way for future research endeavours. The urgency of this endeavour is underscored by the increasing frequency of fire-related incidents and the ever-evolving dynamics of disaster response.

CRediT authorship contribution statement

Milad Haghani: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Ruggiero Lovreglio:** Formal analysis, Writing – original draft, Writing – review & editing. **Mary Langridge Button:** Formal analysis. **Enrico Ronchi:** Conceptualization, Writing – original draft. **Erica Kuligowski:** Conceptualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors do not have any conflict of interest.

Data availability

Data will be made available on request.

Acknowledgments

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Appendix

Table A1
Details of the document co-citation network in HBiF

Cluster ID Name Objective descriptors *Author descriptor*	Cluster statistics - size - silhouette score - mean year (ref) - year range (ref) - mean year (citing) - year range (citing)		Influential references Highest local citation count		Strongest citation burst (strength, duration)			Highest centrality		Highest coverage citing articles	
Cluster #1	S	329	[14]	116	[14]	8.91	2008–2015	[63]	0.03	[24]	120
	SS	0.811	[64]	74	[65]	8.64	2006–2010	[66]	0.03	[12]	73
- high-rise building	MY(ref)	2006	[67]	72	[68]	8.63	1996–2009	[69]	0.03	[70]	71
- high-rise building evacuation	YR(ref)	1900–2019	[72]	48	[67]	8.45	2011–2015	[68]	0.02	[73]	46
- merging flow	MY(citing)	2017	[65]	46	[64]	7.81	2006–2010			[74]	43
- crowd guidance	YR(citing)	2004–2021	[68]	35	[75]	6.4	2003–2012			[76]	42
- tall building			[78]	33	[79]	6.31	2011–2017			[23]	40
			[79]	29	[80]	5.9	2009–2017			[81]	37
			[82]	28		5.43	2014–2017			[13]	34
				28	[13]	5.15	2013–2017				
			[13]	28							
Cluster #2	S	320	[15]	253	[83]	6.92	2011–2014	[84]	0.02	[24]	102
	SS	0.873	[16]	89	[16]	6.69	2010–2015	[85]	0.02	[86]	49
- pedestrian evacuation	MY(ref)	2006	[87]	46	[88]	6.63	2013–2017	[89]	0.02	[90]	47
- evacuation efficiency	YR(ref)	1970–2020	[91]	36	[92]	5.89	2012–2015	[93]	0.02	[73]	46
- evacuation dynamics	MY(citing)	2016	[94]	36	[95]	5.72	2008–2015			[96]	43
- evacuation assistant	YR(citing)	2003–2021	[97]	36	[98]	5.68	2011–2015			[73]	42
- turning behavior			[99]	35	[87]	5.52	2011–2017			[73]	39
			[95]	35	[100]	5.12	2007–2010			[76]	37
			[101]	34	[99]	5.01	2011–2017			[102]	33
			[103]	33	[84]	4.93	2011–2016			[81]	32
			[104]	33							
Cluster #3	S	287	[53]	50	[105]	5.91	2009–2015	[106]*	0.05	[21]	85
	SS	0.905	[107]	32	[108]	5.55	2014–2019		0.04	[18]	75
- rapid systematic review	MY(ref)	2008	[109]	31	[110]	4.72	2016–2019	[53]	0.02	[111]	64
- wildfire threat	YR(ref)	1900–2020	[112]	31	[107]	4.58	2012–2016	[113]	0.02	[17]	54
- wildfire evacuation	MY(citing)	2017	[108]	31	[114]	4.35	2010–2015	[116]	0.02	[20]	50
- early literature	YR(citing)	2009–2021	[118]	29	[54]	4.23	2009–2015	[119]	0.02	[120]	47
- bushfire part			[121]	29	[122]	4.17	2014–2017	[123]	0.02	[19]	45
			[124]	28	[125]	3.91	2009–2015	[126]	0.02	[127]	42
			[128]	26						[129]	41
Cluster #4	S	250	[2]	43		4.7	2010–2014	[130]	0.03	[131]	52
	SS	0.924		31		4.18	2006–2009			[23]	29
- using polynomial chaos expansion	MY(ref)	2001	[132]	27	[133]	4.01	2013–2018			[134]	24
- uncertainty analysis	YR(ref)	1900–2020	[133]	24	[135]*	4.01	2010–2013			[22]	23
- occupant evacuation	MY(citing)	2014	[136]	18		3.95	2006–2012			[137]	21
- building fire	YR(citing)	2000–2021	[135]*	15						[138]	16
- building fire risk			[139]*	14						[140]	16
			[141]	13						[142]	16
			[143]	11						[144]	16
Cluster #5	S	238	[25]	33	[27]	5.3	2016–2019	[145]	0.02	[24]	94
	SS	0.86	[27]	31	[25]	5.13	2009–2015			[70]	53
- human crowd	MY(ref)	2012	[146]	29	[146]	4.12	2015–2021			[147]	52
- collective egress	YR(ref)	1900–2020	[148]	28						[12]	49
- lecture hall	MY(citing)	2020	[149]	27						[131]	48
- agent-based modeling approach	YR(citing)	2012–2021	[150]	27						[86]	42
- decision strategy			[151]	26						[90]	41
			[152]	25						[73]	41
			[117]	24						[71]	39
Cluster #6	S	203	[153]	31	[154]	6.5	2007–2014	[46]	0.06	[28]	78
	SS	0.906	[155]	27	[143]	4.89	2013–2018	[46]	0.04	[30]	41
- modeling pre-evacuation	MY(ref)	1993	[154]	21	[156]	4.19	2015–2019	[155]	0.03	[157]	40
- world trade center tower	YR(ref)	1950–2017	[158]	21	[159]	4.01	2014–2018	[160]	0.03	[155]	26
- interface communities	MY(citing)	2015	[46]	20					0.03	[161]	24
- model user (	YR(citing)	1985–2021	[162]	19				[163]	0.02	[164]	21
- representing human behaviour			[143]	17					0.02	[165]	20
			[156]	16						[20]	19
			[166]*	15						[167]	18
			[168]	15							
Cluster #7	S	199	[169]	31	[170]	6.48	2010–2014		0.02	[171]*	53
	SS	0.936	[172]	31	[173]	5.26	2010–2017	[174]	0.02	[175]	39
- evacuation planning	MY(ref)	1999		26	[172]	4.99	2017–2021	[176]	0.02	[177]	23
- shelter location	YR(ref)	1959–2015	[174]	20	[178]	4.98	2009–2016	[179]	0.02	[36]*	23
- routing algorithm	MY(citing)	2014	[170]	19		4.69	2008–2018			[34]	22
- benders decomposition approach	YR(citing)	2002–2021	[180]	19	[174]	4.64	2010–2018			[181]	22
- evacuation route assignment			[178]	18	[182]	4.04	2010–2016			[183]	20
			[184]	17	[169]	4	2011–2016			[115]	20

(*continued on next page*)

Table A1 (*continued*)

Cluster ID Name Objective descriptors *Author descriptor*	Cluster statistics - size - silhouette score - mean year (ref) - year range (ref) - mean year (citing) - year range (citing)		Influential references Highest local citation count		Strongest citation burst (strength, duration)			Highest centrality		Highest coverage citing articles	
			[173]	16						[34]	20
				16							
Cluster #8	S	182	[185]	31	[186]	5.26	2015–2019	[187]	0.03	[37]	34
	SS	0.911	[186]	27	[188]	4.88	2015–2019	[188]	0.02	[120]	31
- national address point database	MY(ref)	2004	[189]	20	[190]	4.13	2012–2017	[191]	0.02	[192]	24
- wildfire public safety	YR(ref)	1900–2020	[187]	18	[193]	3.9	2007–2011			[194]	19
- relative effectiveness	MY(citing)	2016	[193]	17						[124]	17
- urban evacuation	YR(citing)	2007–2021	[195]	16						[196]	15
- environmental hazard			[190]	16						[23]	15
			[197]	15						[198]	15
			[188]	14						[20]	15
			[199]	14							
Cluster #9	S	175	[30]	93	[200]	4.58	2012–2016	[201]	0.05	[12]	35
	SS	0.892	[202]	51	[203]*	4.23	2016–2019	[202]	0.02	[204]	29
- italian-style historical theatre	MY(ref)	2008	[77]	45						[205]	26
- virtual environment	YR(ref)	1958–2020	[206]	39						[39]	26
- photoluminescent wayfinding	MY(citing)	2018	[207]	32						[26]	25
- occupants evacuation	YR(citing)	2006–2021	[208]	28						[38]	23
- architecture modification				25						[41]	21
			[209]	24						[210]	20
				21						[70]	20
										[211]	19
Cluster #10	S	167	[31]	54	[212]	9.45	2006–2009	[45]	0.03	[213]	28
	SS	0.937	[214]	53	[215]	5.35	2013–2018	[215]	0.02	[216]	26
- road tunnel	MY(ref)	2000	[212]	53	[214]	4.26	2009–2015	[31]	0.02	[42]	24
- social influence	YR(ref)	1951–2020	[217]	48	[218]	4.07	2005–2009	[219]	0.02	[220]	22
- virtual reality	MY(citing)	2017	[221]	45	[222]	3.82	2008–2011			[26]	22
- evacuation behavior	YR(citing)	1996–2021	[29]	39						[44]	20
- emergency evacuation			[215]	37						[26]	20
			[222]	32						[12]	19
			[26]	31						[74]	18
			[47]	31						[40]	18
Cluster #11	S	161	[223]	16	[223]	4.73	2007–2011			[224]	27
	SS	0.954	*	8						[53]	20
- rodeo-chediski fire	MY(ref)	2003	[225]	8						[122]	19
- fragmenting influence	YR(ref)	1957–2017	[224]	7						[226]	19
- wildland fire	MY(citing)	2012	[228]	5						[229]	16
- santa fe fire protection district	YR(citing)	2005–2017								[227]	16
- local approaches										[105]	15
Cluster #12	S	152	[230]	155		4.31	2005–2008	[231]*	0.02	[232]	41
	SS	0.958	[233]	18	[234]	3.81	2008–2015			[235]	20
- engineered fire safety design	MY(ref)	1995	[236]*	18						[237]	15
- integrating human factors issue	YR(ref)	1900–2018	[234]	10						[79]	15
- fire safety science	MY(citing)	2013	[238]	8						[12]	13
- occupant evacuation model	YR(citing)	1999–2021	[239]	7						[234]	12
- kin behavior				7						[240]	11
										[32]*	11
Cluster #13	S	151		5						[28]	74
	SS	0.985	[241]	5						[242]	29
- scholarly study area	MY(ref)	1986								[64]	22
- engineering design standard	YR(ref)	1900–2000		3						[68]	20
- mass-transport vehicle	MY(citing)	1998	[243]	3						[244]	20
- toxic product yield	YR(citing)	1994–2001		3						[235]	2
- human behaviour											
Cluster #14	S	131		24		5.42	2003–2012		0.04	[30]	38
	SS	0.956	[245]	19		5.16	2002–2013	[246]	0.04	[247]	19
- high place	MY(ref)	1997	[248]	17	[246]	4.32	2002–2012		0.03	[246]	19
- smoke hazard	YR(ref)	1958–2018			[248]	4.21	2003–2013			[249]	19
- sports stadium	MY(citing)	2011	[246]	16						[250]	18
- future issue	YR(citing)	1999–2021	[251]	14						[252]	17
- motivation level				13						[29]	16
			[253]	10							
Cluster #15	S	125	[254]	27		3.88	2013–2017	[255]	0.03	[175]	37
	SS	0.957	[256]	26	[254]	3.85	2002–2008			[175]	35
- australian case study	MY(ref)	2007	[257]	9						[112]	17
- bushfire emergency evacuation	YR(ref)	1959–2019		9						[258]	16
- short-notice bushfire emergency evacuation	MY(citing)	2017								[259]	14

(*continued on next page*)

Table A1 (*continued*)

Cluster ID Name Objective descriptors *Author descriptor*	Cluster statistics - size - silhouette score - mean year (ref) - year range (ref) - mean year (citing) - year range (citing)		Influential references Highest local citation count		Strongest citation burst (strength, duration)			Highest centrality		Highest coverage citing articles	
- possibilistic scheduling	YR(citing)	2008–2021								[260]	11
- robust stochastic vehicle										[261]	11
										[262]	10
Cluster #16	S	115	[263]	2				[264]	0.05	[265]	51
	SS	0.998	[266]	2							
- plant health	MY(ref)	2003	[267]	2							
- landscape management	YR(ref)	1973–2010	[268]	2							
- global change	MY(citing)	2010	[264]	2							
- emergency evacuation	YR(citing)	2010–2010	[269]	2							
- pedestrian evacuation											
Cluster #17	S	110	[270]	6						[271]	32
	SS	0.985	[272]	6						[274]	23
- catastrophic event	MY(ref)	1996	[275]*	5						[276]	15
- aircraft evacuation certification	YR(ref)	1970–2006	[272]	4						[277]	13
- commercial aircraft-cabin egress	MY(citing)	2002		3							
- current state	YR(citing)	1998–2006	[278]*	3							
- future research			[279]	3							
Cluster #18	S	103	[280]*	59	[281]	9.15	1995–2013	[280]	0.05	[282]	48
	SS	0.949	[281]	26	[283]	5.23	2009–2013	[281]	0.04	[284]	26
- transport airplane	MY(ref)	1990	[283]	17	[242]	4.55	1998–2011	[283]	0.02	[285]	24
- evacuation system	YR(ref)	1963–2017	[286]	15						[177]	20
- considering evacuation route	MY(citing)	2010	[242]	10						[287]	20
- basic principle	YR(citing)	1995–2021	[288]	7						[282]	18
- building evacuation problem										[289]	14
										[290]*	11
										[273]	10
Cluster #19	S	100	[276]	15	[276]	3.97	2001–2009		0.02	[272]	38
	SS	0.976	[291]	10						[30]	34
- aviation accident report	MY(ref)	1993	[292]	8						[282]	15
- human experience	YR(ref)	1900–2014	[274]	7						[293]	14
- aircraft accident statistics	MY(citing)	2010								[29]	12
- aircraft accident database	YR(citing)	1998–2018								[294]	11
- defining building evacuation route											
Cluster #20	S	94	[295]	32	[296]	4.11	2017–2021			[42]	18
	SS	0.945	[297]	21						[74]	13
- quantitative risk assessment	MY(ref)	2007	[296]	20						[298]	13
- stochastic-based approach	YR(ref)	1900–2020	[299]	20						[300]	10
- underground road tunnel	MY(citing)	2018	[40]	13						[43]	9
- quantitative risk assessment method	YR(citing)	2005–2021		11						[301]	8
- thermal radiation			[302]	11							

Search Query

TI=(Fire AND evacuation*)*

OR

TI=("fire evacuation" OR "fire* evacuations")*

OR

AB=("fire evacuation" OR "fire* evacuations")*

OR

AK=("fire evacuation" OR "fire* evacuations")*

OR

TS=((“building fire”) AND (“human behaviour*” OR “human response” OR “evacuation behaviour*” OR “escape behaviour*” OR “evacuation* response” OR “egress behaviour*”))*

OR

TS=(("shopping mall" OR “shopping centre” OR hotel OR hospital OR stadium OR theatre OR school) AND fire* AND (“evacuation behaviour*” OR “escape behaviour*” OR “evacuation* response” OR “egress behaviour*”))*

OR

TS=(("shopping mall" OR “shopping centre” OR hotel OR hospital OR stadium OR theatre OR school) AND fire* AND (emergency OR evacuation OR escape) AND (“human behaviour*” OR “human response”))*

OR

TS=((“built environment” AND fire*) AND (“human behaviour*” OR “human response” OR “evacuation behaviour*” OR “escape behaviour*” OR “evacuation* response” OR “egress behaviour*”))*

OR

TS=((“fire safety” OR “fire evacuation”) AND (“evacuation* behaviour*” OR “evacuee* behaviour*” OR “human behaviour*” OR “occupant* behaviour*” OR “egress behaviour*” OR “evacuation model*” OR “evacuation simulation”))*

OR

TS=((“evacuation time” OR “pre-evacuation*” OR “pre-movement time” OR “evacuation efficiency” OR “evacuation delay”) AND (building* OR facility* OR “built environment*” OR occupant* OR “resident*” OR evacuee*))*

OR

TS=((“human behaviour* in fire*”) OR “building* fire evacuation*”)*

OR

TS=(“evacuation procedure” AND emergency* AND (occupant* OR resident*))*

OR

TS=((“evacuation drill” OR “egress drill*” OR “evacuation trial*” OR “evacuation exercise*”) AND (building* OR pedestrian* OR crowd* OR “built environment*” OR “confined space*” OR evacuee* OR occupant*))*

OR

TS=(“fire evacuation drill” OR “fire emergency drill”)

OR

TS=((“human behaviour” OR “human response” OR “evacuation* behaviour*” OR “escape behaviour*” OR “egress behaviour*”) AND “fire” AND (building* OR “built environment*” OR “ship” OR “tunnel*” OR “aircraft*” OR “vessel*” OR “subway station*” OR “metro station*” OR “train station*” OR airport*))*

OR

TS=((“aircraft evacuation”) OR (“ship evacuation*”) OR (“vessel evacuation*”) OR (“tunnel evacuation*” AND fire*) OR (“train evacuation*”) OR (“building emergency evacuation*”) OR (“building evacuation*” AND fire*) OR ((“indoor emergency evacuation*”) AND fire*) OR (“aircraft emergency evacuation*”) OR (“ship emergency evacuation*”) OR (“vessel emergency evacuation*”) OR (“tunnel emergency evacuation*”) OR (“train emergency evacuation*”))*

OR

TS=(("wildfire*" OR "bushfire*" OR "wildland fire*" OR "forest fire*" OR "mega fire*" OR "megafire*" OR "wildland-urban interface fire*" OR "WUI fire*") AND (“evacuation behaviour*” OR “evacuee*” OR “evacuation response” OR “evacuation*” OR “household* evacuation*” OR “household* response” OR “household preparedness” OR “homeowner behaviour*” OR “human* behaviour*” OR “human* response” OR (“traffic” AND “simulation”)))

OR

TS=((“wildland-urban interface” OR “WUI” OR “Urban-wildland” OR (“fire*” AND community*) OR “fire risk mitigation” OR “wildfire risk mitigation”) AND *(“evacuation behaviour*” OR “evacuee*” OR “evacuation response” OR “evacuation*” OR “household* evacuation*” OR “household* response” OR “household preparedness” OR “homeowner behaviour*” OR “human* behaviour*” OR “human* response”))*

)

NOT

TS=(earthquake OR Tsunami OR cyclone OR flood OR "chemical spill" OR "chemical leakage" OR “storm" OR hurricane OR “A decomposition approach for the stochastic asset protection problem”)

. (*continued*).

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Study of the Occupants' Behaviour During the 2 Forest Laneway Fire in North York, Ontario January 6, 1995

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Guylène Proulx
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We are very grateful to the occupants of the 2 Forest Laneway building, who agreed willingly to participate in this study by answering the questionnaire or meeting with us. We understand that it was not easy to describe what had happened during this traumatic fire. A large number of people took the time to fill out this long questionnaire providing us with first hand information without which this study would not have been possible.

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Mr. William Hiscott - Investigator, OFM
Mr. Robert Harpur, P.Eng - Fire Protection Engineer, OFM

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EXECUTIVE SUMMARY

On January 6th 1995, at around 5:00 in the morning, a fire started on the north-east corner of the 5th floor at 2 Forest Laneway in North York, Ontario. It appeared that the fire started in the living room of Unit 509. The sole occupant reports the following: he was working on his computer in the second bedroom when at around 5:00 he noticed smoke coming from the living room couch. He tried to extinguish the fire but rapidly the situation got out of control. He left the area and the apartment door remained open.

The North York Fire Department received the first call at 5:09. Upon arriving on location at 5:14, they discovered Apartment 509 engulfed in fire. This fire took the lives of 6 people who were found in the two staircases on the upper floors. Other occupants suffered from smoke inhalation and had to be treated in hospital.

The National Fire Laboratory of the National Research Council Canada (NRCC) and the Office of the Fire Marshal of Ontario (OFM) agreed to collaborate on a study of the occupants' behaviour during the fire. Both groups agreed on the importance of gathering data on human behaviour during this major highrise apartment building fire.

The study used a questionnaire mailed to occupants of every unit in the building. The questions were aimed at identifying the way and the time at which occupants became aware that something unusual was happening. Once they became aware of the fact that it was a fire, what were their first few actions. There were questions on the time at which occupants left their units, as well as the smoke and lighting conditions they encountered during their evacuation. Some occupants mentioned to the media about not hearing the building fire alarm; therefore, some questions attempted to identify the locations and times that this situation occurred. A number of occupants had to turn back in the staircases and return to their units or had to take refuge in a neighbour's unit; it was necessary to know where and when these situations occurred. The smoke condition on different floors of the building was an essential variable, as well as the actions occupants undertook to ensure their safety. Variables such as gender, age and limitations were identified, since these are parameters that can play an important role during a building evacuation.

A total of 233 questionnaires were returned representing 190 units, 54% of all apartments from which responses could be expected. This return rate is very good, since most research using questionnaires to study human behaviour after a fire has a return rate of about 30%. The questionnaires returned were coded, scored and input into a data sheet. The data were analysed using Excel and SPSS, a powerful statistical software package.

Four major findings were identified during this study. First of all, the characteristics of the occupants of the building proved to be significant. The most significant differences were related to the ages of the respondents, as those aged 65 and over had a tendency to exhibit different behaviours from younger occupants for such

factors as their perception of the alarm, their choice of actions and their knowledge of fire safety. Older occupants were told about the fire more often than they heard the fire alarm. They were less likely to try to evacuate by themselves or to go onto their balconies. They were also more likely to seek information but had a limited knowledge of fire safety.

The second important factor was the location of the respondent in the building. The situation was much more serious on the 5th floor, on which the fire occurred, and was accurately perceived so by its occupants. The floors situated below the fire floor appear to have been only slightly affected by the fire. The location of the occupants had a direct effect on their choice of actions and on their evacuation possibilities. Occupants on the upper floors were more likely to have to turn back and seek refuge during their evacuation. A greater proportion of them also thought that they could go to the roof to take refuge. Above the 16th floor, a higher number of respondents judged that the fire alarm was not loud enough. Occupants of different areas were also different in their behaviour, specifically in the north-east quadrant, which is the quadrant in which the fire occurred.

The third factor, dealing with smoke conditions, cannot be considered separately from the location of the respondents since smoke conditions varied greatly from one area of the building to another. Floors situated above the neutral plane contained significantly more smoke than floors below, with the exception of the 5th and 6th floors. The presence of smoke was the major factor in determining the evacuation potential of occupants. Both staircases appear to have been clogged with smoke only minutes after the fire alarm sounded.

The time to start evacuating is the fourth factor and is also closely linked to the smoke conditions. For people living above the 5th floor, only those leaving their units at a very early time had a chance of reaching ground level safely. As time progressed, the propagation of smoke and heat made it impossible for people to get past the 5th floor and many had to return to their apartments or seek refuge in another unit until the situation was under control. They were evacuated later by rescue personnel.

Analyses showed that many occupants were prepared to travel through smoke, even though it could endanger their lives. This illustrates the need for public education on the danger of smoke. A large number of occupants had not received appropriate fire safety information. Some specific groups of people, particularly, lacked fire safety information: senior citizens, not employed people and those with different cultural backgrounds, especially those speaking a language other than English at home. It appears essential to provide fire safety information through a variety of means such as fire safety signs, posted evacuation procedures, brochures, training classes and publicity campaigns. It seems important to use multiple means to communicate fire safety information to make sure that the message reaches the building users and that everyone has access to the information. Once fire safety information is provided, it would be useful to assess the occupants' understanding of what they are expected to do during a fire by carrying out fire drills. Holding regular fire drills is a good way to educate occupants and increase public awareness of fire safety.

This fire demonstrated that communication to the occupants on immediate measures to be taken during a fire needs to be improved. A number of people did not hear the alarm, mostly older occupants or people living in corner units. The P.A. system was also inefficient in communicating with the residents. Judicious use of the media during such a fire situation could prove to be an effective way to provide information.

RÉSUMÉ

Le 6 janvier 1995, aux environs de 5 h du matin, un incendie s'est déclaré au 2, Forest Laneway, à North York en Ontario. Le sinistre aurait pris naissance dans le salon de l'appartement 509, situé à l'angle nord-est du 5e étage. L'unique occupant de cet appartement a déclaré par la suite qu'il était en train de travailler à l'ordinateur dans sa salle de travail quand, vers 5 h, il a remarqué de la fumée provenant du divan du salon. Il a tenté d'éteindre le feu mais s'est aperçu rapidement qu'il en avait perdu la maîtrise. Il a pris la fuite en laissant la porte de son appartement ouverte.

Le service d'incendie de North York a reçu un premier appel à 5 h 09. Arrivés sur les lieux à 5 h 14, les pompiers ont constaté que l'appartement 509 était la proie des flammes. Ce sinistre a coûté la vie à 6 personnes, qui ont été retrouvées dans les deux cages d'escalier aux étages supérieurs. D'autres occupants ont dû être traités à l'hôpital suite à l'inhalation de fumée.

Conscients de l'importance de recueillir des données sur le comportement des occupants au cours de cet incendie majeur dans un immeuble d'appartements de grande hauteur, le Laboratoire national de l'incendie du Conseil national de recherches du Canada (CNRC) et le Bureau du commissaire des incendies (BCI) de l'Ontario ont convenu de collaborer à une étude.

L'enquête reposait sur un questionnaire, qui a été posté aux occupants de tous les appartements de l'immeuble. Les questions visaient à déterminer de quelle façon et à quel moment les occupants s'étaient rendu compte que quelque chose d'inhabituel se passait et quelles avaient été leurs premières réactions. Il y avait des questions sur le moment où les occupants avaient quitté leur appartement ainsi que sur les conditions d'enfumage et d'éclairage pendant leur évacuation. Certains occupants ont mentionné aux médias qu'ils n'avaient pas entendu l'alarme; des questions ont donc été prévues pour déterminer les endroits et les moments où cette situation s'est produite. Un certain nombre d'occupants ont dû rebrousser chemin dans les cages d'escalier et revenir à leur appartement ou demander refuge à des voisins; il fallait savoir où et quand ces situations se sont produites. Les conditions d'enfumage sur les différents étages de l'immeuble constituaient une variable essentielle, tout comme les mesures prises par les occupants pour assurer leur sécurité. D'autres variables comme le sexe, l'âge et les handicaps des occupants ont été considérées, car elles peuvent jouer un rôle important au moment de l'évacuation.

Deux cent trente-trois questionnaires ont été retournés par les occupants de 190 appartements, ce qui représente un taux de réponse de 54 %. Cette participation est très élevée, car pour la plupart des recherches utilisant un questionnaire visant à étudier le comportement des gens pendant un incendie, le taux est d'environ 30 %. Les réponses recueillies ont été codées, comptabilisées et consignées sur une feuille de calcul informatisée. Les données ont été analysées à l'aide d'Excel et de SPSS, un puissant logiciel statistique.

L'étude a permis d'identifier quatre facteurs déterminants. Le premier, les caractéristiques des occupants, semble avoir un effet prépondérant. Les différences les plus importantes étaient liées à l'âge des répondants : les personnes âgées de 65 ans et plus ont généralement des comportements différents de ceux des plus jeunes sous divers aspects, par exemple la perception de l'alarme, les réactions et la connaissance de la sécurité incendie. Plus souvent qu'autrement, les occupants âgés ont été avisés du feu de vive voix, car ils n'avaient pas entendu l'alarme. Ils avaient moins tendance à évacuer les lieux par leurs propres moyens ou à se réfugier sur le balcon. Ils cherchaient davantage à s'informer mais avaient une connaissance limitée de la sécurité incendie.

Le deuxième facteur important était l'emplacement de chaque appartement. La situation était beaucoup plus grave au 5^e étage, où le feu avait pris naissance, et ses occupants l'ont nettement perçu. Les étages au-dessous du 5^e ne semblent avoir été que peu affectés par le feu. L'emplacement des occupants avait un effet direct sur leurs réactions et sur leurs possibilités d'évacuation. Les occupants des étages supérieurs ont souvent dû revenir sur leurs pas et chercher refuge. Nombre d'entre eux pensaient qu'ils pourraient trouver refuge sur le toit. Au-dessus du 16^e étage, un nombre plus élevé de répondants jugeaient que le signal d'alarme n'était pas assez fort. Le comportement des gens variait également en fonction du secteur où ils se trouvaient, en particulier ceux du quadrant nord-est, où le feu a pris naissance.

Le troisième facteur, les conditions d'enfumage, ne peut être considéré indépendamment de l'emplacement du répondant, car ces conditions variaient grandement d'un endroit à l'autre. Les étages situés au-dessus du niveau de pression neutre étaient beaucoup plus enfumés que ceux au-dessous, exception faite des 5^e et 6^e étages. La présence de fumée était le facteur prépondérant qui déterminait les possibilités d'évacuation des occupants. Il appert que la fumée a envahi les deux cages d'escalier quelques minutes seulement après le déclenchement de l'alarme.

Le délai d'évacuation, qui constitue le quatrième facteur, est aussi étroitement lié aux conditions d'enfumage. Dans le cas des étages situés au-dessus du 5^e étage, seuls les gens qui ont quitté très rapidement leur appartement ont eu la chance de se rendre au rez-de-chaussée en toute sécurité. Après quelques minutes, la propagation de la fumée et la chaleur ont fait qu'il était absolument impossible de descendre au-delà du 5^e étage et bon nombre d'occupants ont dû rebrousser chemin jusqu'à leur appartement ou trouver refuge chez des voisins jusqu'à ce que la situation soit maîtrisée. Ils ont ensuite été évacués par les secouristes.

Les analyses ont montré que de nombreux occupants étaient prêts à affronter la fumée même s'ils mettaient ainsi leur vie en péril. Voilà qui illustre bien la nécessité d'informer les gens des dangers de la fumée. Un grand nombre d'occupants n'étaient pas bien renseignés sur la sécurité incendie. Certains groupes manquaient particulièrement d'information : les personnes âgées, les gens sans emploi et ceux d'origine culturelle différente, surtout ceux qui parlent une autre langue que l'anglais à la maison. Il paraît essentiel de transmettre l'information sur la sécurité incendie par différents moyens comme la signalisation, l'affichage des consignes d'évacuation, des dépliants, des séances de formation et des campagnes publicitaires. Il semble important d'emprunter différents véhicules pour communiquer l'information sur la sécurité incendie afin de veiller à ce que le message atteigne tous les occupants et que tous aient accès à l'information. Une fois l'information transmise, il serait utile de vérifier, au moyen d'exercices d'évacuation, si les occupants ont bien compris ce qu'ils ont à faire en cas d'incendie. Ces exercices constituent une bonne façon d'éduquer les occupants et de sensibiliser davantage le public à la sécurité incendie.

Ce feu a montré qu'il faut mieux informer les occupants des mesures qu'ils doivent prendre dès les premiers instants d'un incendie. Un certain nombre de personnes, surtout les personnes âgées ou les gens habitant les appartements situés dans les angles de l'immeuble, n'ont pas entendu l'alarme. Le réseau de communication phonique ne permettait pas de joindre efficacement les occupants. Un usage judicieux des médias d'information, dans ce genre de situation, pourrait constituer une façon efficace de transmettre l'information.

1.0 INTRODUCTION

The study of occupant behaviour during a fire incident is one of the best ways for researchers to learn about the impact of human factors on the circumstances and outcome of a fire. The victims of a fire are prime witnesses; they can easily describe their perception of the event, their interpretation and their reactions during the fire. The data gathered in a human behaviour study can provide extremely valuable and unique information to researchers, code developers, enforcement officials and public safety officials. Such findings will enhance their understanding of the conditions encountered in the building at the time of the fire, the behaviour of different occupants during the event and the rationale behind their decisions and can result in improved codes, regulations and practices to prevent future occurrences of this type.

The National Fire Laboratory of the Institute for Research in Construction, National Research Council of Canada (NRCC) and the Office of the Fire Marshal (OFM) are extremely interested in increasing their respective knowledge bases in the area of human behaviour to enhance their respective mandates in fire safety. The fire at the 2 Forest Laneway building, although tragic, provided a unique opportunity to study the occupants' behaviour under an actual fire conditions. This fire is believed to be an infrequent, significant event for a highrise residential occupancy.

On the day of the fire, the Office of the Fire Marshal contacted NRCC to explore and establish the basis for a collaborative project to study the occupants' behaviour during this fire. Since both NRCC and the OFM were greatly interested in the potential findings from such a study, a joint venture partnership agreement was established.

Fire statistics for the province of Ontario show that during the five year period between 1989 and 1993, a total of 42 people died in highrise (over 5 storey) residential building fires [1]. This represented an average of eight deaths per year in such buildings. During this period none of the fire resulted in more than two fatalities. In light of these statistics, the 2 Forest Laneway Fire, where six persons died, appears to be an uncommon and significant event that warrants study in considerable detail.

The findings from the study will be used to develop recommendations to improve fire safety in highrise apartment buildings. This work will help to define better evacuation procedures, training and education programs, as well as changes in regulations and codes of practice. Diffusion of the results will be accomplished through scientific publications, conferences, magazines and presentations to specific groups. The results of this study will be presented during the Coroner's Inquest associated with this significant fire. The results will also be used to verify the NRCC computer model FiRECAM [2], which is used to assess the risk to life of occupants from fires. The results will be used by the OFM to further develop their framework model "Comprehensive Fire Safety Effectiveness Model" [3], which can be used either in a macro or micro framework to provide guidance in optimizing fire safety effectiveness.

2.0 STUDY OBJECTIVES

The general objective of this study was to gather information on the behaviour of the occupants who were in the building at the time of the fire incident. It is very important to identify what went wrong during this fire as well as what went right. The occupants are the best individuals to explain the danger they were exposed to, their understanding of the situation and the different actions they took during the fire.

The study is aimed at identifying the way and the time at which occupants became aware that something unusual was happening; and once aware it was a fire, what actions the occupants undertook. The time at which occupants left their units is also important, as well as the smoke and lighting conditions they encountered during their evacuation. Some occupants mentioned to the media about not hearing the building fire alarm; it is therefore important to identify the locations where this situation occurred. A number of occupants had to turn back in the staircase and return to their units or had to take refuge in a neighbour's unit; it is necessary to know where and when these situations occurred. The smoke condition on the different floors of the building is an essential variable, as well as the actions occupants undertook to ensure their safety when they encountered smoke. Variables such as gender, age and limitations are identified since these are parameters that can play a role during a building evacuation.

A human behaviour study is a systematic method to gather essential information about a traumatic situation such as a fire. This kind of study has the great advantage of helping others to draw a clear picture of the fire situation sometime after the event. The results will facilitate the work of investigators and researchers who have to understand the overall fire situation to develop recommendations to prevent such a tragedy from recurring.

3.0 THE FIRE INCIDENT

On January 6th 1995, at around 5:00 in the morning, a fire started on the north-east corner of the 5th floor at 2 Forest Laneway in North York, Ontario. From the preliminary investigation, it appeared that the fire started in the living room of Apartment 509. According to the deposition of the occupant of Unit 509, at that time he was alone in his apartment and was working on his computer in the second bedroom. At around 5:00, he noticed smoke coming from the living room, where he found a smouldering fire on the couch. He attempted to extinguish the fire using a saucepan filled with water. Unexpectedly, the couch burst into flames. Due to the smoke in the room, he opened the living room patio door to vent the room. Meanwhile, the two men living next door were awakened by the smell of smoke. These two men investigated their own apartment in search of the fire and discovered that the smoke was coming from the apartment next door. One of the neighbours knocked on the door of Unit 509 to alert the occupant to the fire. The occupant of Unit 509 came to the door and the two men attempted unsuccessfully to use a fire extinguisher taken from a nearby fire hose cabinet. During that time, the second neighbour returned to his apartment to call 911. Rapidly the situation got out of control. The neighbour activated the alarm pull-station located next to the staircase door. The three men left the area with two other neighbours using the elevator. The door to the fire apartment was left open.

The North York Fire Department received the first call at 5:09. Upon arriving on location at 5:14, they discovered that Apartment 509 was engulfed in fire and flames were visible outside coming through the patio door.

This fire resulted in the loss of life of six people who were found in the two staircases on the upper floors. Others suffered from smoke inhalation and had to be treated in hospital.

4.0 RESEARCH STRATEGY

To gather information on human behaviour during the 2 Forest Laneway Fire, there are different research methods available such as face-to-face interviews, phone interviews or a questionnaire survey [4]. Each method could be applied to a different extent; for example, the face-to-face interview can be used to interview 15 subjects during 3 hours each or 500 occupants can be asked a few precise questions. It is important to select the best method for the specific research context and decide on the best way to apply this method.

A few criteria were used to decide on which research strategy was most suitable. These criteria were: time, cost, feasibility, staff needed, and results expected. A strategy involving direct interviews, either face-to-face or by telephone, with the occupants was rejected because this method would have taken a lot of time, would have required trained staff to carry out the interviews, was costly and the data gathering would have been tedious to code and analyze. The mailed questionnaire presented the advantages of reaching all occupants at the same time, it required less staff to be involved in gathering the information, it was cost effective, it limited the amount of data to code, it was easier to analyze because the questions were the same for everyone and it still gave excellent information. A questionnaire mailed to occupants of every unit in the building was the strategy selected.

To allow for people who wanted to participate in the study but who did not want to fill out the questionnaire, a phone number was provided for individual interviews. Occupants could call the principal researcher to set a time for a face-to-face interview at a location of their choice. Four occupants asked for meetings in their apartments. During these meetings, the conversation was recorded and the questionnaires were filled out with them. Their questionnaires were analyzed with the questionnaires returned by mail.

This research strategy was approved by the Human Subjects Research Ethics Committee of the National Research Council Canada. To ensure confidentiality to the respondents, the name of the occupant did not appear on the questionnaire, although the unit number was pre-printed for coding purposes. All questionnaires were mailed on January 31, 1995, 25 days after the fire.

It is important to mention that a separate questionnaire was delivered to every unit in the building by the investigation team of the Office of the Fire Marshal. The results of that questionnaire are not considered in this report.

4.1 The Questionnaire

The questionnaire comprised 64 questions, with a number of sub-questions, for a total of 167 elements that respondents had to answer (see Annex 1). Different styles of questions were used [4]. A majority of questions were closed-ended questions, such as "Did you call 911? Yes ❑ No ❑" or "What time was it?" A number of other questions were open-ended, giving the opportunity to the respondent to describe something in a few words, such as in the question "While staying in your unit, what did you do?" Usually the respondent had only one line to answer open-ended questions. This design offered sufficient flexibility to the respondent while keeping later coding and scoring of the answers simple. At the end of the questionnaire, the respondent was asked to draw his or her evacuation route on the building plans provided and to write on the back of this page any complementary information considered to be important.

The questions were presented under eight headings. Section 1 was the respondent Profile, to provide demographic data on the respondent and the other people who were in the unit at the time of the fire. Section 2 was on the Initial Actions of the respondent, from how he or she became aware of the incident and the first few actions up to the time at which the person left the unit. Section 3 concentrated on the Evacuation of the Building from the time at which the respondent left the unit, the movement in the stairs and the time at which ground level was reached. Section 4 dealt with the Alarm and Public Announcement that the respondent perceived during the whole event. Section 5 was on the Smoke Condition in the unit as well as during the movement to reach safety. Section 6 was about the Rescue Effort and the presence of firefighters and police officers in the building. Section 7 was on the Fire Safety Knowledge and Experience of the respondent in relation to this building. Finally, Section 8 presented a floor plan and an elevation of the building to help the respondent sketch his or her Evacuation Movement.

The formulation of the questions was inspired by the work of Prof. John L. Bryan and the questionnaires he used to study the fires at the MGM Grand Hotel [5], the Westchase Hilton [6], Georgia Towers [7] and Thurston Hall [8]. Previous questionnaires used to study human behaviour during evacuations, such as the New York World Trade Center Study [9, 10] and fire drills [11,12], were also used. A number of reports and papers from researchers in other countries were reviewed. The Ontario report on "The

Public Inquiry into Fire Safety in Highrise Buildings" 1983 [13] was also reviewed. The Office of the Fire Marshal provided a list of points to be covered in the questionnaire and finally different persons from the National Research Council, the Office of the Chief Coroner, the North York Fire Department and the National Fire Protection Association gave input on the formulation of the questions.

Two copies of the questionnaire were sent to every unit in the building. The first page of the questionnaire specified that everyone in the unit who was over 14 years old at the time of the fire should fill out a copy of the questionnaire, extra copies could be obtained by calling the principal researcher. A covering letter asked the occupants to contact the principal researcher if they wanted a face-to-face interview in the language of their choice. A pre-paid return envelope was provided.

Respondents could provide their name and address on the last page of the questionnaire to receive a free copy of the report. This last page was immediately detached from each questionnaire when received and put in a separate box to ensure confidentiality of the respondents.

5.0 QUESTIONNAIRE ANALYSIS

The questionnaires returned were coded, scored and input into a data sheet. A coding manual was developed. The data were analyzed using the software packages SPSS for Windows Version 6.01 and Excel Version 5.0. SPSS is a very powerful statistical software package for social sciences and can perform a multitude of statistical analyses.

Descriptive statistics were calculated to summarize the results and look at frequency distributions, percentages and means. Correlation analyses were also used to identify the degree of relationship between two dependent measures using the Pearson Correlation Coefficient. Cross tabulations were used with Chi-Square tests to determine the relationship between two nominal scale variables such as the Yes/No questions or gender comparisons. All these statistical tests were judged significant at the 0.05 level or when $p \leq 0.05$ [14], which is the accepted convention for testing hypothesis in social sciences.

5.1 Questionnaires Returned

The building at 2 Forest Laneway has a total of 365 apartments. According to the building management, on the day of the fire, 10 units were vacant. Overall, responses from 349 units could be expected, after subtracting the units for the six casualties.

A total of 233 questionnaires were returned, representing 190 units or 54% of all the apartments from which responses could be expected in the building. This is a very good return rate. Most questionnaires used to study human behaviour during fires are sent essentially to a sample of the whole population and the return rate is about 30% [5, 9]. Considering that the questionnaire for this study was sent to every unit, representing the whole population, the 54% return implies that the results can be generalized to the entire building with confidence.

The questionnaires were mailed out 25 days after the fire. Around this time, most occupants started moving back to their apartments after many days spent away to allow for cleaning and repairs. Figure 1 shows that over 80% of the questionnaires returned arrived within 3 weeks of the mailing. This fast return of the questionnaires implies that most respondents answered the questions in the month following the fire, which improves the consistency of the responses. The last questionnaire used in the analysis arrived on April 28, 1995.

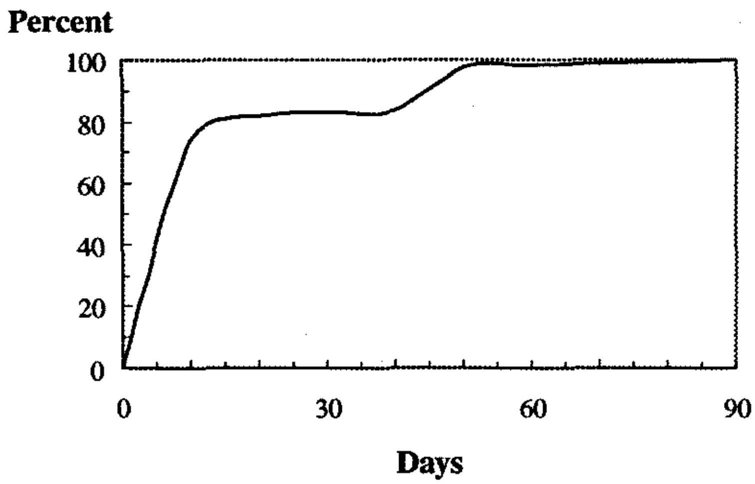

FIGURE 1: Distribution Over Time of Questionnaires Returned

Of the 233 occupants who returned the questionnaire, 14 or 7% mentioned they were not in the building at the time of the fire. The total number of questionnaires used in this analysis corresponds to the 219 respondents from 176 units who were in the building at the time of the fire. Except for the first floor, where there are 4 units and for which no questionnaire was returned, the average return was 7 questionnaires per floor (there are 10 units on the 2nd floor and 13 units on all other floors).

It is impossible to know exactly how many people were in the building on the day of the fire. It is, however, possible to calculate an approximate value from the results of the survey. The results show an average of 1.65 occupants per unit. Out of the 365 units of the building, 10 were vacant at the time of the fire, for a total of 355 occupied units (355 x 1.65 = 586). A percentage of 7% of 586 should be deducted for the people who were out, giving an approximate total of 545 occupants in the building that morning.

5.2 Response Analysis

None of answers given by the respondents was changed for the analysis. In a few cases, it was clear that the answer was not correct or accurate, however, answers were taken as given without modification. One aspect that is likely to be somewhat inaccurate is the specific times provided for different events. In all time-based analyses used in this study, it is difficult to determine the accuracy of the results. All respondents filled in the questionnaire approximately three weeks after the incident and while many remembered numerous details about the situation, specific times may not be absolutely accurate. As well, the occupants were caught in a fire emergency and may not have given much consideration to the time, concentrating their energies on finding safe solutions to the problem at hand. One clear example of that problem is illustrated by the fact that three of the respondents mentioned being alerted by the building fire alarm before 5:00, which appears very unlikely. Nonetheless, they were included in the analysis without changing their answers. Respondents also had a tendency to round off the given times; therefore these time-analyses should be used with caution, especially when considering small time intervals.

It was essential throughout this research to ensure confidentiality of the respondents. The ethics committee at NRCC has very strict requirements protecting the privacy of any person participating in a research project [15]. In order to meet the confidentiality requirements and to simplify the analysis, some of the data were grouped. The data were grouped by the age of the occupants, the floors where occupants resided and the spatial location of their units.

The analyses compare the occupants according to three age groups: 18 to 40 years old, 41 to 64 years old and 65 years old and over. Table 1 gives a distribution of the respondents in terms of their gender and their age. The majority are women (55%), and 53% of respondents are between the ages of 18 and 40. Respondents range in age from 16 to 90 years old. One female respondent did not specify her age.

TABLE 1: Profile of Respondents

Age Group	Male		Female		Total	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
1 to 17	2	0.9	1	0.5	3	1.4
18 to 40	51	23.3	66	30.1	117	53.4
41 to 64	27	12.3	29	13.2	56	25.6
65 and older	18	8.2	24	11.0	42	19.2
No answer	0	0.0	1	0.5	1	0.5
Total	98	44.7	121	55.3	219	100.0

Some respondents did not answer all questions in the questionnaire. The results in some cases are given as a valid percent, which corresponds to a percentage of people who answered this specific question, as opposed to a percentage of all respondents.

The building was divided into groups of floors. Figure 2 presents the six floor groups. The first floor group comprises Floors 1 to 4, which are floors located beneath the fire floor. The 5th floor, or fire floor, forms a group by itself. The third group consists of Floors 6 to 10 just above the fire floor. Another group is made of Floors 11 to 16 (note that there is no 13th floor). The fifth floor group is made of Floors 17 to 21. Finally, the last group represents Floors 22 to 30. The two last groups of floors are located over the theoretical neutral plane of the building. This is an important distinction because the neutral plane is the horizontal level where the air pressure inside equals that outside; smoke rises above the neutral plane to the upper floors of a building [16, 17]. Not every floor group contains the same number of floors; however, this distribution is acceptable to take into account the possible smoke movement in the building.

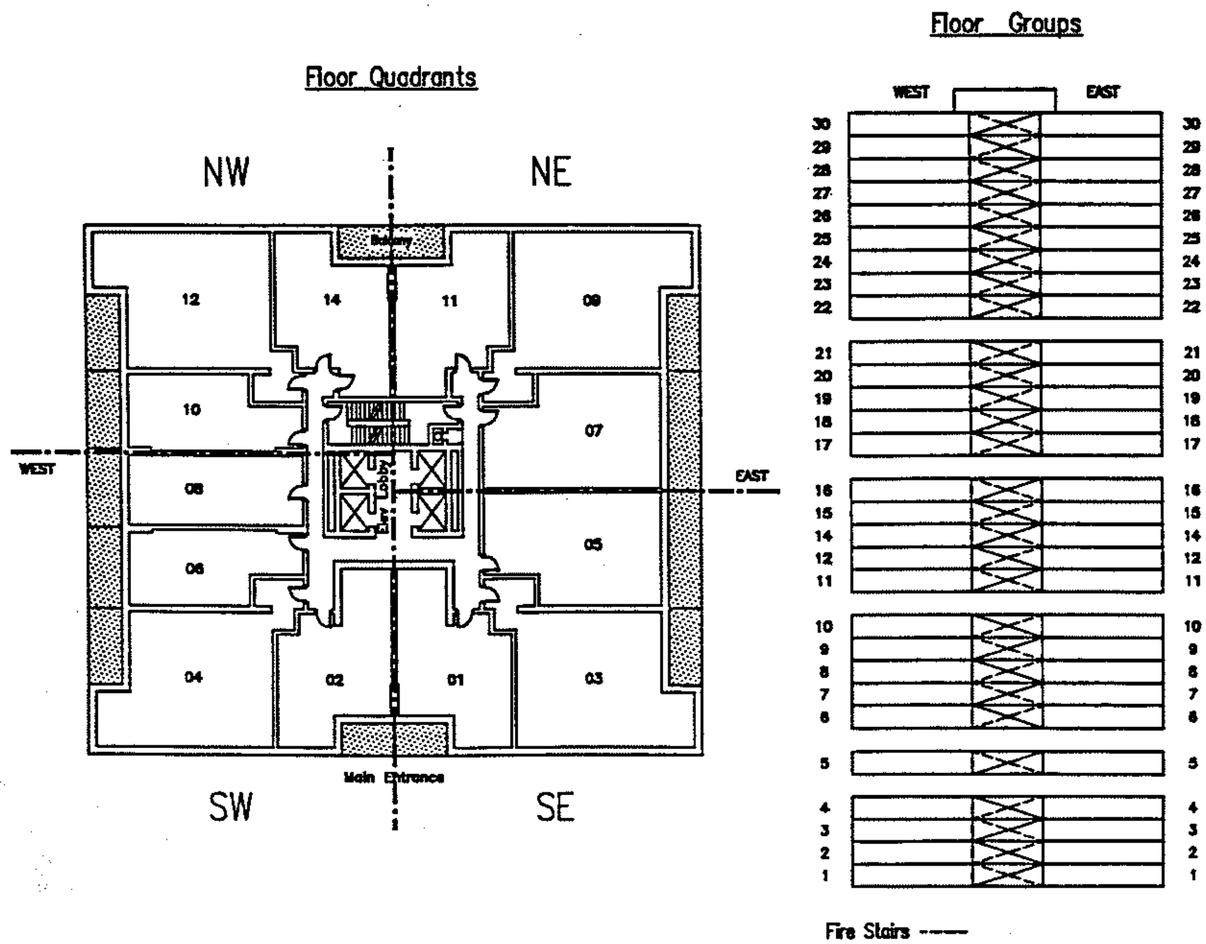

FIGURE 2: Floor Plan and Building Elevation

Each floor of the building was divided in four quadrants according to cardinal points. Figure 2 shows a typical floor plan and the dividing lines of the four quadrants. The units ending with numbers 07, 09 and 11 are in the north-east quadrant, numbers 01, 03, 05 are in the south-east, numbers 02, 04, 06 and 08 are in the south-west and numbers 10, 12 and 14 are in the north-west.

This grouping of the data allows the researcher to meet the confidentiality requirements in reporting the results but also simplifies the analysis and helps to generalize the results. Using groups helps in identifying patterns and enables the researcher to obtain better understanding of the findings.

There are two separate staircases in the building. In this report, they will be referred to as the Fire Staircase and the Other Staircase. The term "Fire Staircase" is used for the staircase which has a door facing the odd-numbered units on the 5th floor. The door to that staircase on the 5th floor is located diagonally across the corridor from Unit 509, where the fire started. Due to this proximity, the smoke density in the Fire Staircase could be different than that in the Other Staircase. Because such scissor-stairs are complex, it is important to refer to Figure 3, which presents a schematic representation of the two staircase organization.

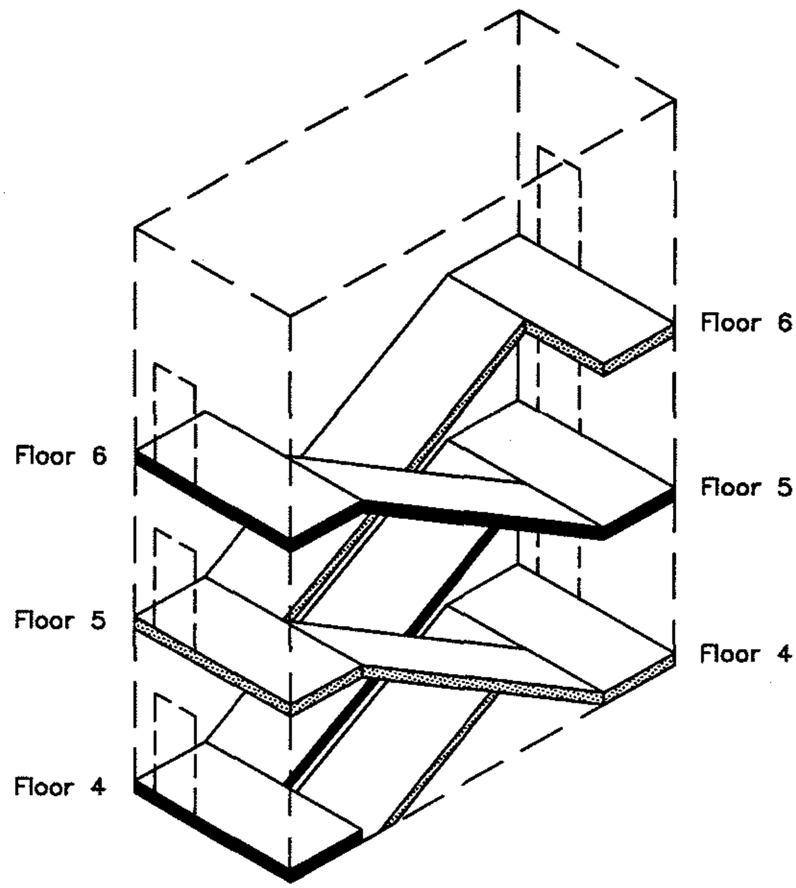

FIGURE 3: Schematic Representation of Scissor-stairs

6.0 OCCUPANT PROFILE

The first section of the questionnaire considered the occupant profile. Of the 219 respondents who were in the building at the time of the fire, 121 (55%) were females and 98 (45%) were males. People of all ages (between 16 and 90 years old) answered the survey, as shown in Table 2. The average age of the respondents was 44 years old and the median was 37 years. Overall, 69% of respondents were less than 50 years old and 19% were over 65 years old. Both males and females are represented in each age category. The average age for women was 45 years and the average for men was 43 years.

TABLE 2: Age Distribution of Respondents

Age Group	Frequency	Percent
11 - 20	6	2.7
21 - 30	57	26.0
31 - 40	57	26.0
41 - 50	37	16.9
51 - 60	10	4.6
61 - 70	19	8.7
71 - 80	19	8.7
81 - 96	13	5.9
No answer	1	0.5
Total	219	100.0

Table 3 shows the distribution among different types of occupations. Under the category "Professional" are included individuals working for example as: accountants, engineers, researchers, managers, programmers, social workers, registered nurses and teachers. The "Support staff" category refers to employment such as: secretary, clerk, librarian, dental assistant or mechanic. Some young children are included under the category "Student," which also refers to adult students. All people without specific employment are declared "Not employed," including housewives and other stay-at-home workers. Finally the term "Retired" is used only for people who specified that they were retired, as opposed to anyone over the age of 65.

Table 4 summarizes the limitations reported by the respondents, such as difficulties that could affect a respondent's ability to evacuate a building in an emergency situation. Limitations due to health include heart and lung problems, as well as asthma, to name only a few. Physical problems include mainly weak or broken limbs and other difficulties possibly resulting in impaired mobility. Perceptual problems refer to poor eyesight or a hearing impairment.

TABLE 3: Occupation of Respondents

Occupation	Frequency	Percent
Professional	95	43.4
Support staff	55	25.1
Student	15	6.8
Not employed	9	4.1
Retired	41	18.7
No answer	4	1.8
Total	219	100.0

A total of 14% of respondents reported having limitations. This is representative of the general Canadian population where, according to Statistics Canada, 14.5% of the people have limitations of one type or another and live in private households [18, 19].

TABLE 4: Limitations of Respondents

Type of limitations	Frequency	Percent	Valid Percent
Health	11	5.0	36.7
Pregnancy	4	1.8	13.3
Physical	9	4.1	30.0
Perceptual	5	2.3	16.7
Sound sleeper	1	0.5	3.3
No limitation	107	48.9	-
No answer	82	37.4	-
Total	219	100.0	100.0

The valid percent represents the percentage of the total number of people who answer a specific question when excluding all missing answers. The percent, however, refers to the overall percentage of people in that category with respect to the total number of respondents to the questionnaire.

Tables 5, 6 and 7 are similar to Tables 2, 3 and 4, respectively, but apply to an additional person present in the apartment, with the respondent, at the time of the fire. At that time, 49% of apartments were occupied by only one person, namely the respondent. When a second individual was present, as in 51% of apartments, in 55% of the cases it was a female and in 45% it was a male. In 50% of cases, the second occupant was an adult who had a "Professional" occupation. Only 10% of the second occupants had limitations.

When there were two respondents from a single unit, the second respondent was considered as a second (or third, or fourth) person in the first respondent's questionnaire and vice versa. This implies a doubling of some of the data for Tables 5 to 12. The information is not doubled in any of the other analyses; each questionnaire is analyzed as describing the behaviour of the first respondent and since no one returned more than one completed questionnaire, there is no doubling of the results.

TABLE 5: Age of Second Person

Age Group	Frequency	Percent	Valid Percent
11 - 20	5	2.3	4.5
21 - 30	32	14.6	39.1
31 - 40	30	13.7	27.3
41 - 50	17	7.8	15.5
51 - 60	11	5.0	10.0
61 - 70	8	3.6	7.2
71 - 80	5	2.3	4.6
81 - 96	2	0.9	1.8
No other person	107	48.9	-
No answer	2	0.9	-
Total	219	100.0	100.0

TABLE 6: Occupation of Second Person

Occupation	Frequency	Percent	Valid Percent
Professional	53	24.2	50.0
Support staff	23	10.5	21.7
Student	9	4.1	8.5
Not employed	9	4.1	8.5
Retired	12	5.5	11.3
No other person	107	48.9	-
No answer	6	2.7	-
Total	219	100.0	100.0

TABLE 7: Limitations of Second Person

Type of limitations	Frequency	Percent	Valid Percent
Health	5	2.3	45.5
Pregnancy	2	0.9	18.2
Physical	2	0.9	18.2
Perceptual	2	0.9	18.2
No limitation	52	23.7	-
No other person	107	48.9	-
No answer	49	22.4	-
Total	219	100.0	100.0

Tables 8, 9 and 10 reflect the characteristics of a third person present in the apartment at the time of the fire. Only 9% of respondents (20 out of 219) reported that their apartment was occupied by more than two people. In the cases where a third person was present, 65% of the time it was a male and 35% of the time it was a female. Fifteen of the 20 'third persons' were children or teenagers who were 'Students.'

TABLE 8: Age of Third Person

Age Group	Frequency	Percent	Valid Percent
0 - 10	10	4.5	50.0
11 - 20	5	2.3	25.0
21 - 30	1	0.5	5.0
41 - 50	2	0.9	10.0
51 - 60	1	0.5	5.0
71 - 80	1	0.5	5.0
No other person	199	90.9	-
Total	219	100.0	100.0

TABLE 9: Occupation of Third Person

Occupation	Frequency	Percent	Valid Percent
Professional	1	0.5	7.7
Support staff	1	0.5	7.7
Student	10	4.6	76.9
Retired	1	0.5	7.7
No other person	199	90.9	-
No answer	7	3.2	-
Total	219	100.0	100.0

TABLE 10: Limitations of Third Person

Type of limitations	Frequency	Percent	Valid Percent
Health	1	0.5	100.0
No limitation	6	2.7	-
No other person	199	90.9	-
No answer	13	5.9	-
Total	219	100.0	100.0

Tables 11 and 12 reflect the characteristics of a fourth person present in the apartment at the time of the fire. Only 5% of respondents (10 out of 219) reported that their apartment was occupied by more than three people. In half of the cases, the fourth person present was a male and in the other half, it was a female. This fourth person was a child or teenager in eight of the 10 cases. No limitation was reported for any of the 'fourth' persons present in the apartment.

TABLE 11: Age of Fourth Person

Age Group	Frequency	Percent	Valid Percent
0 - 10	6	2.7	60.0
11 - 20	2	.9	20.0
31 - 40	1	0.5	10.0
41 - 50	1	0.5	10.0
No other person	209	95.4	-
Total	219	100.0	100.0

TABLE 12: Occupation of Fourth Person

Occupation	Frequency	Percent	Valid Percent
Support staff	2	0.5	16.7
Student	3	2.3	83.3
No other person	209	95.4	-
No answer	4	1.8	-
Total	219	100.0	100.0

Only one respondent declared that there were five people in the apartment at the time of the fire. The fifth individual was a 40 year old female, not employed and with no limitations.

Overall, 55% of the respondents were females and 45% were males. Their average age was 44 years. Forty-three percent of the respondents were "Professionals" and 25% were "Support Staff." Another 19% of the respondents who were retired and 7% were students. Close to half of the respondents (49%) were alone in their units at the time of the fire, while 37% of the units had two occupants, 9% had three and 5% had four or more. The average number of occupants in each unit at the time of the fire was 1.65. Of the 42 people with limitations, which includes respondents and all other persons present in the unit, 40% had a health problem, 26% had physical limitations, 6 women (14%) were pregnant, 17% had a perceptual problem and one (2%) was a sound sleeper.

The great majority of respondents (83%) reported using mostly English for verbal communication at home. Ten percent of people reported speaking Chinese: ten people spoke Cantonese and five people did not specify Cantonese or Mandarin. They were combined in Table 13 as speaking Chinese at home. The Indian language refers to people speaking either Farsi (two people) or Punjabi (one person).

TABLE 13: Language Used at Home

Language	Frequency	Percent	Valid Percent
English	125	57.1	83.3
Chinese	15	6.8	10.0
French	4	1.8	2.7
Indian	3	1.4	2.0
Korean	2	0.9	1.3
Spanish	1	0.5	0.7
No answer	69	31.5	-
Total	219	100.0	100.0

7.0 FIRE SAFETY KNOWLEDGE AND EXPERIENCE

Fire safety knowledge varied a great deal from one individual to the other. Table 14 sums up the various sources of information to which the respondents could have had access. These sources could have provided them with information on which actions to take in a fire situation. Of the respondents speaking a language other than English at home, 42% mentioned not having any previous information on actions to take in a fire situation, compared to only 15% for the English speaking group. Analysis showed no significant difference between genders ($\chi^2 = 49.74$, DF = 1, $p = 0.48$) in terms of whether or not they obtained any information on fire safety. Women, however, were more likely to obtain the information at work, while men obtained more information in publications or from the radio and television.

TABLE 14: Previous Sources of Information on Procedures in a Fire Situation

Source	Frequency	Percent
Multiple	60	27.4
Work	35	16.0
School	24	11.0
Publication	24	11.0
Radio, TV	11	5.0
Others	18	8.2
No information	35	16.0
No answer	12	5.5
Total	219	100.0

People in the 18-40 age group were more likely than older people to have received general fire safety information at school (15%), at work (13%) or to have been exposed to multiple sources of information (43%). People between the ages of 41 and 64 were more likely to have received information at work (27%), in publications (15%), from multiple sources (20%) or to have no information at all (16%). Seniors (65+ years old) generally obtained their information in publications (35%) or by other non-specified sources (24%); they were also more likely to have had no information at all (24%).

Analysis showed a significant difference between people with different occupations ($\chi^2 = 14.97$, DF = 4, p = 0.00). Working adults, such as professionals and support staff, were more likely to have had previous information than not employed people. Only 40% of the not employed people had access to previous information, compared to 83% of all respondents. Working adults generally obtained their information at school, at work or through multiple sources. Retired people were informed mostly through publications.

7.1 Length of Stay

On average, the respondents had been living in the 2 Forest Laneway Building for close to 4 years at the time they answered the questionnaire; but the mean length of stay was only of 1 year and 9 months, with answers ranging from one week to 20 years, as shown in Table 15. A statistical analysis showed a relationship between the length of time a person had lived in the building and that person's knowledge of the evacuation procedure ($\chi^2 = 31.18$, DF = 5, p = 0.00). People who had lived in the building for more than four years were much more likely to be familiar with the evacuation procedure than people who had moved in during the last year. People who had lived in the building for one to two years, however, were generally slightly more familiar with the evacuation procedure than those with two to four years of residence.

TABLE 15: Length of Stay in the 2 Forest Laneway Building

Length	Frequency	Percent
1 year or less	77	35.2
1 to 2 years	47	21.5
2 to 3 years	22	10.0
3 to 4 years	13	5.9
4 to 10 years	36	16.4
10 to 20 years	24	11.0
Total	219	100.0

Sixty-one, or 30% of the respondents, were aware of the evacuation procedure for the 2 Forest Laneway building, having read about it on written notices and signs (2 or 4%), in the hall (38 or 73%) or in the "Building Information Packet" (12 or 23%). Based on that information, 6 people believed they were supposed to evacuate, 5 thought they ought to stay in their apartments and 35 knew not to use the elevator. Men were significantly more likely to be familiar with the evacuation procedure than women ($\chi^2 = 6.86$, DF = 1, p = 0.01).

Among the 25 respondents who mentioned using another language than English at home, two or 8% said they knew about the evacuation procedure by reading the information posted in the hall, which informed them that they should not use the elevator. Twenty-one of them (84%) were not familiar with the procedure and two (8%) did not answer the question. For the 117 English speaking respondents who answered this question, 31% were familiar with the building evacuation procedure. From that group, 72% had read the posted instructions and 28% had read the "Building Information Packet"; the majority of them (80%) recalled that they should not use the elevator during a fire.

Statistical analysis showed a significant difference between age groups ($\chi^2 = 8.68$, DF = 2, p = 0.01). Respondents over 64 years old were more likely to be aware of the evacuation procedure for the building than respondents aged 18 to 40. No significant difference was found between respondents having different types of occupation ($\chi^2 = 8.35$, DF = 4, p = 0.08). Forty-seven percent of retired people were aware of the procedures compared to 13% of not employed respondents, 23% of professionals, 29% of support staff and 33% of students.

Thirty-nine or 19% of the respondents had experienced a fire before, ranging in time from two years ago to 45 years ago. This experience had no impact on their first action that morning or on their feelings during the event. They had no tendency to judge the situation as more serious or less serious than the occupants who had not had a previous fire experience ($\chi^2 = 6.16$, DF = 3, p = 0.10).

7.2 Fire Drills and False Alarms

It is interesting to note that three people thought they had previously participated in a fire drill in this building, even though management confirmed that such an exercise with all the occupants had not been held. Two of them thought it had been done in the summer of 1994. False alarms have been occurring regularly and 144 people, or 68%, were aware of such alarms. Table 16 shows the frequency of false alarms, according to the respondents, over a period of one year preceding the survey.

TABLE 16: Occupants' Assessment of Number of False Alarms in the Past Year

Number of Alarms	Frequency	Percent	Valid Percent
0	2	0.9	2.2
1 to 3	73	33.3	78.5
4 to 6	14	6.4	15.1
7 to 10	4	1.8	4.4
No answer	126	57.5	-
Total	219	100.0	100.0

According to the North York Emergency Call Reporting System, a total of 11 false alarms had been recorded in 1994 in the 2 Forest Laneway building. Three false alarms had been recorded in 1993. Table 17 shows the frequency and type of false alarms recorded during 1993 and 1994.

TABLE 17: Number of Actual False Alarms in the Past Two Years

Type of False Alarm		1993	1994
Malicious False Alarms	Manual Pull Station Activated	2	1
Accidental False Alarms	Sprinkler Pressure Change	1	3
	Detector Activated		1
	Equipment Malfunction		4
	Smoke, steam, etc. (mistaken for fire)		2
Total		3	11

7.3 Use of Stairs

Prior to the day of the fire, 62% of the respondents had used the stairs. Analysis showed a significant difference between age groups. People in the 18-40 age group were more likely than the 65+ age group to have used the stairs prior to the fire ($\chi^2 = 6.11$, DF = 1, p = 0.01). This difference was not significant between the 18 to 40 and 41 to 64 age groups ($\chi^2 = 2.40$, DF = 1, p = 0.12) and between the 41 to 64 and 65 and over age groups ($\chi^2 = 0.90$, DF = 1, p = 0.34). When comparing blocks of floors, a significant difference appears, showing that people living below the 17th floor were also more likely to have used the stairs in the past than the people living on the 17th floor and above ($\chi^2 = 16.50$, DF = 5, p = 0.01). There was no significant difference found between the previous use of the stairs by men and by women ($\chi^2 = 1.15$, DF = 1, p = 0.28).

Surprisingly, 10 or 5% of the respondents believed there was only one staircase in the building, 182 or 83% knew there were two staircases, two people or 1% thought there were more than two and 25 or 11% did not answer the question. Of the 10 people who thought there was only one staircase in the building, 3 had used the stairs before, five were men and five were women, all were younger than 65, except one who was 87 years old and none of them had limitations, with the exception of one lady who was pregnant at the time. The two people who thought there were more than two staircases were both men, aged 22 and 43 and one of them had used the stairs before. All these twelve people lived between the 5th and the 27th floors.

7.4 Exit to the Roof

In general, 47 people or 22% think that it is a good idea in a fire to try to exit to the roof of a building while 164 or 78% do not agree. There is no statistical significant difference to show that people on higher floors were more likely than people on lower floors to think that, in general, it would be a good idea to go onto the roof of a building ($\chi^2 = 8.74$, DF = 5, p = 0.12).

Prior to this fire, 39 of the residents (19%) thought they could go to the roof of the 2 Forest Laneway building while 163 (81%) did not think they could exit onto the roof of this building. The people who thought the roof would be a good exit to get away from the fire believed it would be a safer place and/or a good place to eventually be rescued (14 people or 36% of those in favour of the roof exit). A number of them thought that going to the roof might be a good idea depending on the situation and whether the door to the roof was locked. People living between the 17th and the 30th floors inclusive were more likely to think that they should exit onto the roof of the 2 Forest Laneway building in the event of a fire ($\chi^2 = 14.44$, DF = 5, p = 0.01).

7.5 Injuries

Injuries to people in the building, related to this fire were reported by 11 or 5% of the respondents. Seven of them suffered from smoke inhalation, two from exhaustion, one from exposure to the cold and one did not specify the nature of the injury.

8.0 ACTIONS PRIOR TO EVACUATION

This section contains a detailed analysis of the initial actions of the respondents prior to their evacuation. First of all, it examines the circumstances of the initial awareness stage. Secondly, it discusses the actions taken by the respondents from the time they were made aware of the emergency situation to the time they left their apartments to evacuate the building.

8.1 Initial Awareness

The majority of the occupants of the building (57%) were first made aware that something unusual was happening by the sound of the alarm. Table 18 describes the various ways in which people were alerted. The second way by which occupants were alerted was by being told by another person (17%). A number of occupants were alerted by the smoke (14%) or by the sound of movement (7%).

There is no statistical evidence to show that men and women were alerted in different ways ($\chi^2 = 2.96$, DF = 4, p = 0.56). Analysis showed, however, a significant difference in the way older people became aware that something was happening, compared to younger people ($\chi^2 = 35.62$, DF = 8, p = 0.00). Compared to the 18 to 40 and 41 to 64 year olds, the occupants over 64 years old were significantly more likely to be told about the situation rather than to perceive the alarm or the smoke. The younger groups were generally warned by the alarm and the presence of smoke.

TABLE 18: Initial Awareness of Occupants

Cause	Frequency	Percent
Alarm	125	57.1
Being told	37	16.9
Smoke	31	14.2
Hearing movement	15	6.8
Smoke and alarm	10	4.6
No answer	1	0.5
Total	219	100.0

The location of the unit in the building in terms of floor level and quadrant was not shown to have a significant effect on the way people became aware that something unusual was occurring (floor level: $\chi^2 = 29.93$, DF = 20, p = 0.07; quadrant: $\chi^2 = 15.90$, DF = 12, p = 0.20). This can be explained by the fact that most people were alerted by the sound of the alarm (see section on Alarm and Public Announcements) which probably sounded throughout the building at the same time. A higher percentage (28%) of respondents from the 22nd to the 30th floors, however, said that they initially noticed the smoke compared to respondents living on lower floors: 15% for residents living between the 17th and 21st floor, 15% between the 11th and 16th floor, 9% between the 6th and the 10th floor and 8% between the 2nd and the 4th floor. On the 5th floor, two-thirds of respondents noticed the smoke before anything else.

8.2 Time of Initial Awareness

Respondents had a marked tendency to round off the various reported times, therefore, the time analyses should be used with caution, especially when considering small time intervals. Very few people gave time measures that were not multiples of five. The time reported by the respondents should not be used to determine within one minute the time at which the fire started, the alarm rang, the smoke appeared or any other significant event. For events of less significance or that were less noticeable, respondents could easily round off the time measure by more than five minutes, giving answers with respect to the closest half hour in many cases.

Figure 4 shows the different times at which people became conscious of the emergency situation. It illustrates in 5 minutes intervals the time frequencies for the period between 5:00 and 6:00. This is the period of time during which 93% of the respondents became aware that something was happening. With the exception of the 2nd floor, where respondents noticed something unusual was happening on average around 6:10, the average time to notice something was happening for all the other floors was 5:11. When considering all blocks of floors but the 5th floor, between 5:00 and 6:00, there is no significant difference for the time of initial awareness of the respondents at different levels ($\chi^2 = 10.11$, DF = 8, p = 0.26).

There is a significant difference in the way residents were alerted as a function of the time of initial awareness ($\chi^2 = 48.97$, DF = 6, p = 0.00). Occupants aware of the presence of the fire before 5:15 were more likely to have been alerted by the alarm bell, while occupants alerted at 5:15 and later were more likely to have been told about the fire or to have seen or smelled the smoke.

Statistical analysis showed a correlation between the age and the time of awareness ($r = 0.14$, $p = 0.04$). People in the 65 and over age group were alerted significantly later than younger residents. The difference is not significant between the 18 to 40 age group and the 41 to 64 age group. On average, people aged 65 and over became aware of the problem at 5:21, compared to 5:12 and 5:11 for the other two age groups.

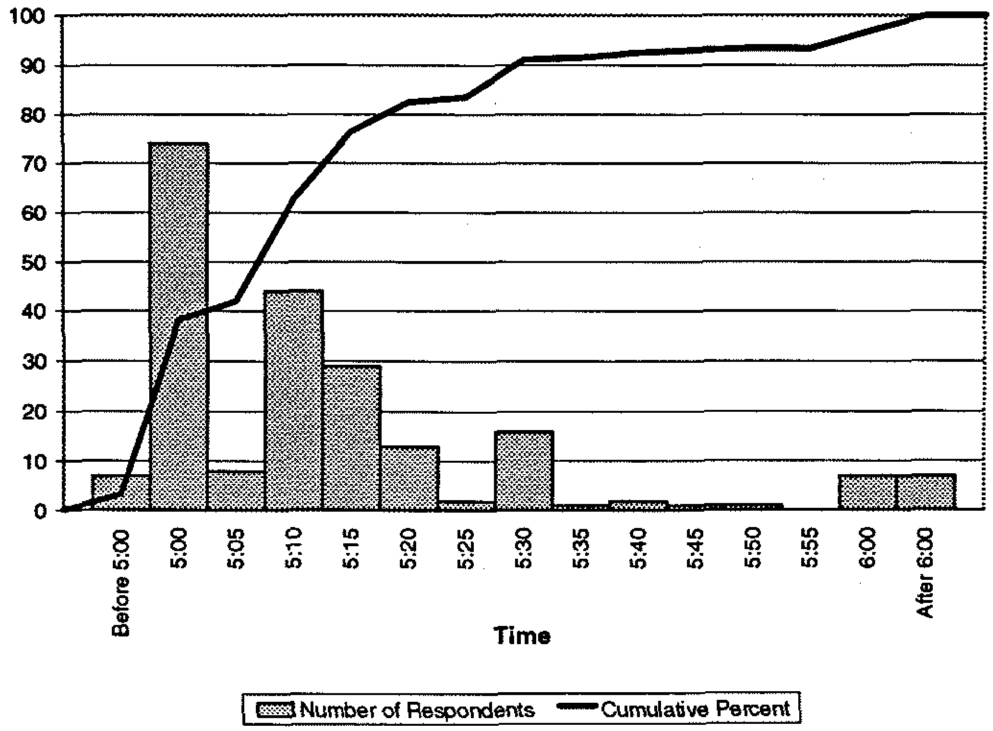

FIGURE 4: Frequency of Initial Awareness between 5:00 and 6:00

8.3 Activity at Time of Initial Awareness

Table 19 shows that 92% of people were in bed and 84% were asleep until some initial sign awoke them and they first acknowledged that something unusual was happening. No difference was found between the people who were asleep and those who were awake at the time of initial awareness ($\chi^2 = 3.20$, DF = 3, p = 0.10). People who were awake at the time of initial awareness did not realize that there was a problem significantly earlier than the people who were asleep.

TABLE 19: Activity at Time of Initial Awareness

Occupation	Frequency	Percent
In bed - Asleep	185	84.5
In bed - Awake	16	7.3
Awake and active	7	3.2
In washroom	5	2.3
Eating	2	0.9
No answer	4	1.8
Total	219	100.0

8.4 Seriousness of Situation

Table 20 shows the respondents' initial interpretation of the situation in terms of the seriousness of the event. No relation has been found between the initial perception of the situation and the respondent's floor, if the fifth floor is excluded from the calculations ($\chi^2 = 11.36$, DF = 12, $p = 0.50$). The people on floors situated closer to the fire were not more likely to think that the situation was very serious than the people located much farther from the 5th floor. There appears to be a significant difference where the fifth floor is concerned: 4 out of 5 fifth floor respondents believed the situation was *Extremely Serious*.

TABLE 20: Initial Interpretation of the Situation

Interpretation	Frequency	Percent
Not at all serious	79	36.1
Only slightly serious	38	17.4
Moderately serious	56	25.6
Extremely serious	39	17.8
No answer	7	3.2
Total	219	100.0

Females generally thought at first that the situation was more serious than men. This gender difference was statistically significant ($\chi^2 = 7.50$, DF = 3, $p = 0.05$). The correlation analysis also showed that age groups were statistically different. The occupants over 65 years old judged the situation as significantly more serious than the younger groups ($r = 0.20$, $p = 0.00$). Analysis did not show a significant difference between people having different occupations ($\chi^2 = 17.13$, DF = 12, $p = 0.14$). The presence of another person was not shown to cause a significant difference in the initial interpretation of the situation ($\chi^2 = 1.04$, DF = 3, $p = 0.79$).

8.5 First Action Taken

Occupants described a variety of first actions taken. In order to facilitate the analysis of these first actions, it was important to define categories. Previous research on human behaviour in fire situations has categorized the actions of occupants into nine categories from *Investigation* to *Protective Action* (see Table 21) [5, 9, 20]. In relation to these categories, the first actions following initial awareness reported by the occupants of the 2 Forest Laneway building are listed in Table 21. The *Investigation* category refers to actions such as: getting out of bed, checking the corridors, checking the apartment, looking out the window or feeling the door. *Seeking Information* can be described as talking to neighbours or others, calling the building management or calling 911. A number of people reported stopping the smoke from entering, which is a *Protective Action*. *Alerting* is often done by warning others and *Waiting* describes best the people who reported doing nothing. No one reported actions falling in other categories such as *Preparation to Evacuate*, *Evacuation*, *Assisting* or *Seeking Refuge* as their initial action.

Analysis on the actions reported by the occupants did not show a difference between genders ($\chi^2 = 2.01$, DF = 4, p = 0.73). It appears males and females were equally likely to take the various actions described in Table 21. Statistical analysis showed that there was a difference between people alone in their units and people who were not alone ($\chi^2 = 13.37$, DF = 4, p = 0.01). The difference resided mainly in the fact that people who were alone in their apartments were unlikely to list *Alerting* as their first action but were more likely to *Investigate* or *Seek Information*. In fact none of the 104 people who were alone in their units said their first action had been to *Alert*. When a second person was present in the apartment, 12% of respondents' first action was to *Alert*.

TABLE 21: First Action Following Initial Awareness

Action	Frequency	Percent
1. Investigation	135	61.6
2. Seeking Information	20	9.1
3. Preparation to Evacuate	0	0.0
4. Evacuation	0	0.0
5. Alerting	13	5.9
6. Assisting	0	0.0
7. Seeking Refuge	0	0.0
8. Waiting	34	15.5
9. Protective Action	11	5.0
No answer	6	2.7
Total	219	100.0

Statistical analysis showed a difference between people with different occupations ($\chi^2 = 22.71$, DF = 8, p = 0.00) when comparing professionals, support staff and retired occupants. Professionals were more likely to *Wait* than the others, respondents working as support staff had a tendency to ***Investigate*** and retired people were more likely to take ***Protective actions***. No evidence has been found to suggest that limitations had an effect on a person's first action, however, the sample of people with limitations was very small ($\chi^2 = 19.05$, DF = 16, p = 0.27).

Statistical analysis showed a significant difference between age groups ($\chi^2 =$ 25.69, DF = 8, p = 0.00). Respondents aged 65 and older were more likely to ***Protect*** or ***Seek Information***, people aged between 41 and 64 were more likely to ***Investigate*** and people between 18 and 40 years old were more likely to *Alert* or to *Wait*. The difference is not significant between the respondents 18 to 40 years old and those 41 to 64 years old ($\chi^2 = 6.26$, DF = 4, p = 0.18).

The time of first awareness was not shown to have a significant effect on the choice of first action ($\chi^2 = 16.96$, DF = 12, p = 0.15). However, as shown in Table 22, a higher proportion of people with an early initial awareness time decided to *Wait* or to *Alert*. People with a later initial awareness time were more likely to ***Investigate*** or to *Protect*. The expected values are shown in parentheses in Table 22 beside the actual numbers. The expected values correspond to the values that would have been obtained if there was absolutely no difference among the various categories, corresponding to a perfect fit of the normal curve. The expected value for any given cell can be obtained by multiplying the sum of the row by the sum of the column and dividing by the sum of all cells in the table.

TABLE 22: First Action as a Function of the Time of Initial Awareness

Action	TIME								Row Total	
	Before 5:05		5:05 to 5:14		5:15 to 5:24		After 5:24			
Investigate	50	*(51.3)*	30	*(32.3)*	33	*(28.5)*	22	*(22.8)*	135	63%
Wait	15	*(12.9)*	10	*(8.1)*	8	*(7.2)*	1	*(5.7)*	11	5%
Seek Info	7	*(7.6)*	5	*(4.8)*	3	*(4.2)*	5	*(3.4)*	20	9%
Alert	6	*(4.9)*	4	*(3.1)*	0	*(2.7)*	3	*(2.2)*	13	6%
Protect	3	*(4.2)*	2	*(2.6)*	1	*(2.3)*	5	*(1.9)*	34	16%
Column Total	81 38%	-	51 24%	-	45 21%	-	36 17%	-	213 100%	100%

The resident's initial interpretation of the seriousness of the situation was likely to affect his or her first action. Statistical analysis showed a significant difference between people who had different initial perceptions of the gravity of the situation ($\chi^2 = 43.45$, DF = 12, p = 0.00). People who thought the situation was *Not at all Serious* were much more likely to *Wait*, people who thought the situation was *Only Slightly Serious* or *Moderately Serious* decided in a greater proportion to *Investigate* and people who believed the situation to be *Extremely Serious* were more likely to *Alert*.

Table 23 shows how previous information about fire safety or information on the building evacuation procedure affected residents' first actions. Analysis showed there was a significant difference between people who had had some form of previous information on actions to take in a fire situation and those who had not had any information (χ^2 = 11.79, DF = 4, p = 0.01). People exposed to previous information were more likely to *Investigate*, while people without any previous information were more likely to *Seek Information* or to *Wait*. Analysis did not show a significant difference between people who were aware or not aware of the evacuation procedure and their first action (χ^2 = 9.01, DF = 4, p = 0.06).

TABLE 23: First Action as a Function of Fire Safety Knowledge

Knowledge	TYPE OF FIRST ACTION										Row	
	Investigate		Protect		Seek Info		Alert		Wait		Total	
Obtained Previous Information on Fire Safety												
Yes	113	*(105)*	8	*(8.3)*	12	*(16.6)*	10	*(9.9)*	25	*(28.1)*	168	83%
No	14	*(21.9)*	2	*(1.7)*	8	*(3.4)*	2	*(2.1)*	9	*(5.9)*	35	17%
Column Total	127	-	10	-	20	-	12	-	34	-	203	100%
	63%		5%		10%		6%		17%		100%	
Aware of Building Evacuation Procedures												
Yes	43	*(38.1)*	6	*(3.3)*	3	*(5.6)*	3	*(3.5)*	5	*(9.5)*	60	30%
No	86	*(90.9)*	5	*(7.7)*	16	*(13.4)*	9	*(8.5)*	27	*(22.5)*	143	70%
Column Total	129	-	11	-	19	-	12	-	32	-	203	100%
	64%		5%		9%		6%		16%		100%	

Statistical analysis showed no significant difference between people who had experienced a fire before and those who had not (χ^2 = 1.08, DF = 4, p = 0.90).

8.6 Awareness of the Fire

Following an initial awareness, some action is likely to be performed by an individual, as described by the categories in Table 21. The completion of that action will generally give the person a better understanding of the situation. As a result of the information obtained in one way or another, eventually all occupants were made aware that there was a real fire. Table 24 describes the different cues leading to that understanding.

Analysis showed no significant difference between genders (χ^2 = 3.35, DF = 8, p = 0.91). People of different age groups, however, became aware that there was a fire in ways that are significantly different (χ^2 = 26.36, DF = 16, p = 0.05). People in the 18-40 and 41-64 year age groups were more likely to notice signs of smoke (smell and sight), while people in the 65 year and older age group were more likely to be told. The difference between the ways of becoming aware that it was a real fire is not significant between the 18-40 and 41-64 year age group ($\chi^2 = 5.58$, DF = 8, p = 0.69). No relation has been established between the fire cues described in Table 24 and the quadrant block in which the respondent's unit is located ($\chi^2 = 31.64$, DF = 24, p = 0.14).

TABLE 24: First Cues of a Fire Emergency Situation

Cue	Frequency	Percent
Saw smoke	81	37.0
Smelled smoke	60	27.4
Told by others	32	14.6
Saw fire trucks outside	20	9.1
Told by firefighters	8	3.7
Opened door	6	2.7
Heard fire crackling	4	1.8
Heard alarm	3	1.4
Alarm and smoke	1	0.5
No answer	4	1.8
Total	219	100.0

8.7 Attempt to Give or Obtain Information

Table 25 shows the respondents' attempts to contact others to give or obtain information on the situation prior to their evacuation. Overall, 129 people (59%) successfully used one form of communication or another to obtain and/or give information concerning the situation. A number of people used more than one form of communication; this explains why the frequencies in Table 25 add up to more than 129.

In summary, the 911 emergency service was contacted by 16% of all respondents. They were informed that they should remain in their units, stay calm, put towels to seal the door and go on the balcony. Unfortunately, the times of these calls were not reported in the questionnaires and it is not possible to determine when a particular response was provided by 911.

None of the respondents said they pulled the fire alarm. Obviously, if the alarm was already ringing, this was not of any use but, since many of them reported not hearing the alarm, it is interesting to note that no one tried to activate it. It could be explained by the fact that the people who were not woken up by the alarm, in many cases, were woken up by the smoke and chose not to go into the corridor to pull the alarm.

A large number of people (35% of respondents) called friends or relatives, in most cases to let them know that they were safe and sound. Ninety-six people (46%) listened to the radio or watched television while staying in their units. Some of them reported that this was frustrating since the news would report that there was a fire, which they obviously knew at that time and that people had died, which was frightening them, without giving any information on what to do if one was still inside the building.

Statistical analyses have shown no significant difference between genders or between age groups in terms of the respondents' communication efforts. This applies to all the items listed in Table 25.

In Table 25, the number starting each line in the "Information Received" column corresponds to the number of respondents who received that information.

TABLE 25: Communication Effort

Action	Frequency	Information Received
Call 911	36	12 Towels at door 9 Stay calm and in unit 5 Towels and balcony 4 Go on balcony 1 Evacuate
Call fire department	4	1 Evacuate 1 Towels at door 1 Firefighters coming
Operate fire alarm pull station	0	
Alert other occupants	35	How: 14 Tell others 13 Knock on door 4 Balcony
Telephone friends or relatives	75	
Watch television or listen to radio	96	37 Fire in building 21 Follow instructions 18 People have died
Call security	2	

8.8 Stay in their Units

As many as 29% of the occupants did not mention any activity, which may imply that they left their apartments immediately. A number of individuals, however, stayed in their units rather than trying to evacuate immediately. Table 26 shows their motivation in staying in their apartments and Table 27 lists their activities during the wait. A majority of occupants (50%) reported there was too much smoke to attempt an evacuation and 13% thought it was safer to stay inside their units. Another group, representing 20% of the respondents to this question, said they had been told to stay in their units, generally by the rescue personnel. Seven people (5%) stayed in their apartments because they were not worried. The latter were generally situated on the west side of the building, where less smoke was reported. They often did not think the situation was serious and thought the fire would not spread to their floor. The four people who were unsure of what to do saw smoke in the corridors and were not sure whether they should evacuate immediately or stay in their units, therefore, they decided to wait for instructions or further development of the situation. The reasons motivating people to stay in their units were not significantly different between males and females ($\chi^2 = 0.09$, DF = 3, p = 0.99) or between age groups ($\chi^2 = 9.53$, DF = 6, p = 0.15).

TABLE 26: Reasons People Stayed in their Units

Reason	Frequency	Percent	Valid Percent
Too much smoke/heat	85	38.8	54.8
Told to stay	31	14.2	20.0
Safer inside	20	9.1	12.9
Unsure it was a real fire	19	8.7	12.3
No answer	64	29.2	-
Total	219	100.0	100.0

TABLE 27: Activity While Staying in Unit

Occupation	Frequency	Percent	Valid Percent
Go on balcony	51	23.3	34.9
Seal door	28	12.8	19.2
Seal door and go on balcony	19	8.7	13.0
Wait	14	6.4	9.6
Watch TV	14	6.4	9.6
Get dressed	7	3.2	4.8
Breakfast	6	2.7	4.1
Call others	4	1.8	2.7
Look out window	2	0.9	1.4
Look for water	1	0.5	0.7
No answer	73	33.3	-
Total	219	100.0	100.0

While staying in their apartment, 35% of occupants simply went onto their balconies. Some 19% sealed their door and another 13% specified that they sealed the door and then went onto their balconies. A number of people (10%) watched television, 10% waited, 5% got dressed, 4% had their breakfast and 3% made phone calls.

Following the different categories of actions described in Section 8.5, no significant difference was observed between genders ($\chi^2 = 5.17$, DF = 4, p = 0.27). Statistical analysis, however, showed a significant difference between age groups ($\chi^2 = 16.82$, DF = 8, p = 0.03). People between the ages of 18 and 64 were more likely to complete *Protective actions* while a higher percentage of people 65 years old and older decided to *Seek information.* The difference was not significant between the 18 to 40 and 41 to 64 year age groups.

8.9 Go Onto Balcony

All units in the 2 Forest Laneway Building have access to a private balcony. Many residents (72%) chose to stay on their balconies rather than inside the apartment during the fire, in many cases because smoke had entered the apartments. Table 28 describes the occupants' use of their balconies. Of the 142 occupants who went on their balconies, 48% left the door open. Smoke on the balcony was reported by 66 people, representing 67% of people who answered this question. Smoke and heat were present on 6% of the balconies.

TABLE 28: Use of the Balcony

		Frequency	Percent	Valid Percent
1) Did you go on the balcony?	Yes	142	64.8	71.7
	No	56	25.6	28.3
	No answer	21	9.6	-
IF YES (to question 1)				
2) Did you leave the door open?	Yes	69	31.5	47.9
	No	75	34.2	52.1
	No answer	75	34.2	-
IF YES (to question 1)				
3) Was there smoke on the balcony?	Smoke	66	30.1	66.7
	Smoke and Heat	6	2.7	6.1
	No	27	12.3	27.3
	No answer	120	54.8	-

Statistical analysis showed no significant difference between genders ($\chi^2 = 0.69$, DF = 1, p = 0.41), however, there was a significant difference between age groups ($\chi^2 = 5.71$, DF = 2, p = 0.05). People 65 and over were significantly less likely to go on their balconies. Many of them explained their decision by stating that it was very cold outside on that January morning. The temperature was recorded as -8°C that morning.

8.10 Time to Leave Unit

The time at which people left their units varies greatly, as shown in Figure 5. Three respondents declared that they had left their apartments before 5:00 after perceiving fire cues. One is a 4th floor resident who left at 4:55, a second one left the 19th floor at 4:31 and both are sure of the accuracy of their reported time. Finally, a third occupant said he left his 7th floor apartment at 4:00 but is not sure of that time. All this is rather surprising since it is unlikely that the fire started before 5:00. On the other hand, one respondent did not leave her apartment until 13:00; on the day following the fire, that is, more than 24h after the fire. She said she did not know that the entire building had been evacuated until a rescue officer found her at that time.

In general, people who successfully evacuated the building without help immediately after becoming aware of the fire, did so between 5:00 and 6:00. The majority of people who waited in their units left the building with the help of firefighters or police officers between 10:00 and 12:00. The time at which people left their units is significantly related to the time at which they realized there was a problem ($\chi^2 = 56.65$, DF = 9, p = 0.00). People who were alerted before 5:15 were significantly more likely to leave their units before 5:30 than people who were alerted at 5:15 and after.

It has not been shown that people living on lower floors were significantly more likely to leave their units earlier or later than others ($\chi^2 = 10.54$, DF = 10, p = 0.39). Statistical analysis showed, however, that there was a significant difference between age groups ($\chi^2 = 15.69$, DF = 6, p = 0.02). Occupants aged 18 to 40 had a net tendency to leave their units before 5:30, while occupants 41 years old and older were more likely to leave their units much later in the day, often between 10:00 and 12:00.

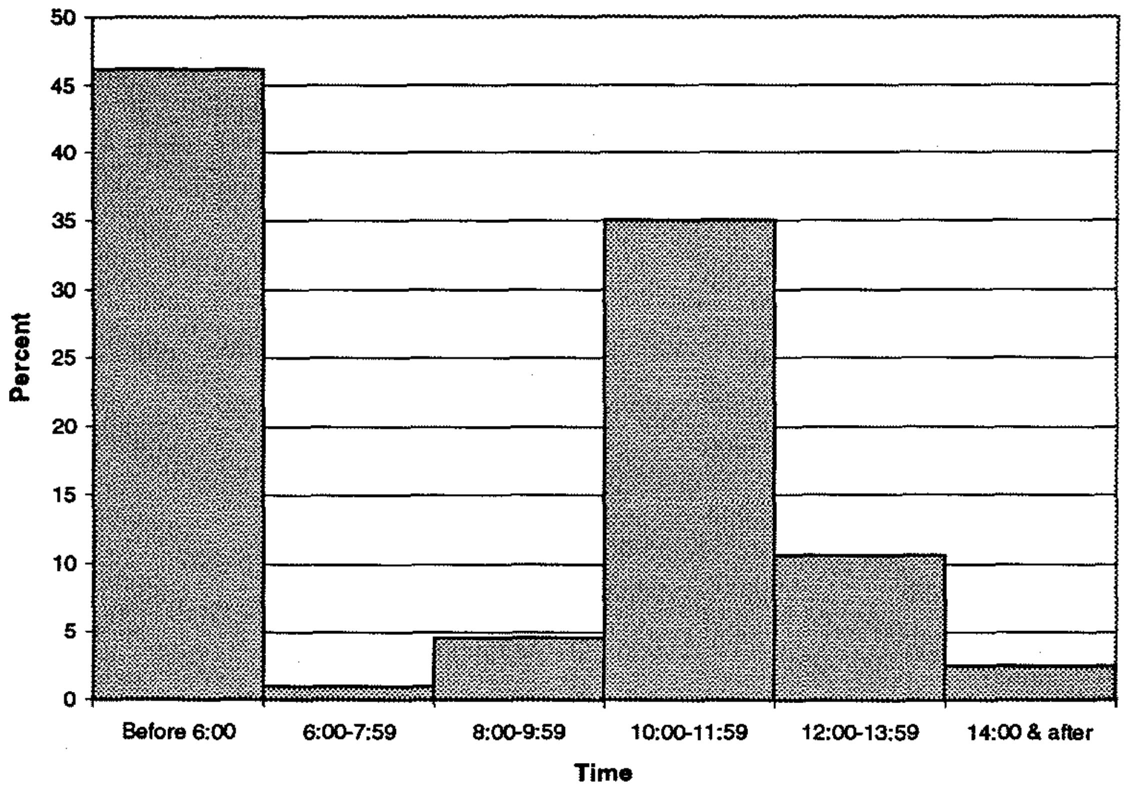

FIGURE 5: Time at Which People Left their Units

People who had been given previous information on fire safety were not significantly different from the others and that information did not seem to have an effect on their departure time ($\chi^2 = 0.76$, DF = 3, p = 0.86). Occupants who were aware of the evacuation procedure were not significantly different either and that awareness did not affect the time at which they left their units ($\chi^2 = 0.93$, DF = 3, p = 0.82).

When leaving their apartments, 95% of occupants locked their door and 97% remembered to take their key. These numbers do not take into account the 8 respondents who did not answer this question. Statistical analysis showed no significant difference between genders or between age groups, possibly because such a small number of people forgot to lock their doors and/or take their apartment keys.

9.0 EVACUATION OF THE BUILDING

The term "Evacuation of the Building" was interpreted by some of the respondents as referring to any initial attempt, successful or not, to leave the building. It was interpreted by others as the final move leading to their departure from the building. Many people attempted a first evacuation early in the morning but were forced back into an apartment by the smoke and/or the heat. Later in the day, they proceeded to evacuate the building under the guidance of rescue officials. In much of this analysis, it was necessary to establish a distinction between the occupants who evacuated on their own, generally in the early stages of the fire, and those who evacuated later with the help of rescue personnel.

9.1 Groups Who Separated

Of the 112 respondents who were not alone in their units, only two declared that they did not stay in the apartment together but did not give any reason for their separation. This implies that at least one of the occupants left the unit before the other(s).

Fourteen of the respondents (6% of all respondents but 13% of respondents to this question) reported that they had been separated from the people with whom they left their units to evacuate. One couple was separated when the firefighters and police officers proceeded to evacuate everyone left in the units, and the elevator could only contain a certain number of people. Two of the respondents had provided a refuge for other people and the refugees stopped by their own apartments before evacuating. The thick smoke in the stairs on the 12th floor separated one couple when it caused one of them to faint. They were rescued and pulled out of the staircase by another resident. One couple was separated for a minute when one of them chased after a cat which had run away. While in the stairs, one couple was separated when one of them went back to their apartment for a forgotten wallet. Finally one group was separated when one of them stayed to help a pregnant woman, while the other people in the unit went looking around the floor to the different staircases to find the best escape route for their group. Ninety-six respondents

(87% of respondents to this question) declared that they had not been separated from their group. Fifty percent of respondents did not answer the question. The location of the respondent's apartment in terms of the floor block ($\chi^2 = 3.85$, DF = 5, p = 0.57) or the quadrant ($\chi^2 = 1.61$, DF = 3, p = 0.66) was not shown to have a significant effect on the likelihood that someone would be separated from his or her group.

9.2 Try to Meet Someone

Before leaving the building, 30 or 16% of respondents said they tried to meet someone from another unit. Two-thirds of them however, declared that they had met that person in the hall, in the stairs or in the lobby. This could indicate that they did not really *intentionally try to meet* that person before leaving the building but rather that they simply *met* that person during their evacuation. Four more respondents indicated that they actually went to someone's apartment to find that person. The others did not provide an explanation. No evidence has been found to suggest that the gender ($\chi^2 = 0.10$, DF = 1, p = 0.75) or the age of the respondent affected his or her likelihood of trying to meet someone before leaving the building ($\chi^2 = 3.20$, DF = 2, p = 0.20).

9.3 Use of the Elevator

When evacuating, 83 people or 40% of respondents said they used the elevator, successfully or not and with or without the rescue personnel. Only 4 of the 219 respondents, however, reported having tried to use the elevator without specific instructions from the rescue personnel. In the first case, a small group of five people from the 5th floor successfully took the elevator to the main floor at apparently 5:20, after trying unsuccessfully, because of the smoke, to reach the east side staircase door. Shortly after 5:00, someone on the 7th floor tried to use the elevator, but since that did not work, went back to a neighbour's apartment, after trying unsuccessfully to exit via one of the staircases. At 5:30 on the 10th floor, someone tried to get on an elevator but was forced back into an apartment by the smoke in the hallway. At 8:30 on the 12th floor, a person tried to leave by the elevator, which was not in operation and the person had to use the stairs. Finally, the rescue personnel evacuated everyone left in the building, floor by floor, using the elevator to evacuate 37% of the respondents, mostly those living above the 7th floor. Six people were evacuated by the rescue personnel before 8:00, 9 were evacuated between 8:00 and 9:59 and 109 were evacuated at 10:00 or after. These numbers reflect all the people evacuated by the rescue personnel, not only those who used the elevator to reach the ground level.

In total, after a careful look at each of the questionnaires, it was determined that 162 people or 74% of the respondents used the elevator to reach ground level, all (but one group of five people) under the guidance of rescue personnel. A total of 57 or 26% used the stairs to reach ground level. These statistics reflect how people finally reached ground level to exit the building, without any consideration given to possible earlier unsuccessful attempts to evacuate by either the stairs or the elevators. Of the 162 people who took the elevator to reach ground level, 16 were in a somewhat special situation in that they started by using the stairs, went down a number of flights of stairs before having to take refuge in an apartment on another floor and were later evacuated by elevator from that floor.

9.4 Use of the Staircases

Six people (6% of the 105 stairs users) indicated that they took the stairs to go up, while 97 or 92% of stairs users indicated that they had tried to go down. Two stairs users did not specify their direction. Of the six going up, four had to do so because of the smoke: three on the 19th floor and one on the 21st floor. A fifth one was trying to reach a family member living on an upper floor and the 6th person did not provide an explanation.

Of the 105 people or 48% of respondents who attempted to use the stairs to evacuate, 69% (or 71 people) used the stairs before 6:00. Table 29 gives a detailed account of these 71 people. All these occupants have the following conditions in common:

- They personally made the decision to evacuate.
- They made that decision within 5-10 min of becoming aware that there was a real fire.
- They started evacuating before 6:00.
- They tried using the stairs to evacuate.
- They did all of this without instructions or help from the rescue personnel.

The 'Starting Time' given for each person in Table 29 corresponds to the time at which the person mentioned leaving his or her unit. The time given in brackets in the 'Reached Ground' column corresponds to the time at which the person finally reached the ground level. People are divided into two categories: those who 'Reached Ground,' making it to the first floor in their first attempt to evacuate; and those who 'Turned Back,' which refers to the people who went back to their units or took refuge in another unit for some time. These people, very often because of the smoke density in the staircase, had to abandon their evacuation until they received instructions and were helped to evacuate by the rescue personnel later in the day.

Twenty-nine people, 41% of the 71 people listed in Table 29 as having used the stairs without assistance before 6:00, tried to use the Fire Staircase. Their average starting time was 5:14. The nine persons who started from floors under the fire floor all reached the ground level by the Fire Staircase within 5 minutes. A total of four people who started above the fire floor, also reached the ground level using the Fire Staircase. Three of them reached the first floor within five minutes. The fourth person reported reaching ground level 30 minutes after leaving the 19th floor unit without providing explanations for what he or she did during that period of time, except that this person started by going upwards.

A lady on the 20th floor deserves a special note for being the one to make it from the highest floor while taking the Fire Staircase. She explains her success and rapid response by "I had a dream on the night of the fire that I and my neighbours had to evacuate the building by the stairwell because of an earthquake, not a fire. When the alarm sounded, I was mentally prepared." Of the people starting above the 9th floor, 16 or 80% had to turn back, returning to their apartments or finding refuge in another unit.

Of the 42 people (59% of the 71 people listed in Table 29) trying to evacuate by the Other Staircase before 6:00, 12 or 29% made it to ground level. The average starting time for the people trying to use the Other Staircase was 5:16. For the 35 people starting above the 5th floor, 5 or 14% succeeded in reaching ground level and 30 people had to turn back. Only one person coming from above the 7th floor was able to reach ground level between 5:00 and 6:00: an occupant who left the 21st floor at 5:15. All the people reaching ground level completed their descent within 5 minutes, with the exception of someone on the 7th floor who required 7 minutes to reach the first floor. Unfortunately not all respondents were able to report specific times with great accuracy and therefore only a very limited number of time-based comparisons can be made with acceptable levels of accuracy.

There are a few cases, included in Table 29 under the Other Staircase column, that deserve further explanation. On the 19th floor, a woman reported leaving her unit at 4:35, after being woken up by the fire alarm at 4:31 and says that she is sure of that time. It is strongly believed, however, that the fire alarm did not sound until after 5:00. The same can also be said of a man who left his 4th floor unit in the south-east quadrant at 4:55 after hearing the alarm at 4:50 and is positive this time is accurate.

Analysis shows a statistical difference between the floor of origin of the occupants and the likelihood of using the stairs to evacuate. People living below the 6th floor or between the 17th and the 21st floor were significantly more likely to use the stairs to evacuate than the occupants of other floors ($\chi^2 = 31.20$, $= 5$, $p = 0.00$). Respondents living in one quadrant do not appear to have been more likely to use the stairs to evacuate than people living in any of the other quadrants ($\chi^2 = 1.40$, DF = 3, $p = 0.70$). For these comparative analyses, all of the people using the stairs at one moment or another were considered, whether they used the stairs for an early evacuation or whether rescue personnel took them down the stairs much later in the day. People usually used the staircase door closest to their apartment; ten of the respondents, however (10% of stairs users), used the staircase on the other side of the floor.

A total of 52 men (60% of male respondents) used the stairs to evacuate while 53 females (48% of female respondents) did the same. Analysis, however, did not show a significant difference between genders for use of the stairs during the fire ($\chi^2 = 2.83$, DF = 1, $p = 0.09$). Statistical analysis showed a significant difference between age groups ($\chi^2 = 13.10$, DF = 2, $p = 0.00$). Respondents between the ages of 18 and 40 were more likely than older respondents to use the stairs to evacuate. The difference is not significant between the 41-64 year age group and the 65 year old and over ($\chi^2 = 2.72$, DF = 1, p = 0.10).

TABLE 29: Use of Stairs Before 6:00

Floor	Fire Staircase			Other Staircase		
	Starting Time	Reached Ground	Turned Back	Starting Time	Reached Ground	Turned Back
2				5:15	2 (5:15)	
3	5:10 5:16 5:30	1 (5:10) 1 (5:17) 1 (5:30)		5:10 5:15	1 (5:10) 2 (5:16, 5:20)	
4	5:05 5:08 5:15 5:20 5:30	2 (5:05, 5:10) 1 (5:10) 1 (5:18) 1 (5:22) 1 (5:35)		4:55 5:50	1 (4:57) 1 (5:55)	
6				5:10 5:20	1 (5:12) 1 (5:20)	
7				5:00 5:20	 1 (5:27)	1
9				5:25		2
10	5:10	1 (5:15)	1			
14				5:15		1
15	5:10		1			
16	5:10 5:20	1 (5:15)	 1	5:20 5:45		1 1
17	5:15		2	5:10 5:20		1 1
18	5:20		1	5:15 5:20		1 1
19	5:15	1 (5:45)		4:35 5:15 5:25	1 (?)	 2 1
20	5:00	1 (after 5:00)				
21	5:15		1	5:10 5:15 5:20	 1 (5:18)	1 2
22	5:15		1			
23	5:05		1			
24	5:00		1	5:15		1
25				5:10 5:15 5:20		3 3 2
26	5:10		2			
27	5:10		2			
28	5:15		1	5:40		1
29				5:10		3
30	5:15		1	5:20		1

9.5 Changing Staircase and Turning Back

While in the stairs, 14 people or 13% of stair users had to change staircases, because of the smoke in 12 of the 14 cases. Another 47 people or 45% of stair users, while on their way down the stairs, had to turn back. The 46 people who gave reasons for turning back are shown in Table 30. A majority of the evacuating occupants (85%) turned back because of the smoke. Forty-one of them (39% of stairs users or 87% of people who turned back) went back to their apartments. Five men and one woman did not go back to their apartments after turning back, which implies that they took refuge in another unit.

Statistical analysis showed a significant difference between occupants of different age groups ($\chi^2 = 8.52$, DF = 2, p = 0.01). People 65 years old and over were less likely to turn back. The statistical difference is not significant between the 18 to 40 and 41 to 64 year age groups or between genders ($\chi^2 = 0.80$, DF = 1, p = 0.37)

TABLE 30: Reasons for Turning Back in the Stairs

Reason	Frequency	Percent	Valid Percent
Smoke	39	17.8	84.8
Crowded / Smoke	2	0.9	4.3
Dark	2	0.9	4.3
Instructions	2	0.9	4.3
Pregnant	1	0.5	2.2
Did not turn back	64	29.2	-
No answer	109	49.8	-
Total	219	100.0	100.0

The analysis also showed a significant difference in the likelihood of turning back according to the floor the occupant left when considering all blocks of floors ($\chi^2 = 48.52$, DF = 5, p = 0.00), or when considering only blocks of floors above the 5th floor ($\chi^2 = 21.27$, DF = 3, p = 0.00). People living above the 16th floor were much more likely to have to turn back. It was not shown that the apartment quadrant had an effect on the rate of turning back ($\chi^2 = 5.04$, DF = 3, p = 0.17).

Five respondents (5% of stairs users) said they had difficulty opening the staircase door for a number of different reasons. One claims that the 1st floor door was locked. This is true from the outside but should not have caused a problem for someone trying to exit. Turning the door handle in the wrong direction, however, can give the impression that the door is locked when it actually is not. On the 29th floor, the smoke made it difficult to see the door and the handle for another one of the respondents. On the 24th floor, someone reported having difficulty opening the staircase door without providing any further information. On the 6th floor, two people reported that the west staircase door was locked, which is very unlikely since this door was not equipped with a lock. This was the Fire Staircase only one floor above the fire. It is likely that the door was blocked or jammed, possibly because of the air movement in the staircase or due to the effect of the fire that might have twisted the door. A few hours later someone reported using that door to evacuate without any problem.

9.6 People in Corridors and Staircases

Table 31 is an indication of the density of people in the corridors and in the staircases.

TABLE 31: People Encountered in Corridors and Staircases

Number of people encountered	Corridors			Stairs		
	Frequency	Percent	Valid Percent	Frequency	Percent	Valid Percent
0	72	32.9	52.2	34	15.5	34.0
1 - 10	51	23.3	37.0	50	22.8	50.0
11 - 20	13	5.9	9.4	12	5.5	12.0
+20	2	0.9	1.4	4	1.8	4.0
No answer	81	37.0	-	119	54.3	-
Total	219	100.0	100.0	219	100.0	100.0

From these results it does not appear that the crowd in the corridors or in the staircases was a major factor during this fire. A majority of respondents to that question (84%) saw 10 or fewer occupants during their use of the stairs. In general, respondents saw 3 or 4 people in the corridor and 5 to 6 people in the stairs.

9.7 Refuge Activities

Table 32 describes the movement from their original location to their refuge location, of the 44 respondents who moved from one unit to another during the fire. Twenty-six of 44 people (60%) changed floors before having to take refuge in another unit. Of those individuals, 16 or 62% reportedly had to find refuge because of the smoke. It was not specified whether they encountered excessive smoke, forcing them to seek refuge, while in their own units or while in one of the staircases. It is likely that, in many cases, they encountered smoke in the stairs; this would explain why people travelled on average 9 floors before seeking refuge. Among the 18 people (40% of the 44 respondents) who changed units while remaining on the same floor, only three moved to another unit because of the smoke, while many others were motivated to relocate mainly to join family, friends or neighbours for help and support.

TABLE 32: Voluntary Relocation of Individuals between Units

Location of refuge	# of people in unit (total, or tenant + other)	Original location of refugee	Knew tenants of refuge unit	Length of stay (hours)	Reason for refuge
7 SE	2 + 1	7 NE			
7 NW	4	10 NW (1 person) 14 SW (1 person) 17 SE (1 person)	no no no	5:30 6:00 7:00	proximity smoke smoke
7 NW	4	7 SW (1 person)	no	3:00	
7 ??	1 + 1	7 NW	yes	1:00	confused
8 SW	approx. 10	17 SW (2 people) 24 NE (1 person) 27 SW (2 person)	no no no	6:00 6:00 8:00	smoke
9 SW	1 + 15	9 SW (1 person) 28 NE (1 person)	yes no	6:00 5:00	invited smoke
9 NE	2 + 1	24 NW	no	5:00	smoke
10 SE	3 + 4	10 SW (3 people) 27 ?? (1 person)	no		smoke
10 SE	5	15 SW (1 person)	no	6:10	smoke
10 NE	8	25 SE (2 people) 25 NE (1 person)	no yes	4:00 5:00	smoke
11 SE	3 + 1	11 NE			
11 SW	1 + 1	11 NW	no	6:00	locked out
12 NE	1 + 6	12 NE (3 people) 12 NW (1 person) 16 SW (2 people)	no	5:00	fainted
12 SW	1 + 1	12 NW			
15 SE	2 + 1	22 SE			
16 SE	2 + 1	16 SE	no	0:30	confused
18 SW	2 + 6	21 SE (2 people)	no	2:00-2:30	smoke
18 NW	1 + 1	18 NE	no	5:00	smoke
20 SW	1 + 2	29 SW	yes	0:10	family
22 NE	4 + 1	22 ??			
23 SE	4	28 NE (1 person)	no	2:00	needed air
23 SE	1 + 2	23 NW	yes	6:00	friends
23 NE	3	17 NE (1 person) 21 NE (1 person)	no	1:00 3:00	smoke
24 SE	2 + 2	24 SE	yes	5:00	smoke
24 NW	2 + 2	24 NW 25 SW	yes no	6:00 2:00	invited smoke
28 SW	1 + 5	21 NE 21 NW			
29 SE	2 + 3	25 NE (2 people) 30 ?? (1 person)	no	5:00-6:00	smoke
29 NE	2 + 2	19 NE	no	2:30	smoke
29 NW	1 + 1	29 NW			
30 SW	1 + 2	30 SW 19 SE			

The majority of people (17 out of 29 or 59%) who gave information on their relationship to the tenant of the rescue unit did not know the tenant who offered them refuge and had to do so because of the smoke. Another four (14%) had to ask strangers for refuge for reasons other than smoke, such as injuries and one did not give a reason for seeking refuge. Of the remaining seven (25%) who moved to be with people they knew, only two did so because of the smoke; the rest were looking for comfort and support from friends and family.

Most people stayed in the unit in which they took refuge until rescue personnel instructed them to safely exit the building. Some of them were permitted to go back to their units to pick up necessities before leaving the building. On average, they spent over 4 hours in the refuge apartment before being allowed to exit the building.

9.8 Occupants with Limitations

The respondents' profiles included in this report provide information on different limitations that the respondents had which could possibly have impeded their evacuation. In some cases, the evacuation scenario of a respondent was affected by that limitation; while in other cases, limitations did not result in any problem during evacuation.

Ten people who had asthma or heart problems remained in their units until they were evacuated using the elevator by rescue personnel between 10:00 and 12:00, depending on the floor. Four pregnant women also waited and were taken down by elevator; one of them, however, indicated that she had tried to use the stairs earlier but had to abandon this attempt because of her condition.

Five people reported having hearing problems, although none of them is completely deaf. Three of them were awoken by the presence of smoke, one by his wife, and one by a phone call from a sister. None of them were impeded in their evacuation by the fact that they were hearing impaired. One man on the 5th floor, south-west quadrant, said he was a very sound sleeper but the smoke woke him up at 5:15. Once awake, he had no difficulty evacuating the building through the staircase at around 7:00, after waiting on his balcony for the smoke to dissipate.

Some other people had specific mobility problems. One lady on the 2nd floor, who used a walker, evacuated using the stairs with the help of rescue personnel around 14:00. A person on the 3rd floor, who was unsteady walking, was able to evacuate alone at 5:10 using the stairs. A woman, who has multiple sclerosis, on the 6th floor also used the stairs at 11:30, with help from friends and rescuers. On the 6th floor, a man, recovering from a lung operation, evacuated using the stairs with his adult daughter at 5:10. A person, who uses a cane, was helped down the stairs by firefighters later in the morning. Finally five people, located on the 17th floor and above, were taken down by police officers using the elevator between 10:00 and 13:00: one with weak legs, one in a wheel chair, one with a broken foot, one using a cane and one using a walker.

9.9 Exit Used

Table 33 lists the doors used by the respondents to exit the building. The majority of respondents to this question (63%) reported using the lobby door and another 29% used the exit leading to the 4 Forest Laneway building. An important number of respondents (48 or 22%) did not specify which exit door they used.

TABLE 33: Exit Used During Evacuation

Exit Location	Frequency	Percent	Valid Percent
Lobby	107	48.9	62.6
To 4 Forest Laneway	49	22.4	28.7
Parking garage	11	5.0	6.4
Back exit	4	1.8	2.3
No answer	48	21.9	-
Total	219	100.0	100.0

9.10 Time to Reach Safety

Figure 6 is a representation of the time at which people finally reached ground level, considered as the area of safety in this study. The majority of them (56%) exited the building between 10:00 and 12:00. One person was not evacuated until 18:00 and another lady from the second floor stayed in her apartment until 13:00 the next day.

Figure 7 shows the cumulative percent of respondents for the time at which they became aware of the situation, the time at which they left their units and the time at which they reached ground level. Not all respondents answered the three questions. Figure 7 represents strictly the cumulative percent of people answering each question. It should be noted that their time approximations are not always accurate.

As shown in Figure 7, between 6:00 and 10:00 approximately half of the respondents had left their units, but do not seem to have left the building right away. It is unlikely that they just lingered in the corridors. There are two scenarios that can explain what most of them did during that time interval. Some of them indicated that they left their units between 5:00 and 6:00 and that time is represented in Figure 7; however, they had to go back to their units as they were unable to exit at that time, generally because of the smoke in the staircases. They evacuated later in the morning, usually between 10:00 and 12:00, with the help of rescue personnel. The other scenario applies to people who left their units but took refuge in another unit, as discussed previously. They were also later evacuated by the officials.

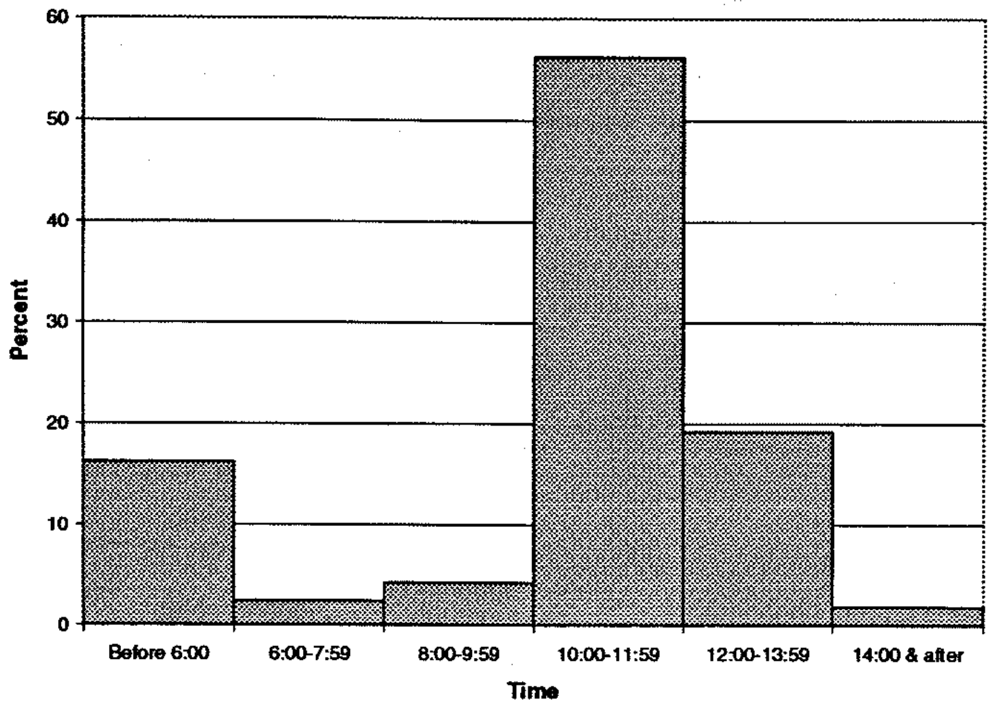

FIGURE 6: Time at Which Occupants Reached Ground Level

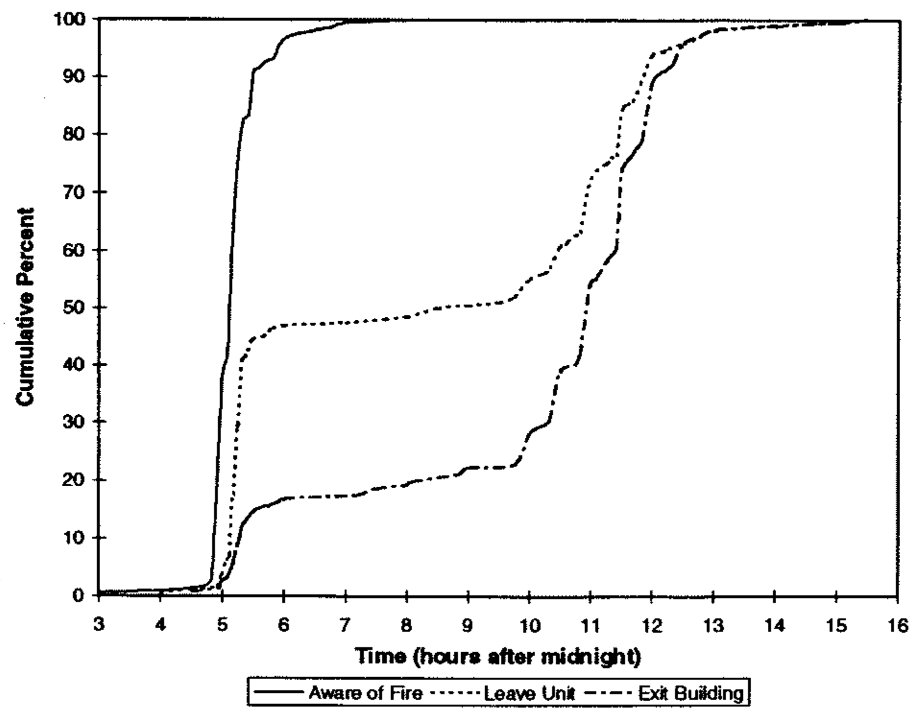

FIGURE 7: Summary Statistics of Evacuation Over Time

9.11 Re-entering the Building

After evacuating, 17 people or 8% of the respondents, consisting of 6 men and 11 women, re-entered the building for a number of reasons. Most of them did that much later in the afternoon, with the knowledge and permission of the police officers or firefighters. They were allowed to get hand bags (7 people), keys (1), medication (4), glasses (1) or pets (1). Three of them went back inside because of the cold. The gender, the age of the respondents or the location of their apartment was not shown to have an effect on whether or not the person would re-enter the building. Statistical analysis did not show that the time at which a person left the apartment had an effect on the likelihood of that person having to re-enter the building ($\chi^2 = 2.63$, DF = 3, $p = 0.45$). None of the people re-entering the building seem to have done so when there was still a risk and when the situation was not under control.

10.0 ALARM AND PUBLIC ANNOUNCEMENTS

The building fire alarm was heard by 164 of the 219 respondents or 75%; 52 or 24% of them did not hear it and three or 1% did not answer the question. All people who heard the alarm were in their apartments at the time. Statistical analysis showed a significant difference between age groups ($\chi^2 = 31.61$, DF = 2, $p = 0.00$). People 65 years old and older were significantly less likely to hear the alarm than younger people. This difference is not significant when comparing respondents 18 to 40 and 41 to 64 years old ($\chi^2 = 1.29$, DF = 1, $p = 0.26$). Statistical analysis showed no significant difference between genders ($\chi^2 = 0.20$, DF = 1, $p = 0.65$). When considering blocks of floors for statistical analysis, a significant difference was found between floors, showing that people on the 6th to the 10th floor were more likely to have heard the alarm ($\chi^2 = 15.86$, DF = 5, $p = 0.01$). Table 34 shows the location of the people who heard the alarm.

TABLE 34: Location of Individuals and Perception of the Building Alarm

Floor	Heard the Alarm	Did Not Hear the Alarm
1 to 4	18	8
5	2	3
6 to 10	30	2
11 to 16	20	14
17 to 21	31	9
22 to 30	63	16
Total	164	52

No statistical evidence was found that would suggest that the quadrant in which people were located could affect their ability to hear the alarm ($\chi^2 = 1.56$, DF = 3, $p = 0.67$). Figure 8 shows the proportion of occupants who did not hear the alarm for each unit. Analysis showed a significant difference between units located in the corners of the building and other units ($\chi^2 = 17.73$, DF = 1, p = 0.00). Occupants of units 03, 04, 09 and 12 were significantly less likely to hear the building alarm; their apartments were situated in the corners of the building.

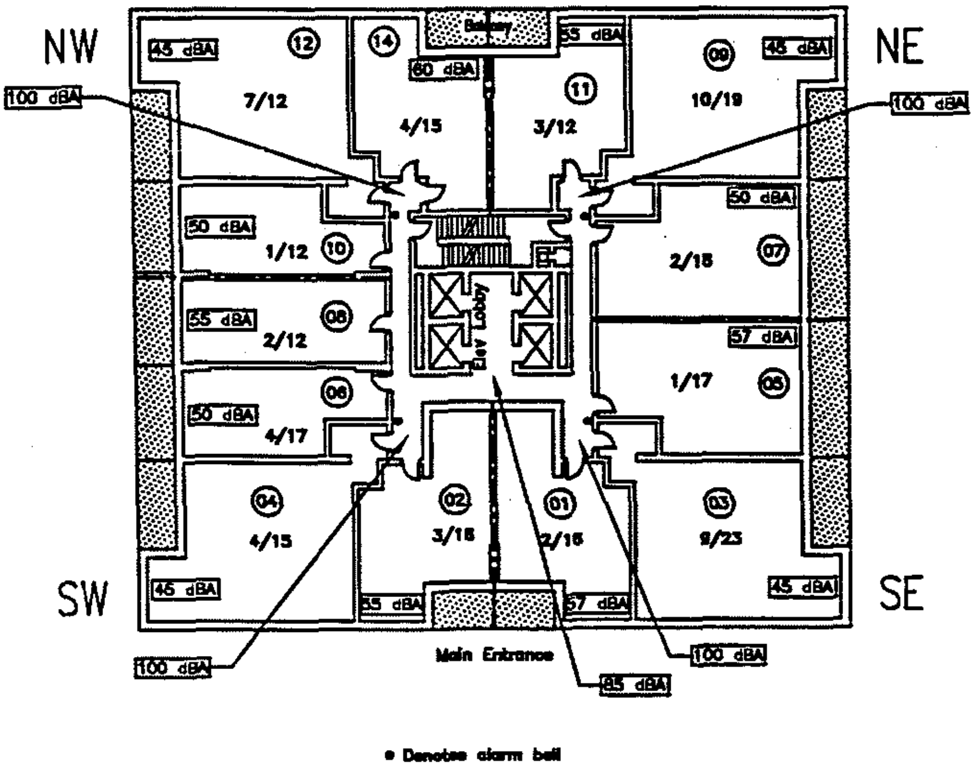

FIGURE 8: Proportion of Occupants Who Did Not Hear the Building Alarm

In the week following the fire, before occupants returned to the building, the OFM did a series of measurements on the sound level of the building fire alarm. Figure 8 shows the sound levels of the alarm in different locations on the 17th floor. In the corridors and elevator lobby, the sound level reached more than 85 dBA. In the bedrooms of some units, however, even with the bedroom door open, the sound level was less than 50 dBA.

The questionnaire asked people to evaluate the volume of the building fire alarm in their apartments, in the corridor and in the staircases. Table 35 shows the results. For the statistical analysis, the *Too Loud* option was not considered since too few people chose that option. Statistical analysis showed no significant difference between the respondents' opinion of the volume of the alarm for different age groups (in apartment: $\chi^2 = 3.89$, DF = 2, p = 0.14; in corridor: $\chi^2 = 2.84$, DF = 2, p = 0.24; in staircase: $\chi^2 = 1.71$, DF = 2, p = 0.42) or between genders (in apartment: $\chi^2 = 2.52$, DF = 2, p = 0.28; in corridor: $\chi^2 = 3.23$, DF = 2, p = 0.20; in staircase: $\chi^2 = 1.31$, DF = 2, p = 0.52). Only five people, four men and one woman between the ages of 26 and 49, suggested that the alarm was too loud in their apartments. All of them lived on the east side of the building: units 03 (3 of them), 07 and 11.

TABLE 35: Sound of the Building Alarm

Volume	In Apartment		In Corridor		In Staircase	
	Frequency	Valid %	Frequency	Valid %	Frequency	Valid %
Not loud enough	77	43	34	23	30	34
Loud enough	97	54	98	65	55	62
Too loud	5	3	18	12	4	4
No answer	40	-	69	-	130	-
Total	219	100	219	100	219	100

Statistical analysis showed that there was a significant difference between different floor blocks ($\chi^2 = 17.06$, DF = 5, p = 0.00). People above the 16th floor were more likely to think that the alarm was not loud enough in their apartments. After statistical analysis, no significant difference of opinion on the volume of the alarm in the corridor was found between people from different floors ($\chi^2 = 8.95$, DF = 5, p = 0.11). Statistical analysis did not show that the location of the apartment in terms of quadrants had an effect on the respondent's opinion of the volume of the alarm, either in the apartment ($\chi^2 = 7.59$, DF = 6, p = 0.27) or in the corridor ($\chi^2 = 9.13$, DF = 6, p = 0.17).

10.1 Alarm Stopped

Only 76 people, 41% of respondents to this question, heard the alarm stop and at that time 63 of them, or 83%, were in their apartments. Four others (5%) were in the staircase, two (3%) were in the corridor, one was in the lobby, one was in a neighbour's unit and the rest do not know when it stopped or did not answer the question. None of the respondents on their balconies heard the alarm stop.

No statistical evidence was found that would suggest a significant difference between people of different floors ($\chi^2 = 9.22$, DF = 5, p = 0.10), between genders ($\chi^2 = 0.12$, DF = 1, p = 0.73) or between age groups ($\chi^2 = 2.74$, DF = 2, p = 0.25). Forty-four percent of people 18 to 40 years old heard the alarm stop, however, compared to only 27% of residents 65 years old and over.

Respondents do not agree on the time at which the alarm stopped. Table 36 illustrates this divergence. The three people who said they thought the alarm stopped after 8:00 also said that they were not sure of the time. Overall, only 32% of people who gave an approximate time at which the alarm stopped were sure of the accuracy of that time.

TABLE 36: Time at Which the Building Alarm Stopped on Each Floor

Floor	Time						Total
	5:00-5:29	5:30-5:59	6:00-6:59	7:00-7:59	8:00+	Not Sure	
2						3	3
3						1	1
4	1						1
5						3	3
6			1			3	4
7			1			1	2
8		2				2	4
9			1			2	3
10	1	3					4
11	1				1	2	4
12					1	1	2
14			1			2	3
15							0
16	1						1
17		1				1	2
18					1		1
19			1			1	2
20			1		1	1	3
21		3				1	4
22	1	3					4
23							0
24		2				2	4
25	2		1	1		1	5
26							0
27				1		1	2
28		1			1		2
29	1			1	2		4
30				1		2	3
Total	8	15	7	4	7	30	71
Valid %	20	37	17	10	17	-	100

In addition to giving the time at which they heard the building alarm stop, the questionnaire asked people how sure they were of that time's accuracy. Figure 9 shows by each bar the total number of people who believe the alarm stopped during that time period, but also indicates the degree of precision of the time given. The height of the bar represents the total number of respondents who gave that time and each sub-section is illustrated in full (e.g., between 5:00 and 5:29, 8 people heard the alarm stop: 3 are sure of that time, 3 remember vaguely and 2 are not sure).

Twelve people said they were sure of the time at which the alarm stopped, but the times they gave varied between 5:00 and 8:00. It is possible that the alarm did not stop at the same time in different sections of the building. In summary, for the respondents who are sure of their reported time, one person heard the alarm stop at 5:00 on the 11th floor; one heard it stop at 5:20 on the 16th floor; according to one respondent it stopped at 5:25 on the 29th floor; according to three people from the 17th, 21st and 24th floor it stopped at 5:30; two people, from the 21st and 22nd floor heard it stop at 5:40; one reported 5:45 on the 21st floor; two said it was at 6:00 on the 14th and the 19th; and finally a resident of the 20th floor said the alarm stopped at 6:30 and an 11th floor resident believes it stopped at 8:00.

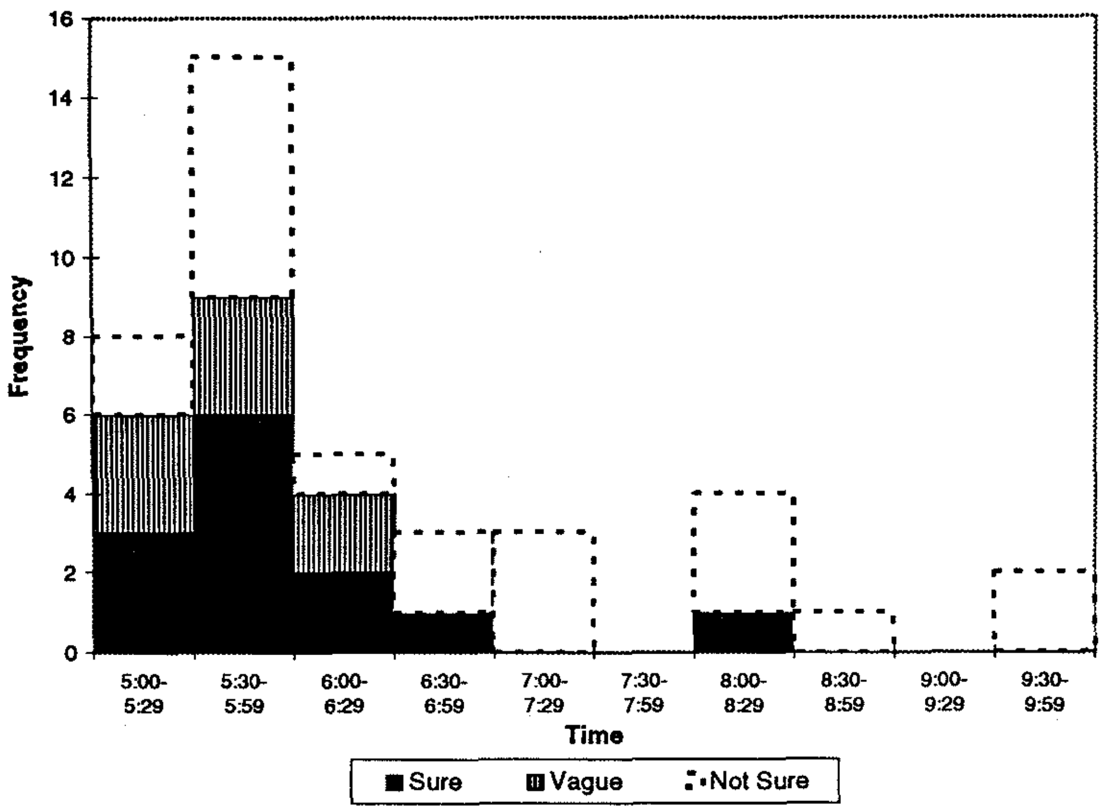

FIGURE 9: Time at Which the Building Alarm Stopped

10.2 Smoke Alarms

A battery operated smoke alarm was present in the apartments of 201 of the respondents or 93% of people who answered this question. Only 28 or 15% of the battery operated smoke alarms were activated. Four of these 28 respondents (14%) decided to remove the battery from their alarm. Table 37 shows the state of the battery operated smoke alarms for residents in each quadrant. Provided the smoke alarms were operational, this is a good indicator of the smoke density in these areas. It appears that more smoke detectors were set off on the upper floors: 20% for the 22nd to the 30th floor compared to 12% for the 2nd to the 21st floor. Statistical analysis showed a significant difference between quadrants ($\chi^2 = 9.29$, DF = 3, p = 0.03). A greater number of smoke alarms were activated in the north-east quadrant which corresponds to the fire area quadrant. Analysis showed no significant difference between age groups for the likelihood that their battery operated smoke alarm would be activated ($\chi^2 = 0.27$, DF = 2, p = 0.87).

TABLE 37: Percentage of Activated Smoke Alarms

Floor	Apartment Quadrant				Total
	NE	NW	SE	SW	
1 to 4	1				1
5				2	2
6 to 10			1	1	2
11 to 16	2	1	2		5
17 to 21	1		3		4
22 to 30	7	1	2	4	14
Total	11	2	8	7	28

10.3 P.A. Messages

Only 10 of the respondents or 5% heard messages from the P.A. system. Five of them (50%) understood they had to stay in their units, one of them understood that he or she should put a towel under the door but the four others (40%) said that the messages were unclear and that they could not understand them. At the time of hearing the P.A. messages, seven of the ten people were in their apartments, one was on the balcony, one was in the hall and one was outside. Since so few people heard the messages, however, it is not possible to obtain a valid comparison between groups. Table 38 provides details on the situation of each person who heard the P.A. system messages. Statistical analysis did not show that people who had heard the building fire alarm were more likely to hear the P.A. system messages ($\chi^2 = 3.03$, DF = 1, p = 0.08)

Twenty-seven of the respondents (12%) heard the firefighters' bullhorn messages, however, the messages were unclear for 21 of them (78%). Four people (15%) understood that they should wait to be rescued, one understood that he or she was to use the staircase and one heard 'Wake up! Fire in the building!' Seven people (26%) were in their units when they heard the message and 19 (70%) were on their balconies. The other person did not indicate where he or she was. Statistical analysis found no significant difference between floors or quadrants (floor blocks: $\chi^2 = 3.94$, DF = 5, p = 0.56; quadrants: $\chi^2 = 1.97$, DF = 3, p = 0.58). This indicates that the location of the apartment in terms of floor level and quadrant had no significant effect on whether or not the resident could hear the bullhorn messages. Surprisingly enough, 44% of people who heard the message were situated between the 22nd and 30th floors and 24% were between the 6th and 10th floors. This is quite far from the source considering messages were coming from firefighters at ground level. Furthermore, no significant difference was found between genders ($\chi^2 = 1.04$, DF = 1, p = 0.31) or age groups ($\chi^2 = 2.22$, DF = 2, p = 0.33).

TABLE 38: Situation of Persons Who Heard P.A. System Messages

Floor of Unit	Quadrant	Location in Unit at Time of Message	Content of Message
2	NE	Apartment	No answer
6	SW	Apartment	Stay in
6	SW	Apartment	Stay in
7	NW	No answer	Message unclear
7	NW	Apartment	Put towel
11	NW	Apartment	Message unclear
15	NW	Apartment	Say in
17	SE	No answer	No answer
24	NW	Hall	Stay in
25	SW	Balcony	Stay in

11.0 SMOKE CONDITION

A series of questions was asked about the smoke conditions in the occupant's unit as well as while the person was evacuating the building. It should be noted that all occupants of the 5th floor reported smoke in the staircase, in the corridor and in their unit.

11.1 Smoke and Heat in Units

Smoke entered the units of 157 of the occupants or 76% of respondents to this question. In 102 of the cases (65% of units with smoke), it entered around the door; 21 persons or 13% observed smoke entering through the ventilation system openings and one person said it was coming in through the window. The remaining 21% of the people were not sure how it entered their units. Figure 10 shows that, in the apartments where smoke was present, it entered before 5:20 in more than 60% of cases. The cumulative percent represents the number of people who saw smoke in their units before a given time, as a fraction of the people who saw smoke in their units over the complete duration of the fire.

Figure 11 is a good indication of the smoke condition on each floor. For each floor it illustrates the percentage of people who declared that smoke entered their apartments. It is clear from Figure 11 that there was smoke present in a larger percentage of the apartments on the higher floors than on the lower floors, with the exception of the 5th floor (where the fire originated) and the 6th floor (situated directly above). Statistical analysis also showed a significant difference among floors. The higher the respondents were, the more likely these people were to see smoke in their apartments ($\chi^2 = 61.24$, DF = 5, p = 0.00).

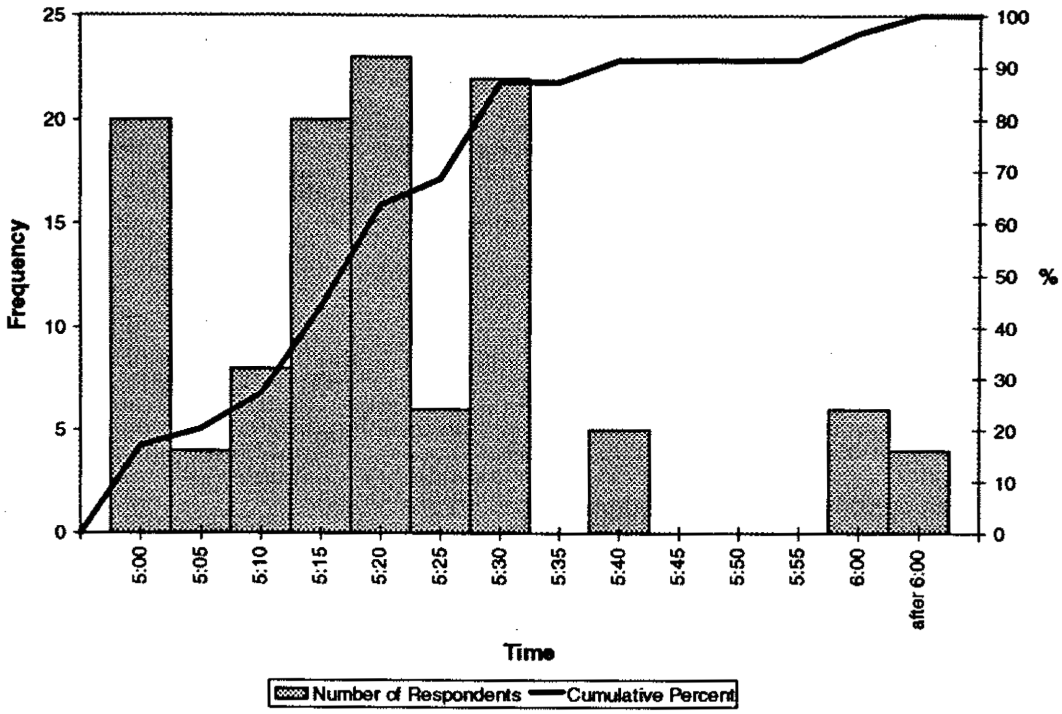

FIGURE 10: Presence of Smoke in Apartments Over Time

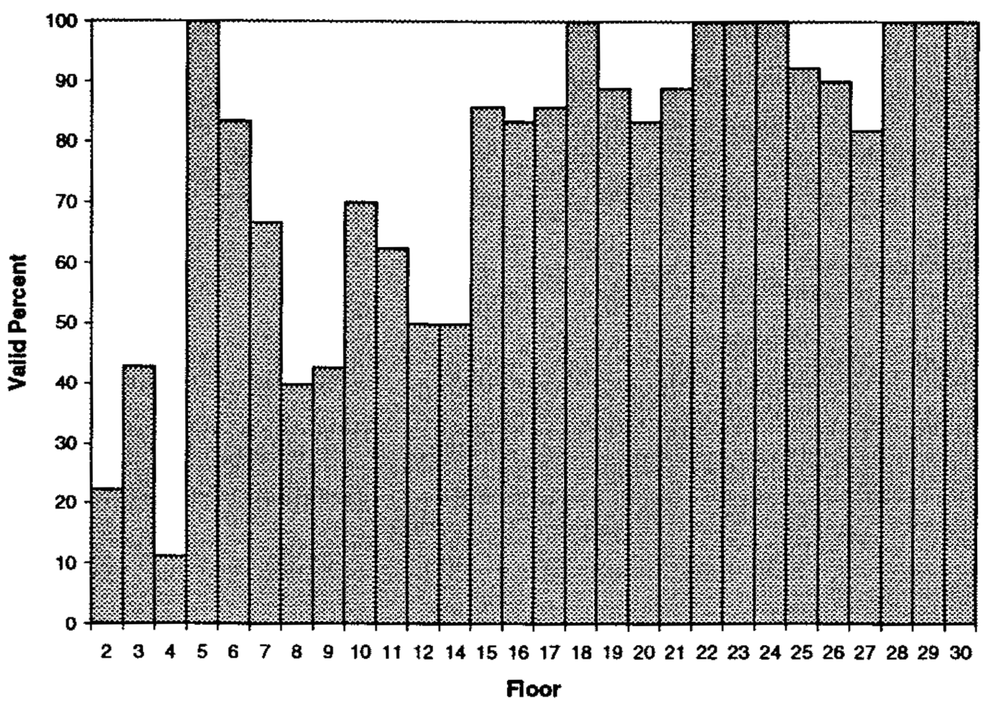

FIGURE 11: Presence of Smoke in Apartments on Each Floor

Statistical analysis showed a significant difference in the appearance of smoke in the units from one quadrant to the other ($\chi^2 = 8.86$, DF = 3, p = 0.03). People in the north-east quadrant (quadrant where the fire occurred) were more likely to see smoke in their units. People in the north-west and south-east quadrants were also more likely to see smoke in their units than people in the south-west quadrant. Statistical analysis did not show that people living on lower floors or closer to where the fire occurred were significantly more likely to see smoke at an earlier time in their apartments than people living on upper floors ($\chi^2 = 8.16$, DF = 9, p = 0.52). Occupants took the measures described in Table 39 to limit the infiltration of smoke.

TABLE 39: Actions Taken to Limit the Entry of Smoke in Unit

Action	Frequency	Percent	Valid Percent
Put wet towel	70	32.0	54.7
Block passage	14	6.4	10.9
Go on balcony	10	4.6	7.8
Leave apartment	7	3.2	5.5
Open window	5	2.3	3.9
Close door	2	0.9	1.6
Nothing	20	9.1	15.6
No smoke entered	51	23.3	-
No answer	40	18.3	-
Total	219	100.0	100.0

Only eight respondents said that they encountered heat in their units. Three of them were situated on the 5th floor (west side), two were on the 6th floor (east side) and one was on the 7th floor (east side). Two more reported heat on the 28th floor.

11.2 Smoke in Corridors

In the corridor, 165 people (81% of respondents to this question) observed smoke. The colour of the smoke was reported by 149 respondent, 57% of them observed grey smoke, according to 26% it was black and 17% saw a mixture of grey and black. Figure 12 shows the frequency of people observing smoke in the corridor over time. More than 50% of the people who saw smoke in the corridor did so before 5:20 and the latest smoke sighting reported was at 7:15. Respondents did not specify if smoke was still present at the time of evacuation of those who did not leave the building until later in the morning with the rescue personnel.

Of the 126 people (58% of respondents) who reported the time at which they saw smoke in the corridor, 113 or 90% said they saw it between 5:00 and 5:44 and 13 or 10% said they saw it at 5:45 or later. Statistical analysis showed a significant difference between blocks of floors regarding the time at which respondents saw smoke in the corridor ($\chi^2 = 18.33$, DF = 6, p = 0.01). People living between the 6th and the 10th floors inclusive were more likely to see smoke between 5:00 and 5:14 in the corridor, which is earlier than people living on upper floors. People living between the 22nd and the 30th floors were more likely to see the smoke between 5:15 and 5:30 and people on the 11th to the 16th floors were more likely to see smoke between 5:30 and 5:44. People on the 17th to the 21st floor were almost equally distributed among the three time intervals, although 85% of them saw smoke before 5:30.

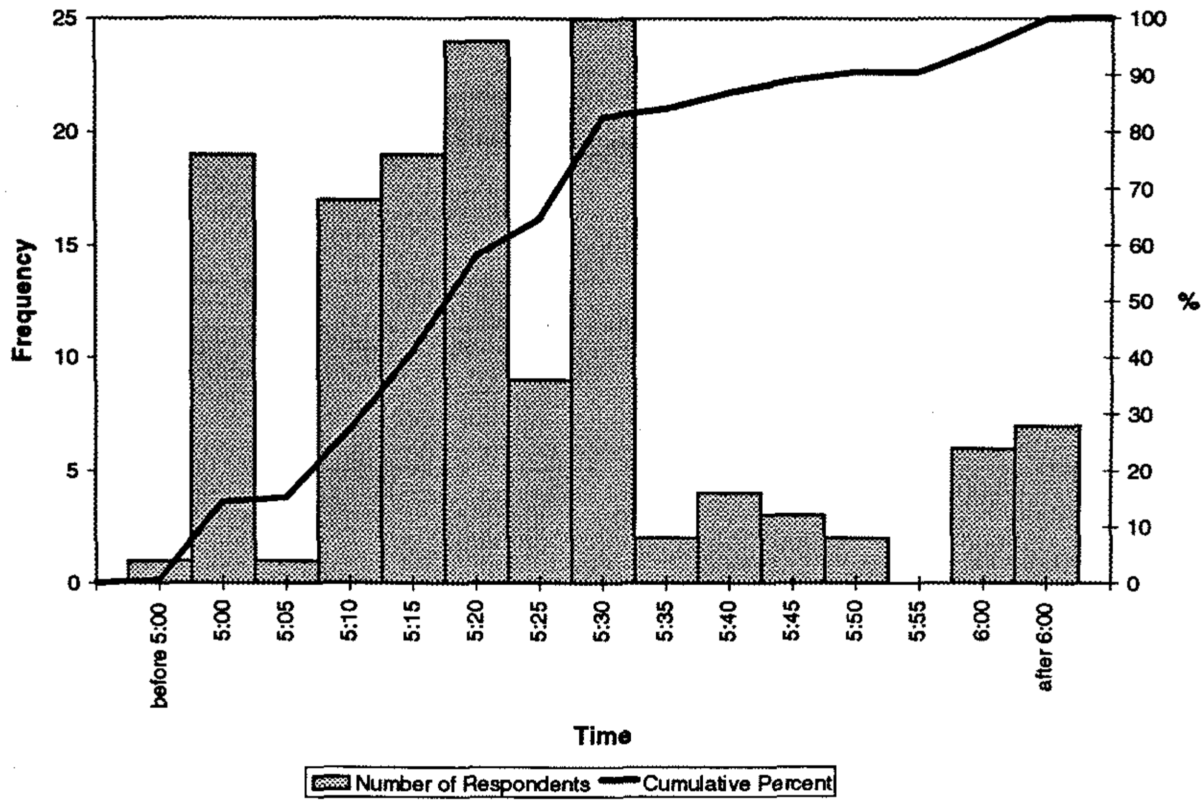

FIGURE 12: Presence of Smoke in Corridors Over Time

Statistical analysis showed a significant difference between floor blocks. The higher the respondent was, the more likely this person was to see smoke in the corridor ($\chi^2 = 55.41$, DF = 5, p = 0.00) with the exception of the 5th floor, where all respondents saw smoke. Figure 13 shows the frequency of respondents noticing smoke in the corridors as a function of the floor on which they were located. The floors, listed in Figure 13, refer to the floor on which each respondent saw the smoke, as opposed to the floor on which the respondent lives. In most cases, these are the same but, in some instances, respondents found refuge on another floor and saw smoke there. Statistical analysis showed no significant difference between the quadrants for the likelihood of seeing smoke in the corridors ($\chi^2 = 2.24$, DF = 3, p = 0.52). Of the 131 people who saw smoke in the corridors and gave an approximation of how many feet they could see in the smoke, 69% reported being able to see less than 10 feet.

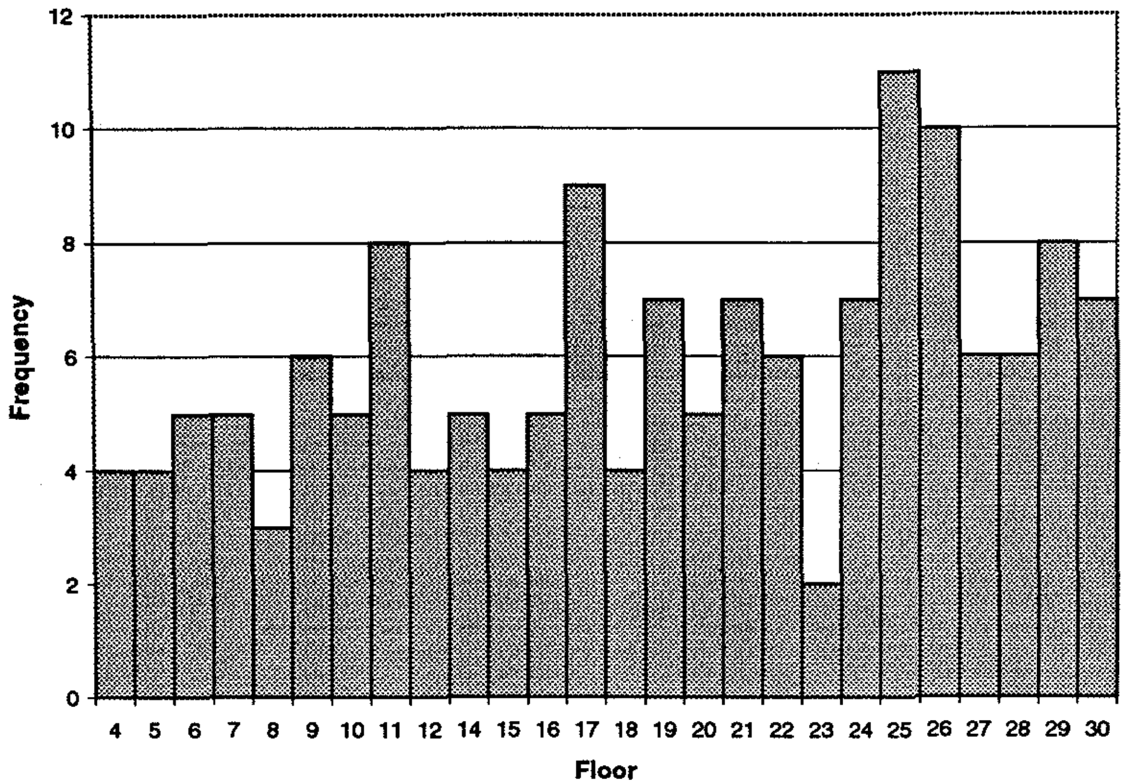

FIGURE 13: Presence of Smoke in Corridors of Each Floor

11.3 Smoke and Heat in Staircases

In the staircases, 99 people, or 75% of 132 respondents who answered this question, said that they saw smoke. The smoke was grey for 37% of them, black for 39%, or a combination of grey and black for 24%. As shown in Figure 14, it was between 5:10 and 5:30 that smoke was encountered by 80% of the 87 people who reported seeing smoke in the staircases and gave the time at which they observed it. This period corresponds to the time at which most people trying to evacuate left their units looking for a way out of the building. Because of the presence of smoke in the staircases, many of them were forced back into their apartments or into someone else's unit. Of the 82 respondents who provided information on how far they could see through the smoke, 74% reported being able to see less than 10 feet.

Statistical analysis showed a significant difference between floor blocks. Respondents living above the 16th floor were more likely to see smoke in the staircases ($\chi^2 = 55.27$, DF = 5, p = 0.00). Only 3 out of 64, or 5% of respondents, using the stairs on the 17th floor and above did not see any smoke, compared to 25% for the 6th to the 16th floor and 83% for the 4th floor and below. It should be noted that the statistical analysis uses the floor on which the respondent lives for comparison, rather than the specific floor on which smoke was seen.

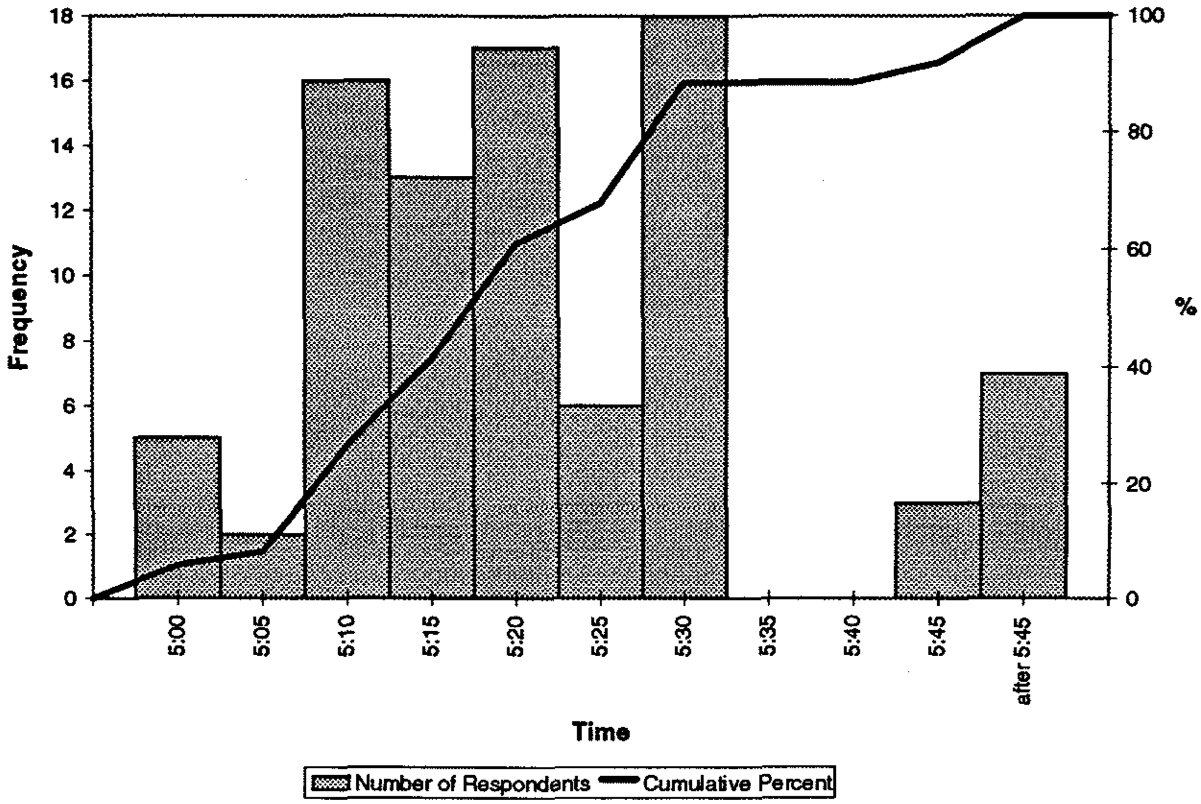

FIGURE 14: Presence of Smoke in Staircases

All the 30 people living on the 5th floor or above who tried to use the Fire Staircase encountered smoke in that staircase. Of the other 46 people (61%) who used the Other Staircase, 42 or 91% saw smoke. Four people did not see any smoke in the stairs. One was coming from the 18th floor at 5:30 and another left the 28th floor at 5:15. Both of them smelled smoke on their way down, at the 11th and 22nd floor levels, respectively, and decided to return to their units. A 7th floor resident left his unit 5 minutes after hearing the alarm and made his way to the ground level without encountering any smoke. Finally an occupant from the 6th floor went down the stairs at 5:20, could smell smoke, but was able to reach ground level and exit the building with no problem. All four of them were using the Other Staircase. Table 40 shows the number of people in each staircase who saw smoke while using the stairs, starting on the 5th floor and above. Expected values are shown in brackets. The analysis did not show that the staircases were significantly different ($\chi^2 = 2.82$, DF = 1, p = 0.09) in terms of the likelihood of people seeing smoke. The number of people who did not see smoke in the staircase, however, is insufficient to produce a valid statistical analysis.

TABLE 40: Frequency of People Seeing Smoke in the Stairs Above 4th Floor

Staircase	Saw Smoke		Did Not See Smoke	
Fire Staircase	30	*(28.4)*	0	*(1.6)*
Other Staircase	42	*(43.6)*	4	*(2.4)*
Total	72	-	4	-

During the evacuation, 12 people encountered heat. It forced three of them to turn back. One of them was a 7th floor resident who tried using the Fire Staircase around 5:30 but had to turn back because of the smoke and heat. The other two were on the 19th floor. One tried to use the Fire Staircase also around 5:30 but after going down a few flights of stairs had to turn back up because of the smoke and heat. The other one reported that the door leading to the Fire Staircase was too hot and the group had to return to their unit.

11.4 Lights and Exit Signs

The state of the lights in the stairs and corridors is described in Table 41. Respondents have diverging ideas on where the lights were on or off. Analysis shows a significant difference between floors. In general, people living between the 5th and the 16th floor were more likely to notice that the lights were off in the corridors while people on the 17th to the 30th floors were more likely to say that the lights were on ($\chi^2 = 52.67$, DF = 5, p = 0.00). A few people on the east and west sides commented on the absence of light in the corridors between the 15th and the 19th floors. Someone mentioned the absence of lights on the 17th floor. Statistical analysis showed a significant difference between quadrants. People living on the west side of the building were more likely to notice the absence of lights ($\chi^2 = 13.63$, DF = 3, p = 0.00). The difference was principally between the south-west and the south-east quadrants of the building.

TABLE 41: State of the Lights in Stairs and Corridors

Location of the Lights	State of the Lights	Frequency	Percent	Valid Percent
CORRIDORS	On	146	66.7	81.5
	Off	33	15.1	18.5
	No answer	40	18.3	-
STAIRS	On	77	35.2	65.3
	Off	41	18.7	34.7
	No answer	101	46.1	-

Some of residents agree on a few things concerning the state of lights in the staircases. After using the stairs, 2 people reported that the lights were off between the

16th and the 19th floors and 2 other people reported the absence of lights, one above the 15th floor and one specifically on the 16th floor. Analysis showed a significant difference between floors. People living between the 5th and the 16th floors reported, in a much greater proportion than on other floors, that the lights were off in the staircase (χ^2 = 35.56, DF = 5, p = 0.00). All occupants of the 5th floor reported an absence of lights.

Thirty-nine or 23% of the 168 respondents to this question noticed the exit signs located in the staircases and corridors. Analysis showed no difference between genders (χ^2 = 0.37, DF = 1, p = 0.54) or between age groups for the likelihood of noticing the exit signs (χ^2 = 0.19, DF = 2, p = 0.91).

12.0 RESCUE EFFORT

Both firefighters and police officers were present at the scene of the fire. Firefighters arrived on the scene at 5:14 to discover Apartment 509 engulfed in fire.

Respondents were not always specific when referring to rescue personnel. The statistics comparing the actions of firefighters and police officers could be somewhat affected by this lack of precision.

12.1 Help from Rescue Personnel and Others

During the evacuation, police officers and firefighters provided help to numerous residents of the building. Table 42 shows a distribution of the groups of rescuers providing help to the respondents during the evacuation.

TABLE 42: Help to Evacuate

Source of help	Frequency	Percent
Police Officers	112	51.1
Firefighters	36	16.4
Police Officers and Firefighters	19	8.7
Other occupants	2	0.9
Someone from your unit	1	0.5
Don't know	6	2.7
No one	26	11.9
No answer	17	7.8
Total	219	100.0

Analysis showed no significant difference between genders (χ^2 = 2.27, DF = 1, p = 0.13) or between age groups (χ^2 = 3.87, DF = 2, p = 0.14); analysis, however, showed that people above the 21st floor were significantly more likely to receive help from rescue personnel during their evacuation than people on lower floors ($\chi^2 = 47.66$, DF = 5, p = 0.00), when comparing blocks of floors for help from officials versus no help. There appears to be a parallel between the use of the stairs and a reduced need for help from rescue personnel: floors below the 6th and between the 17th and the 21st have a higher likelihood of using the stairs and a lower likelihood of receiving help, while above the 21st floor, there is a lower percentage of people using the stairs but a higher percentage of them receiving help from the rescuers. People who were not alone in their units were not significantly different from those who were ($\chi^2 = 1.16$, DF = 1, p = 0.20) and all were equally likely to receive help from the rescue personnel to evacuate.

12.2 Evacuation of the Building by Rescue Personnel

Once the fire was mastered and the danger removed, rescue personnel proceeded to the orderly evacuation of all residents who were still in their units. The manner in which some of these people were evacuated is discussed in Section 9. It appears from occupants' responses that the evacuation started around 10:00. At 6:00, 17% of respondents had evacuated the building, generally on their own. Only 6% evacuated between 6:00 and 10:00. All the others were evacuated by rescue personnel starting around 10:00. The time at which people were asked to evacuate by rescue personnel varies a great deal, as shown in Table 43.

Statistical analysis showed a significant difference between floors ($\chi^2 = 39.72$, DF = 5, p = 0.00). People living on the 22nd floor and above were significantly more likely to wait in their units until they were asked to evacuate by rescue personnel. The firefighters asked 85 respondents (39%) to evacuate, the police officers asked another 76 people (35%) and 53 (24%) of the respondents left on their own initiative. Analysis showed no difference among the residents of the four quadrants ($\chi^2 = 2.56$, DF = 3, p = 0.46).

TABLE 43: Time at Which People Were Asked to Evacuate by Rescue Personnel

Time	Frequency	Percent	Valid Percent
Before 5:00	1	0.5	0.8
5:00 - 7:59	5	2.3	4.0
8:00 - 9:59	9	4.1	7.3
10:00 - 10:59	27	12.3	21.8
11:00 - 11:59	56	25.6	45.2
12:00 - 12:59	23	10.5	18.5
13:00 and after	3	1.4	2.4
Not sure	5	2.3	-
No answer	90	41.1	-
Total	219	100.0	100.0

The rescue personnel instructed 13 people (6%) to evacuate by the stairs; 27 (12%) were told to evacuate by the elevator, 27 (12%) were told to wait and 16 (7%)

agreed to close their door and follow them. The remaining 62% either did not evacuate with the rescue personnel or did not report receiving any instructions. Analysis showed that there was a significant difference between people who had seen smoke in the corridors and those who had not ($\chi^2 = 17.70$, DF = 1, p = 0.00). People who saw smoke in the corridors were more likely to wait for the rescue personnel to evacuate the building.

When evacuating, 66 people or 37% of respondents to this question said that they encountered at least one firefighter in the corridors and 29 or 13% said they encountered at least one firefighter in the staircase. Analysis did not show that the number of people encountering firefighters in the corridors varied significantly from one floor to the other ($\chi^2 = 9.89$, DF = 5, p = 0.08). Statistical analysis showed, however, a significant difference among quadrants. It appears that people living on the west side were more likely to encounter firefighters in the corridors ($\chi^2 = 10.71$, DF = 3, p = 0.01). As for the staircases, analysis showed that people between the 5th and the 10th floors were significantly more likely to encounter firefighters in the stairs ($\chi^2 = 31.67$, DF = 5, p = 0.00) and analysis also showed a significant difference among quadrants ($\chi^2 = 12.42$, DF = 3, p = 0.01). People living on the west side of the building, especially in the north-west quadrant, were more likely to encounter firefighters in the stairs.

The firefighting equipment impeded the evacuation movement of six respondents (3%), five of them in the stairs and one in the corridors, all between the 3rd and 5th floors.

12.3 Feelings During the Event

Table 44 shows the feelings experienced by the respondents during the fire emergency situation. A majority of the respondents (73%) mentioned feeling *Anxious but in control* during the whole event. Ten percent felt *Panicky and unable to think clearly*, 8% felt *Not very concerned* and another 8% felt *Unable to decide what to do*. Only four of the respondents did not answer this question.

TABLE 44: Feelings During Fire Emergency Situation

Feeling	Males		Females		Total	
	Freq.	%	Freq.	%	Freq.	%
Anxious, but in control	71	32.4	88	40.2	159	72.6
Panicky and unable to think clearly	8	3.6	13	5.9	21	9.6
Not very concerned	13	5.9	5	2.3	18	8.2
Unable to decide what to do	5	2.3	12	5.5	17	7.8
No answer	1	0.5	3	1.4	4	1.8
Total	98	44.7	121	55.3	219	100.0

The majority of males and females (74% in both cases) reported feeling *Anxious but in control*. Statistical analysis showed there was a significant gender-based difference with respect to the feelings experienced during this fire ($\chi^2 = 7..47$, DF = 3, p = 0.058). Women were more likely to report being *Unable to decide what to do* or *Panicky and unable to think clearly,* while men were more likely to say they were *Not very concerned.*

Analysis did not show any significant difference between age groups ($\chi^2 = 7.15$, DF = 6, p = 0.31), however, in the 18-40 age group, 14% of respondents felt *Panicky and unable to think clearly* while 4% of the 41-64 age group and 5% of the 65+ age group experienced similar feelings. Statistical analysis did not show that the occupation of the respondent ($\chi^2 = 12.15$, DF = 12, p = 0.43) or the presence of another person in the apartment at the time of the fire ($\chi^2 = 4.70$, DF = 3, p = 0.20) had an effect on occupant's feelings during the event.

There is no correlation between the floor on which residents lived and the way they felt during the fire ($r = 0.05$, $p = 0.40$), however, a higher proportion of respondents below the 5th floor felt *Not very concerned* (23%) compared to the other floors; the number was always 10% or less for floors above the 5th floor. Regardless of the floor, a majority of people felt *Anxious but in control.* No significant difference was found among the different quadrants ($\chi^2 = 3.18$, DF = 9, p = 0.96) but more information would be needed to obtain a valid conclusion. The results, however, seem to indicate that all quadrants were almost identical when it comes to the way people felt.

Statistical analysis showed no significant difference between people who had previous information on actions to take in a fire situation and people who did not ($\chi^2 = 4.89$, DF = 3, p = 0.18). People with no information were slightly more likely to feel *Panicky and unable to think clearly* (17% versus 9% for those with information) or *Unable to decide what to do* (14% versus 7%). The majority of people, however, felt *Anxious but in control* (76% of people with information and 60% of people without previous information).

Statistical analysis showed a significant difference between people who were aware of the building evacuation procedure and people who were not ($\chi^2 = 12.58$, DF = 3, p = 0.01). People who were not aware of the procedure were significantly more likely to feel *Panicky and unable to think clearly* (14%) or *Unable to decide what to do* (10%) even though the majority of them felt *Anxious but in control* (68%). People familiar with the procedure generally felt *Anxious but in control* (87%). Statistical analysis did not show a difference between people who had experienced a fire in the past and people who had not ($\chi^2 = 4.28$, DF = 3, p = 0.23).

After this experience, 41 or 19% of respondents mentioned seeking assistance to deal with the emotional stress of the event and turned to different sources. Eleven of them consulted a psychologist or psychiatrist, 14 saw a medical doctor and one of them talked to a priest or spiritual counsellor. Finally, 15 of the respondents obtained help from other people, mostly friends or family.

Statistical analysis did not show that people of different genders ($\chi^2 = 2.26$, DF = 1, p = 0.13), age groups ($\chi^2 = 3.75$, DF = 2, p = 0.15) or with different occupations ($\chi^2 = 3.80$, DF = 4, p = 0.43) were significantly different concerning the likelihood of seeking assistance. Residents of different floors or quadrants were not more likely to seek assistance (floor blocks: $\chi^2 = 4.63$, DF = 5, p = 0.46; quadrants: $\chi^2 = 5.26$, DF = 3, p = 0.15). The way the respondent felt during the situation did not correspond either to a significant difference in the likelihood of seeking assistance ($\chi^2 = 6.11$, DF = 3, p = 0.11); however, 29% of people feeling *Panicky and unable to think clearly* decided to seek assistance after the fire, compared to 18% of people feeling *Unable to decide what to do* and 15% of people feeling *Anxious but in control.* None of the respondents feeling *Not very concerned* had to seek help after the event.

13.0 DISCUSSION

The data analyses produced a number of interesting findings. This section of the report summarizes the results that emerged as most important in explaining human behaviour during this fire.

Four major findings have been identified. First, the characteristics of occupants who were in the building at the time of the fire proved to be significant. The gender, occupation, limitations, language spoken and age of the occupants in terms or how they perceived and reacted to this event were all included in these characteristics. Secondly, the location of the occupant in the building at the time of the fire appeared as an important factor. The floor and the quadrant in which the occupant was located can explain some of the occupant's reactions. Thirdly, the smoke condition in the building was responsible for the behaviour of a number of the occupants. Many decisions were made in relation to the presence or absence of smoke in the apartment, corridor or stairs. Finally, the time to start determined the success or failure of an attempt to evacuate. The occupants who started their evacuation very quickly, regardless of the floor, managed to reach safety without problem while the occupants who delayed their evacuation were faced with serious smoke conditions and often had to turn back or take refuge in a neighbour's apartment. These major findings are discussed in detail.

13.1 Characteristics of Occupants

The total number of questionnaires returned represents 54% of all the units in the building from which answers could be expected. In this sample, all floors, except the first floor, are represented. Both men and women and people from each age group were present in each floor block.

When comparing men and women's responses to the questionnaire, the results show that there are few differences in their choice of actions and in their perception of the situation. One important aspect where they differ is in terms of whether or not they were familiar with the building evacuation procedure. It appears that a lower percentage of women were aware of the evacuation procedure. Since a relation has been found between the awareness of evacuation procedures and the feeling respondents experienced during the event, it is not surprising that a higher percentage of women felt *Unable to decide what to do* or *Panicky and unable to think;* whereas men were more likely to feel *Not very concerned.* Initially, women were also more likely to take the situation seriously, although it had no significant influence on the choice of first action for occupants of either gender.

The occupation of the respondents was related to a number of differences. It appears that people with different occupations had significantly different access to general information on fire safety. A much higher percentage (60%) of not employed people had not received any previous information on fire safety, while only 17% of working adults were in the same position. People with different types of occupation also had a tendency to take different first actions. *Professionals* were more likely to *Wait*, the majority of *Support Staff* decided to *Investigate* and *Retired* people were more likely to *Protect*. For all types of occupation, however, there was always a majority of people who started by *Investigating*.

The presence of another person in the apartment at the time of initial awareness was not shown to be an influential factor on the behaviour of the respondent. The only noticeable difference was found in the first action. None of the people, who were alone in a unit, initially decided to *Alert*, while 12% of people with another person in the unit said their first action was to *Alert*.

People having limitations were not found to be different in any significant way from people with no limitation; that is, it was not shown that their limitations directly affected their actions or perceptions of the situation. This must be carefully examined since many of the people with limitations were people in the 65+ age group and, as discussed later, people from that age group were shown to behave in significantly different ways. Furthermore, when comparing individuals with limitations and those without, only the individuals reporting specific limitations could be considered. Since only 30 of the 219 respondents reported having limitations and the limitations were diverse, some of the analyses could not be completed because of the small number of subjects.

A significant number of aspects were shown to be linked to the age of the occupant. People aged 65 and over, who represented 20% of the respondents, were especially different from younger respondents. Right from the beginning of the situation, they were different in that they were more likely than others to be told about the problem rather than to notice the building fire alarm or the presence of smoke. Since it has been shown that people who were told about the situation were more likely to realize there was a problem at a later time than those hearing the alarm or noticing the smoke, it is not surprising that people in this age group also took longer to understand that there was a problem. This tendency towards late awareness could also explain why they were significantly different from younger residents in a number of other ways.

Analysis showed that people who were aware of the problem earlier also left their units earlier. Since residents aged 65 and over tended to become aware of the problem later than others, they also had a tendency to leave their apartments later in the day.

When people in the 65 and over age group decided to stay in their units, they were more likely to take that decision because they thought it was safer inside the unit rather than mentioning the presence of smoke in the corridors and staircases as a reason. Since 19% of the older occupants were living below the 5th floor and there was substantially less smoke on these floors, it explains, in part, why some of them were not prevented from leaving because of the smoke.

While staying in their apartments, people aged 65 and over were significantly less likely to go out on their balconies, many of them mentioning that it was very cold outside on that January morning (-8°C). They were also more likely than younger occupants to *Seek Information* in one way or another.

Of the occupants aged 65 and over who decided to exit the building using the stairs, none had to turn back, while half the people aged 18 to 64 had to turn back. Once again, this could be explained by the fact that those who were living below the 5th floor and who took the stairs, did not have any reason to turn back since there was little smoke. For those living above the 5th floor, they simply waited in their units for the most part because it was safer inside, and they evacuated later with rescue personnel when it was safe. Older occupants appear to have been quite realistic about their physical limits and did not attempt an evacuation by themselves.

The use of the stairs during the evacuation was different among the age groups, but in this case, both those 41 to 64 and those 65 years old and over were significantly less likely to use the stairs than those 18 to 40 years old. When examining the occupants' use of the stairs prior to the fire, analysis showed that 65 year old and over residents were less likely to have used the stairs in the past than those 18 to 40 years old.

One problem with people in the 65 and over age group was the fact that they were significantly less likely than others to hear the building fire alarm; this explains why they had to be told about the fire. They did not, however, have significantly different opinions when evaluating the volume of the alarm in the different zones of the building (i.e., apartment, corridors and staircases).

The occupants' fire safety knowledge was different between age groups. First of all, the respondents aged 65 and over were significantly more likely to be aware of the building evacuation procedure than those 18 to 40 years old. When examining respondents' previous knowledge of fire safety, none of the age groups is significantly more likely to have had previous information, however, people of different age groups had a tendency to obtain information from different sources. Most respondents aged 65 and over obtained fire safety information in publications or from other non-specified sources and 24% had not had any previous information. People between the ages of 41 and 64 usually had access to information at work and the majority of respondents aged 18 to 40 were given information at school or through multiple sources. Only 15% and 16% of respondents aged 18-40 and 41-64, respectively, had not obtained any previous information on fire safety.

The language spoken at home was an important aspect, as it was shown to be linked to the occupants' access to information. Of the people speaking a language other than English, 42% had not had any previous information on fire safety, compared to only 15% for the English speaking group. The occupants' awareness of the building evacuation procedure was also affected by the language spoken at home. Only 8% of non-English speaking residents were aware of the procedure, having read about it, in

English, on notices posted in the hall. Of the English speaking residents, 31% were familiar with the procedure.

13.2 Location of the Occupants in the Building

To facilitate analysis of the results, the building was divided into six floor blocks and four quadrants (refer to Figure 2). Residents of the different floor blocks and the different quadrants were compared considering a number of aspects to determine if the location of the respondent's unit had an effect on his or her behaviour during the event.

At the very beginning of the event, excluding the 5th floor block, the time of being alerted and the initial interpretation of the situation was not different from one block to another. On the 5th floor, however, all occupants immediately realized that there was a real fire and took the situation very seriously.

The evacuation routes chosen were different among the various areas of the building. Almost all the residents of the 5th floor and floors below used the stairs to evacuate and did so without waiting for help from rescue personnel. Respondents living between the 17th and the 21st floors were also more likely to use the stairs to evacuate. No apparent explanations for that observation are available, except that many of them tried to evacuate via the stairs early in the morning but had to stop and seek refuge due to the smoke in the staircases. They were evacuated by rescue personnel later in the day.

The lower the resident lived in the building, the more likely this person was to have used the stairs prior to the day of the fire. Of the people using the stairs on that day, 90% took the staircase closer to their apartment and 94% went down the stairs. Four of the six people going up the stairs had to do so because of the smoke. Respondents living above the 16th floor were more likely to have to turn back while in the stairs and go back to their apartments or take refuge in another apartment.

Overall, 75% of all residents heard the building fire alarm but the alarm was not perceived uniformly throughout the building. The most important finding is that only 57% of the occupants of Units 03, 04, 09 and 12 heard the alarm. These apartments are situated in the corners of the building. Sound measurements in the building a few days after the fire showed that the alarm had a sound level of less than 45 dBA in the bedrooms of the corner units. When considering the other units, excluding corner units, 84% of occupants heard the alarm. Although the four alarm bells located in the corridors had a sound level of over 100 dBA, it appears there was a problem of sound attenuation in the corner units.

The respondents' appreciation of the sound level of the alarm was different; people living above the 16th floor were more likely to think that the alarm was not loud enough in their apartments. Overall, 43% of occupants thought the alarm was not loud enough in their apartments and only 3% thought it was too loud. In the corridors, 23% of respondents thought the alarm was not loud enough and 12% thought it was too loud but there is no statistical difference among floors for that finding. In the staircases, 34% of users thought the alarm was not loud enough and only 4% thought that it was too loud.

The fire alarm stopped at one point during that morning, however, it was impossible to determine with relative accuracy the time at which the alarm stopped from the responses of the occupants.

Only 10 respondents (5%) heard the P.A. messages but the messages were unclear for 40% of them. A total of 27 respondents or 12% heard the firefighters' bullhorn messages but those messages were unclear for 21 of them or 78%. The firefighters' bullhorn messages were delivered from the outside of the building, coming from the ground floor around the north-east corner of the building. Statistical analyses showed no difference between the areas of the building, implying that people in the higher parts of the south-west wing mentioned hearing the message just as well as the residents in the lower north-east corner. It is possible however, that some people travelled through the building before finding refuge in another unit and heard the messages from there rather than from their own unit location, which was used for this analysis.

A greater proportion of residents of the 5th floor to the 16th floor noticed that the lights were off in their corridor and in the staircase while people living above the 16th floor were more likely to notice that the lights were on. Residents on the west side of the building were also more likely to notice the absence of lights. Overall, 82% of respondents reported that the lights were on in the corridors and 65% said that they were on in the stairs. All residents of the 5th floor reported the absence of lights. Only 23% of respondents noticed the exit signs located in the staircases and corridors.

Respondents living on the 22nd floor and above were much more likely to wait in their apartments until they were evacuated by rescue personnel, rather than to evacuate on their own. In many cases, however, they tried to evacuate on their own at the beginning of the incident but had to go back to their apartments or to another unit before they were evacuated a few hours later. The occupants of Floors 22 to 30 were also the most likely to receive help from rescue personnel. People living on the 10th floor and below, however, were more likely to meet rescue personnel in the staircases.

Another important result concerns the exit to the roof during a fire emergency situation. Prior to the fire, 39 or 19% of the respondents thought that they could exit onto the roof of the 2 Forest Laneway building. Of those 39 people, 79% were residents of the 17th to the 30th floors. The roof of this building is not accessible, as some discovered on that day.

13.3 Smoke Conditions in the Building

The smoke conditions in the building varied considerably from one area of the building to another. The smoke conditions, as perceived by a respondent, cannot be separated from the location of that respondent when the observation was made. A number of known properties of smoke movement in a highrise building confirm what respondents observed in this fire. The first finding is that all the respondents from the 5th floor saw smoke in their units, in the corridor and in the stairs, when they used them.

Each highrise building has a neutral plane in terms of stack effect, usually situated at mid-height. In the case of the 2 Forest Laneway building, this neutral plane should correspond to the 16th floor level, since there is no 13th floor. Given this neutral plane, with the exception of the 5th floor (the fire floor) where there should have been substantial amounts of smoke, and the 6th floor depending on the amount of leakage, there should be very little smoke from the 1st floor to the 4th floor. The largest amount of smoke should be found on the upper floors, from the 16th floor to the top floor or above the neutral plane. The building was divided into the six floor blocks described earlier to facilitate this comparison of smoke density.

The results obtained from the respondents show that, with the exception of the 5th and 6th floors, the floors below the 15th had significantly less smoke than the floors situated above (refer to Figure 11). Above the 15th floor, over 80% of the respondents observed smoke in their units and the higher the respondents were, the more likely they were to notice smoke in their units. Even between the 7th and 14th floors, more than 40% of respondents indicated that they saw smoke in their units, which denotes the possibility of leakage.

In this fire, it has been shown that both staircases were filled with smoke very early in the incident. Since 65% of the respondents who saw smoke reported that the smoke entered their units around the door, it is likely that the smoke was quite dense in the corridor and that it was partly coming from the staircases, since every time someone tried to use the staircases, they opened the door to the stairs, allowing a substantial quantity of smoke to enter the corridors. Of the people who saw smoke in their units, 13% thought it came in through the ventilation system.

Residents located on the fire side, in the north-east quadrant, were more likely to see smoke in their apartments than the others. Residents on the side opposite the fire side, in the south-west quadrant, were the least likely to see smoke. In more than 64% of units where residents saw smoke, the smoke appeared at or before 5:20 and in 83% of cases, it appeared at or before 5:30. Residents located closer to the fire floor were no more likely than others to see smoke at an earlier time.

In the corridors of the building, 165 people or 81% of respondents saw smoke. More than 50% of them saw it at or before 5:15 and 86% saw it at or before 5:30. With the exception of the 5th floor, where everyone saw smoke in the corridor, the higher the resident was, the more likely this person was to see smoke in the corridor. Of the people who saw smoke in the corridors, 69% reported being able to see less than 10 feet through the smoke. When comparing floors above the 5th floor, it appears that residents of the 6th to the 10th floors were more likely to see the smoke earlier than the others, generally between 5:00 and 5:14, compared to 5:30-5:44 for people on Floors 11 to 16 and 5:15-5:29 for residents of the 22nd to the 30th floors. Unfortunately, no information was collected to determine whether the smoke was still present in the corridors when the rescue personnel asked occupants to evacuate the building later in the day, generally after 10:00.

Of the 87 people who reported the time at which they saw smoke in the staircases, 80% said it was between 5:10 and 5:30. In this case as well, residents living above the 16th floor were more likely to see smoke in the staircases. All people using the Fire Staircase reported seeing smoke in the stairs. Of the people using the Other Staircase, 91% saw smoke during their attempt to evacuate. Four people did not see any smoke in the Other Staircase, but three of those four smelled the smoke and, because of that, two of them decided to turn back. The fourth person apparently made his way down from the 7th floor 5 minutes after hearing the alarm without encountering any sign of smoke.

Only 8 respondents encountered heat in their units, three on the 5th floor, two on the 6th floor, one on the 7th floor and two on the 28th floor. The source of heat on the 28th floor has not been clearly identified. During the evacuation, 12 people encountered heat that forced three of them to turn back.

A battery operated smoke alarm was present in the apartments of 93% of the respondents. Only 15% of them were activated. The proportion of activated smoke alarms is higher on the upper floors: 20% for 22nd to 30th floor, compared to 12% for the 2nd to the 21st floor. Smoke alarms in units located on the fire side, in the north-east quadrant, were more likely to be activated, which is consistent with the finding that a higher proportion of people in these units observed smoke in their apartments.

13.4 Time of Evacuation

In all time-based analyses used in this study, it is difficult to determine the accuracy of the results. All respondents filled in the questionnaire approximately three weeks after the incident and while many remembered numerous details about the situation, specific times may not be absolutely accurate. The respondents seem to have rounded off times when answering the questions. As well, the occupants were involved in a fire emergency and may not have given much consideration to the time, rather concentrating their energies on finding safe solutions to the problem at hand. The large number of responses, however, compensates for the lack of accuracy. The time estimates, even if not perfectly accurate, are very useful in evaluating the chronology of the event.

Two factors played key roles in determining whether an occupant was able to evacuate the building early in the morning or whether the occupant had to wait to be evacuated by rescue personnel much later in the day. The first factor is the location of the occupant's apartment and the second is the time at which the occupant attempted to evacuate. Both of these factors are very important, mostly because they are related to the spread of smoke throughout the building. When examining the evacuation possibilities of the occupants, it is impossible to dissociate the departure time, departure location and the spread of the smoke through the building.

All respondents using either of the staircases from below the 5th floor at any time did not have any smoke-related problems when evacuating. Their evacuation, however, if attempted after the arrival of the firefighters, was sometimes impeded by firefighting equipment.

Anyone using the Fire Staircase from above the 5th floor after the alarm sounded had to travel through smoke. Only people using the stairs very early after the start of the fire were able to get to the ground level without having to turn back or to find refuge. Only three people succeeded, one from each of the 10th, 16th and 20th floors. All three started their descent early, at 5:00 for the occupant of the 20th floor and at 5:10 for the other two people. Sixteen more occupants tried without success to evacuate using the Fire Staircase, all starting at 5:10 or after, except one who left the 23rd floor at 5:05. It is clear that an early start was essential to go down the Fire Staircase successfully before the smoke made it impassable.

In the case of people using the Other Staircase from above the 5th floor, 30 people had to return to their units or find a refuge while five people successfully reached ground level, two of them apparently starting as late as 5:20. Of the people who had to turn back, the average starting time was 5:16, with people from almost all floors attempting to evacuate.

Many occupants had to seek refuge or offer refuge to others during this fire. Of the 44 respondents who had to take refuge in someone else's unit, 21 or 48% did not know the people with whom they took refuge. The 23 others moved to be with people they knew, such as neighbours, friends or relatives. This altruistic behaviour of helping others and offering refuge agrees with the findings of previous similar studies.

It is clear that the considerable propagation of the smoke impeded the evacuation of many people and increased the risk to their lives. It is impossible, however, to determine precisely the location and time at which the situation became intolerable and prevented any further evacuation. An early attempt, preferably through the Other Staircase, gave the best chance for a safe evacuation of the building through the stairs.

14.0 CONCLUSIONS

The results of this human behaviour study during the 2 Forest Laneway Fire raise a number of general issues for improving occupants' fire safety in buildings. Providing information to occupants appears as the leading aspect to improve fire safety. Information on fire safety must be readily available to the population at large. There is a large spectrum of means by which this information can be provided, from fire safety signs to posted evacuation procedures, brochures, training classes and publicity campaigns. It seems important to use multiple means to communicate fire safety information to ensure that the message reaches the building users and that everyone has access to the information.

Fire safety information should be accessible to the increasing number of immigrants to Canada, who are sometimes not fluent in either of the two official languages. In some cases, these new residents have not received any fire safety training at school or at work in their country of origin. Particular attempts must be made to convey fire safety information to these people.

Most people learn about fire safety at school and in the workplace, however, older people or people who spend most of their time at home do not have access to that information. Special efforts must be made to reach these occupants and provide them with appropriate fire safety information.

When providing information on fire safety in highrise buildings, a number of points need to come across very clearly. With a few exceptions, most occupants seem to know that they should not use the elevator during a fire. Many, however, do not fully understand the dangers of smoke and the importance of sealing their units and closing windows and doors. This should be emphasized in fire safety information. Another point that needs reinforcement is the fact that, in almost all apartment buildings, there is no access to the roof, even in a fire situation. Finally, in a fire situation, rescue can take a long time. If occupants are not in immediate danger, they should be prepared to wait for as long as a few hours before rescue personnel can assist them to evacuate; this fact should be made clear to occupants.

Once fire safety information has been provided, one of the best ways to assess occupants' understanding of what they are expected to do during a fire is to carry out evacuation exercises. Regular drills are an excellent means to educate and raise occupants' awareness about fire safety and evacuation procedures. A fire drill gives occupants the opportunity to recognize the sound of the alarm system, to assess the intelligibility of the PA system, if present, to locate the closest exit, to experience using the staircases and to identify the staircase exit locations. Building management, at the same time, can assess the efficiency of the evacuation procedures and identify potential problems.

The 1983 "Public Inquiry into Fire Safety in Highrise Buildings" [13] found that many people turned to the television or radio for information during a fire but often found the information provided to be useless.. At that time, a recommendation was made for members of the Canadian Association of Broadcasters and the Radio and Television News Directors Association to voluntarily modify their procedures during fire situations. Many residents of the 2 Forest Laneway building reported that they turned to the television or radio during the fire only to find, once again, useless information. Further, occupants who listened to the media while still in the building explained that the media information was increasing their anxiety. The emphasis was on the number of casualties discovered so far, suggesting that more might be found, leaving them thinking that they might not survive. Occupants expected to obtain information on appropriate actions to take. An effort must be made to improve this situation by including the media as a means of providing information to the people inside the building during a fire.

Two essential communication devices were shown to be ineffective and unreliable during the 2 Forest Laneway Fire. First, the building fire alarm was very useful in alerting a number of people but the sound level was insufficient in some areas of the building, especially in the corner units. The low sound level of the fire alarm inside apartments in apartment buildings has been observed in a variety of buildings throughout Canada [21, 22]. In apartment buildings where alarm bells are installed only on corridors walls, the sound level of the alarm is often overpowering in the corridors and too low to be perceived in some apartments. Older occupants in any location were less likely to hear the fire alarm. This could be due to the high frequency of the alarm and to the non-modulation of the signal. It is known that older adults, with normal hearing for their age have difficulty hearing sounds with a primary frequency over 2000 Hz. Fire alarms tend to have their main frequency around 4000 Hz, which makes them difficult to hear for older people or for those with a mild hearing loss [23]. Some research suggests that alarm sounds with a primary peak at 500 Hz with a fast modulation could help improve alarm detection [24].

The second means of reaching occupants during an emergency, the building P.A. system, was not efficient in providing residents with information. Some people heard sounds but could not understand the messages. Should this system be intended for use in an emergency, it should be tested, inspected and maintained in order to ensure that messages are intelligible. Voice communication and P.A. systems remain the best way to provide information during an emergency to occupants of a large building. These systems are flexible means of communicating information because it allows the person in authority to give out live messages that can be directed to particular groups of occupants and can be specific in its information content. To make it a useful tool, however, its intelligibility must be improved to make sure that occupants can hear and understand the information.

The 2 Forest Laneway Fire has corroborated a fact now acknowledged in the fire safety community: people are prepared to move through a certain quantity of smoke to evacuate. Occupants who saw smoke did not panic, freeze or became hysterical. Rather, they had a look at the smoky staircase and still tried to make it down. The fact that occupants often try to evacuate, even if there is smoke, emphasizes the importance of leaving the staircase doors unlocked to allow for re-entry on any floor. Given people's normal reaction to move away from a location when conditions become threatening, ideally, the roof should also be accessible as an area of refuge. Accessibility to the roof should be made possible if other safety requirements can be met, otherwise it is important that occupants be made aware of the fact that the roof is not accessible, even during an emergency. If the roof is not accessible, it should be stressed in fire safety information and practice drills, coupled with appropriate signs in the building.

Researchers have emphasized for the last 20 years the fact that panic behaviour is rare during a fire emergency [25, 26]. This study was consistent with previous findings; people did not panic during the 2 Forest Laneway Fire. Many of the occupants felt fearful and anxious, but none of the respondents to the questionnaire acted in an irrational, thoughtless or careless way, which is characteristic of panic. Even though occupants themselves sometimes reported their reactions as "I panicked", they are usually describing sudden fear and stress, but not irrational behaviour. Occupants of the 2 Forest Laneway did not panic during the January 6th fire. Overall, they tried to make what they judged to be the best decisions, with respect to what they knew about fire safety and what they understood of the situation in the building that morning.

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ANNEX 1: Letter to the Occupant and Questionnaire

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Ottawa, Canada
K1A 0R6

National Fire Laboratory
Phone: (613) 993-2204
FAX: (613) 954-0483

NRC·CNRC

25 January, 1995

Occupants
2 Forest Laneway
North York, Ont.
M2N 5X7

Dear Occupants,

We are requesting your cooperation in completing the enclosed questionnaire about your experience during the Forest Laneway high-rise apartment fire on January 6, 1995. There is very limited knowledge on human behaviour during severe fire condition in apartment buildings. Therefore, it is very important that you share your experience with us because it is the best way for us to learn and understand what really happens during a fire. The information you will provide is extremely valuable, it will help us find ways to prevent the recurrence of such tragedies by examining fire safety equipment in buildings, evacuation procedures, fire safety education and regulations.

Please rest assured that your identity and your unit number will be kept strictly confidential. We need to know, however, your location during the fire for analyses purposes. This is why we have already noted your unit number on the questionnaire; if this number is wrong, please correct it.

If you do not want to fill out the questionnaire and would rather have a face-to-face interview in your preferred language, please contact the principal researcher to arrange a meeting: Dr. Guylène Proulx, call collect at, 0-613-993-9634.

This research on the human behaviour during the Forest Laneway fire is a project of the National Fire Laboratory at the National Research Council of Canada. This research will result in a report which will be used by the Office of the Fire Marshal of Ontario and the National Research Council of Canada in their mandate to enhance occupants fire safety.

We thank you for your willing cooperation. If you wish to receive a free copy of the report on the findings of this study, please provide your address at the end of the questionnaire.

Sincerely,

Guylène Proulx

Guylène Proulx, Ph. D.
Research Associate

Canada

Unit:________

Occupants of 2 Forest Laneway
Questionnaire Regarding the Fire on January 6, 1995

Instructions to fill out the questionnaire:

1- If you were not in the building at the time of the fire on January 6, 1995, tick the box underneath and sent back the uncompleted questionnaires in the prepaid envelope.

I was not in the building during the fire ☐

2- Every one over 14 years old, who were in your unit at the time of the fire should fill out a questionnaire. Please give the second copy of the questionnaire to another person who was in your unit. If you need extra copies call collect, Dr. Guylène Proulx at (0-613-993-9634). If you don't need the second copy of the questionnaire simply discard it.

3- While filling out the questionnaire, if you need more space to write down your anwsers simply use the back of the sheet.

4- After filling out this questionnaire, if you feel that some essential element of your experience has been left out, feel free to contact the principal researcher at the NRC. We will be pleased to accept collect call charges if you call (0-613-993-9634) and ask for Dr. Guylène Proulx.

5- Please send back all the completed questionnaires from your unit in the same prepaid envelope enclosed.

SECTION 1: Your Profile

1. Please, state your sex, age and occupation. Add any limitation that may have had an impact on your evacuation, such as, blindness, deafness, use of wheelchair, asthma, pregnancy, having a cast, using a cane, etc.

① ☐ M ☐ F Age ____ Occupation ____________ Limitation ________________

Language used at home:

2. State the sex, age, occupation and possible limitation of all the other persons who were in your unit at the time of the fire. If you need more space use the back of this sheet.

② ☐ M ☐ F Age ____ Occupation ____________ Limitation ________________

③ ☐ M ☐ F Age ____ Occupation ____________ Limitation ________________

④ ☐ M ☐ F Age ____ Occupation ____________ Limitation ________________

⑤ ☐ M ☐ F Age ____ Occupation ____________ Limitation ________________

Canada

SECTION 2: Initial Actions

3. How did you first become aware that there was something unusual occurring in the building?

4. What time was it? How sure are you of the time?

5. What were you doing at that time?

6. How serious did you believe the situation to be at first?
   - ☐ not at all serious ☐ only slightly serious
   - ☐ moderately serious ☐ extremely serious

7. What did you do first?

8. How did you become aware that it was a real fire?

9. Once aware that there was a fire in the building, did you...
   - Call 911? ☐ Yes ☐ No
     If yes, what instruction did you receive?____________________
   - Call the fire department directly? ☐ Yes ☐ No
     If yes, what instruction did you receive?____________________
   - Operate a fire alarm pull station? ☐ Yes ☐ No
     If yes, where was that? __________ Did it work? __________
   - Alert other occupants? ☐ Yes ☐ No
     If yes, how ____________________
   - Telephone friends or relatives? ☐ Yes ☐ No
   - Watch television or listen to radio? ☐ Yes ☐ No
     If yes, what was the information you received? ____________________
   - Other:

10. If you stayed in your unit rather than trying to evacuate right away, why?

11. While staying in your unit, what did you do?

12. Did all the occupants of your unit stay with you? ☐ Yes ☐ No
    If someone left, give the occupant(s) number(s) as listed in question 2: __________

13. Did you provide refuge for other occupants? ☐ No ☐ Yes How many __________
    These people were from which unit?

14. Did you go on your balcony? ☐ Yes ☐ No
    If yes, did you leave the balcony door open? ☐ Yes ☐ No
    While on your balcony, was there... ☐ smoke ☐ heat

15. At what time did you leave your unit? How sure are you of the time?

16. When you left, was your unit door locked? ☐ Yes ☐ No

17. Did you take your key? ☐ Yes ☐ No

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SECTION 3: Evacuation of the Building

18. How many people left your unit with you? ____
    Give the occupant(s) number(s), as listed in question 2: ____

19. If you left as a group, did you remain together throughout the evacuation? ☐ Yes ☐ No
    If not, where were you separated and who left the group? ____
    Why?

20. Before leaving the building, did you try to meet someone from another unit? ☐ Yes ☐ No
    If yes, where did you meet?

21 Did you try to use the elevator? ☐ Yes ☐ No
    If yes, did it work?

22 Did you use the stairs to evacuate? ☐ Yes ☐ No
    Which staircase door did you use to evacuate?
    - ☐ Exit door on the side where units have odd numbers, next to the garbage chute.
    - ☐ Exit door on the side where units have even numbers.

23. When in the staircase, did you go... ☐ up ☐ down
    If you went up, why?

24. Did you have to change staircases during your evacuation? ☐ Yes ☐ No
    If yes, why?

25. Approximately how many people did you encounter in the corridor?

26. Approximately how many people did you encounter in the staircase?

27. On your way down, did you have to turn back up? ☐ Yes ☐ No
    If yes, why? ____
    Did you go back to your unit? ☐ Yes ☐ No

28. During your evacuation, did you take refuge in someone's else's unit? ☐ Yes ☐ No
    If yes, why? ____
    Where did you take refuge? floor ____ unit ____
    Did you know the persons where you took refuge? ☐ Yes ☐ No
    How many people were there? ____
    How long did you stay there?

29. Did you have any difficulty opening the staircase door? ☐ Yes ☐ No ☐ N/A
    If yes, where was that?

30. At what time did you finally reach ground level?

31. Did someone help you to evacuate, such as:
    ☐ someone from your unit ☐ other occupants ☐ firefighters
    ☐ police officers ☐ ambulance people ☐ don't know

32. Which exit at ground level did you use to leave the building?

33. That morning, did you re-enter the building after your evacuation? ☐ Yes ☐ No
    If yes, why?

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SECTION 4: Alarm and Public Announcement

34. During this emergency, did you hear the building fire alarm? ☐ Yes ☐ No
    If yes, where were you when you first heard it?

35. In your opinion, was the sound of the building fire alarm...
    - in your apartment ☐ too loud ☐ loud enough ☐ not loud enough
    - in the corridor ☐ too loud ☐ loud enough ☐ not loud enough
    - in the staircase ☐ too loud ☐ loud enough ☐ not loud enough

36. Did you hear the fire alarm stop? ☐ Yes ☐ No
    If yes, where were you when it stopped? ______
    What time was it? How sure are you of the time?

37. Did you have a battery operated smoke alarm in your unit? ☐ Yes ☐ No
    If yes, did it activate during the fire? ☐ Yes ☐ No
    If yes, did you remove the battery to silence the alarm? ☐ Yes ☐ No

38. Did you hear any messages from the P.A. system? ☐ Yes ☐ No
    If yes, what was the message? ______
    Where were you at that time?

39. Did you hear any messages from the firefighters using a bull-horn? ☐ Yes ☐ No
    If yes, what was the message? ______
    Where were you at that time?

SECTION 5: Smoke Condition

40. Did smoke enter your unit? ☐ Yes ☐ No
    If yes, at what time? ______ How sure are you of the time? ______
    How did it enter? ______
    What did you do about it?

41. Did you see smoke in the corridor? ☐ Yes ☐ No
    If yes, at what time? ______ On what floor? ______
    What was the colour of the smoke? ______
    How many feet could you see through the smoke?

42. Did you see smoke in the staircase? ☐ Yes ☐ No
    If yes, at what time? ______ On what floor? ______ ______
    What was the colour of the smoke? ______
    How many feet could you see through the smoke?

43. Did you encounter any heat in your unit? ☐ Yes ☐ No

44. Did you encounter any heat during your evacuation? ☐ Yes ☐ No
    If yes, did you have to turn back because of this heat? ☐ Yes ☐ No

45. Did you notice any illuminated exit signs? ☐ Yes ☐ No
    If yes, where?

46. While leaving, were the lights on in the corridors? ☐ Yes ☐ No
    If no, where was it?

47. While leaving, were the lights on in the staircases? ☐ Yes ☐ No
    If no, where was it?

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SECTION 6: Rescue Effort

48. Were you asked to evacuate by the firefighters? ☐ Yes ☐ No
If yes, what time was it? ________ How sure are you of the time? ____________
What instructions did you receive?

49. During your evacuation, did you encounter firefighters in the corridor? ☐ Yes ☐ No

50. Did you encounter firefighters in the staircases? ☐ Yes ☐ No

51. Did the firefighting equipment impede your evacuation movement? ☐ Yes ☐ No
If yes, where was that... ☐ corridor ☐ staircase At what level?

SECTION 7: Fire Safety Knowledge and Experience

52. Did you have previous information on actions to take in a fire situation?
☐ at school ☐ at work ☐ publication
☐ radio, TV ☐ other ☐ no information

53. How long have you been living in the Forest Laneway building?

54. Were you aware of the evacuation procedure for the building? ☐ Yes ☐ No
If yes, where did you get this information?____________________
What was the evacuation procedure?____________________

55. Did you participate in a fire drill in this building? ☐ Yes ☐ No
If yes, when?

56. Have you been aware of false alarms in the building? ☐ Yes ☐ No
If yes, how many during the last year?

57. Have you ever used the stairs prior to this fire? ☐ Yes ☐ No

58. How many separate staircases are there in the building at 2 Forest Laneway?

59. In general, do you think it is a good idea in a fire to try to exit to the roof? ☐ Yes ☐ No

60. Prior to that fire did you think you could exit onto the roof of your building? ☐ Yes ☐ No
If yes, why?

61. Have you ever experienced a fire before? ☐ Yes ☐ No
If yes, when was that?

62. Were you or someone of your unit injured during this fire? ☐ Yes ☐ No
If yes who was injured, give occupant(s) number(s) as listed in question 2:____________
What was the injury?

63. During this whole fire experience, how would you describe your feelings?
☐ not very concerned ☐ unable to decide what to do
☐ anxious, but in control ☐ panicky and unable to think clearly

64. Did you seek assistance to deal with the emotional stress of this event? ☐ Yes ☐ No
For example: ☐ psychologist-psychiatrist ☐ medical doctor
☐ priest or spiritual counsellor ☐ other

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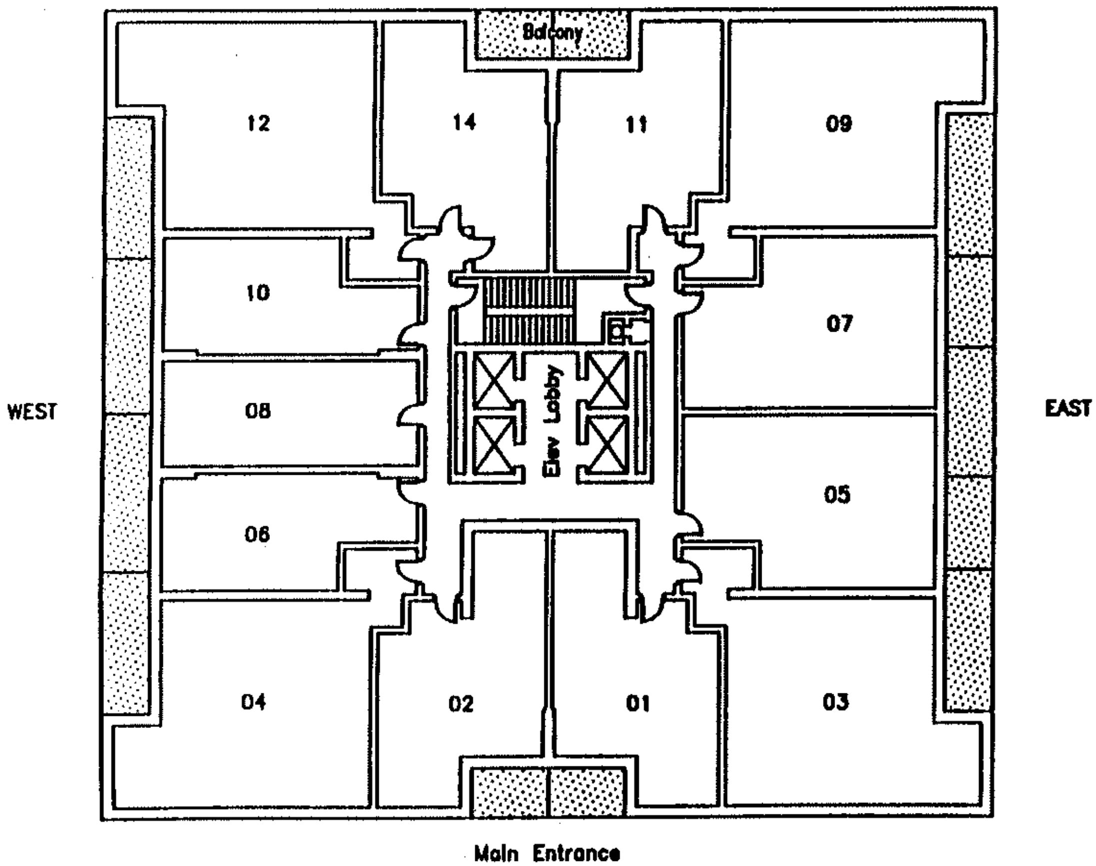
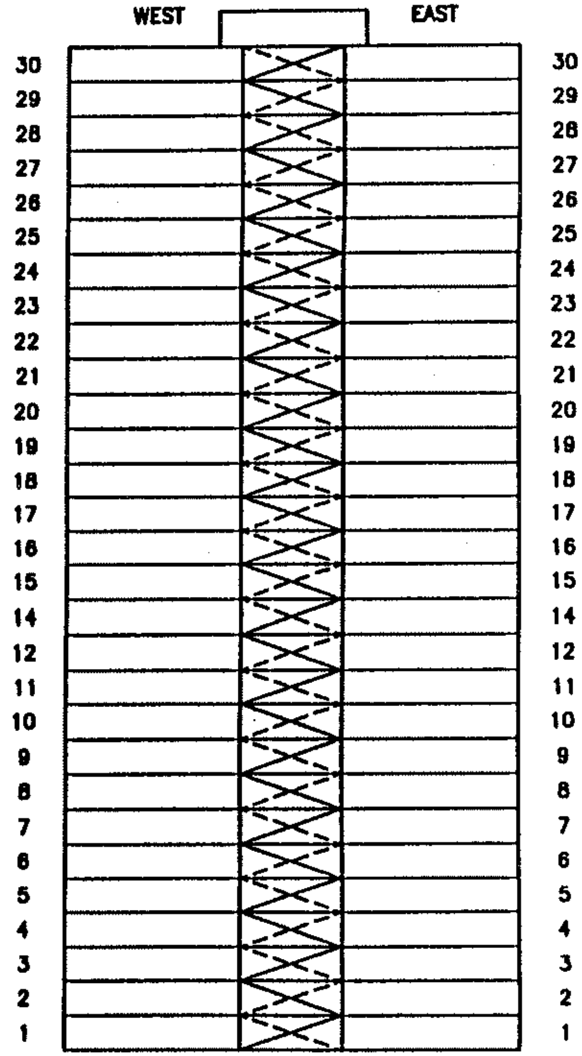
SECTION 8: Your Evacuation Movement

Use the plans provided to draw your evacuation movement. Make sure you identify the location of the unit you left and the staircase you used to leave the building. Add any written comments that could make your sketch easier to understand. If you have difficulty using the building plans, simply describe how you evacuated the building on the back of the sheet.





Thank you for your participation.

If you wish to receive a free copy of the report on the findings from this Human Behaviour Study, please provide your name, address and phone number. The report will be sent to you in a few months, after the Coroner's inquest.

Tel. (   ) ______________

____
____
____
____

Please return this questionnaire as soon as possible in the prepaid envelope enclosed.

7/19/2024

Circumstances surrounding fire-related deaths among Indigenous people in Canada, 2011 to 2020

Eduful, Jeannette
CENTRE FOR POPULATION HEALTH DATA, STATISTICS CANADA

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Acknowledgements

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Overview of the study

Fire-associated morbidity and mortality represent the fourth most common cause of unintentional injuries worldwide, affecting millions of lives.[1] In Canada, an average of 220 fire-related deaths have occurred each year from 2011 to 2020.[2] In the Canadian context, fire-related mortality and morbidity were found to be significantly higher among Indigenous people (First Nations, Métis, and Inuit) – particularly among First Nations people and Inuit– when compared to non-Indigenous people.[3]

The objective of this study is to analyze and compare available data on the circumstances surrounding fire-related deaths among Indigenous people to those among non-Indigenous people.

This study uses data from the Canadian Coroner and Medical Examiner Database (CCMED) and the Canadian Vital Statistics - Death database (CVSD) linked to the 2006 and 2016 Census of Population and the 2011 National Household Survey (NHS). According to the 2016 Census of Population, Indigenous people accounted for 4.9% of the total Canadian population, up from 4.3% in 2011 and 3.8% in 2006.[4,5,6] Of the 2,200 fire-related deaths reported in the CCMED known to have occurred in Canada from 2011 to 2020, over 700 death records linked to the censuses and NHS.

- Among the sample of 700 individuals who had died by fire and who had previously been enumerated in at least one of the two censuses (2006 or 2016) or the National Household Survey (2011), 140 (20%) were Indigenous (First Nations, Métis, and Inuit), a proportion about four times higher than their share of the population.
- Fire-related fatalities were more prevalent among males than females for both Indigenous and non-Indigenous people.
- Indigenous people who died from a fire-related event from 2011 to 2020 were younger on average (mean age of 39 years) compared to non-Indigenous people who died in a fire (mean age of 59 years).
- Fire-related deaths were most common in the winter months for both Indigenous and non-Indigenous people.
- Residential fires accounted for the majority of fire-related deaths among both Indigenous and non-Indigenous people.
- About 1 in 8 (12%) residential fire-related deaths among Indigenous people occurred in residences without a working smoke alarm and this was similar for non-Indigenous residential fire-related deaths.

- About 56% of Indigenous people who died in a residential fire lived in a house that needed major repairs compared with 13% of non-Indigenous people.
- Indigenous people (20%) who died in a residential fire were more often involved in residential fires causing two or more deaths than non-Indigenous people (7%).
- Over two-thirds (68%) of Indigenous people who died in a fire lived in rural areas compared with one-third (34%) of non-Indigenous people who died in a fire.

Introduction

Fire-associated morbidity and mortality represent the fourth most common cause of unintentional injuries worldwide, affecting millions of lives.[1] In Canada, an average of 220 fire-related deaths occurred each year between 2011 and 2020.[2] In the Canadian context, however, fire-related mortality and morbidity were found to be significantly higher among Indigenous people (First Nations, Métis, and Inuit). This particularly applies for First Nations people and Inuit compared to non-Indigenous people living in private dwellings in Canada. [3]

Recent studies have shown that the mortality rate from all fires among First Nations people between 2011 and 2018 was five times higher (rate ratio[i] (RR) = 5.2) compared with non-Indigenous people. Among Inuit, the mortality rate was 17 times higher (RR = 17.3). Specifically, the age-standardized[ii] fire-related mortality rate was 1.6, 0.6 and 5.3 deaths per 100,000 person-years at risk among First Nations people, Métis, and Inuit, respectively, compared to 0.3 among non-Indigenous people.[3]

A British Columbia-based study found that between 1991 and 2001, Indigenous fire-related deaths were nine times higher among Status Indians compared to other residents of the province. Mortality rates were found to be particularly high among children younger than 5 years of age and seniors aged 65 years and older.[7]

There are many factors that are thought to contribute to higher fire-related mortality among Indigenous people. Specifically, inadequate housing, lack of smoke detectors, underfunding of fire services in Indigenous communities, poverty, and lack of legislation mandating adherence to building and fire codes on reserve are all factors that have been suggested to increase risk of fire-related death[8.] In addition, multiple factors such as lower socioeconomic status (low educational attainment, low income, unemployment, etc.), overcrowded living conditions, and limited access to healthcare services in rural locations place Indigenous people at an elevated risk of various types of unintentional injuries including fire-related morbidity and mortality.[9,10,11]

According to the *Ontario Chief Coroner's Table on understanding fire deaths in First Nations*, education and prevention are key to reducing fire fatalities. This includes providing appropriate education on topics like fire escape, fire safety and resource and facility maintenance. In addition, providing funding

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[i]A rate ratio is a relative measure used to compare rates between two populations. In the cited study, the rate ratio was defined as the ratio of the mortality rate among Indigenous people to the mortality rate among non-Indigenous people.

[ii] The age standardized mortality rate is a weighted average of the age-specific mortality rates per 100 000 persons-years at risk of the event in question.

to communities to help with training and education of how to use, install and maintain smoke alarms, including the provision of suitable smoke alarms in accordance with the type of heating sources used.[12]

Although several studies have attempted to explore fire-related mortality and morbidity among Indigenous people in Canada, information gaps remain. The aim of this study is to analyze, summarize and compare the circumstances surrounding fire-related deaths experienced by Indigenous people who died in a fire to those of non-Indigenous people.

Data from the Canadian Coroner and Medical Examiner Database (CCMED) and the Canadian Vital Statistics – Death database (CVSD) were linked to the 2006 and 2016 Census of Population and the 2011 National Household Survey (NHS), to produce a sample of individuals who died in a fire between 2011 and 2020 in Canada. The section Data sources and methodology includes detailed information on the data sources, the linkage process and indicators considered for analysis. The section also presents important limitations which should be considered when interpreting the findings. This report was prepared for and sponsored by the National Indigenous Fire Safety Council (NIFSC), which is funded by Indigenous Services Canada.

Results

Between 2011 and 2020, there were over 2,200 fire-related deaths reported in the CCMED. The CCMED includes data from all provinces and territories except for Manitoba. Of the 2,200 fire-related deaths, 32% (700) of the deceased individuals had a death record that could be linked to at least one of the three sample surveys (i.e., 700 fire-related death records linked to a record from the 2006 and/or 2016 Census of Population and/or the 2011 NHS). It is this sub-sample of fire-related deaths that is the focus of the following analysis. Of the 700 people who died from a fire-related event, 140 people (20%) identified as Indigenous in one of the sample surveys, a proportion about four times higher than their share of the population, suggesting an overrepresentation of Indigenous people in the linked dataset. According to the 2016 Census of Population, Indigenous people accounted for 4.9% of the total Canadian population, up from 4.3% in 2011 and 3.8% in 2006.[4,5,6]

The linked dataset may not be representative of all fire-related deaths in Canada because of the relatively low linkage rate (32%) and because Indigenous people are over-represented among Census of Population and NHS respondents[iii]. However, to assess linkage bias, the distribution of select variables from the linked dataset (i.e., 700 fire-related deaths) was compared to the distribution for the total population of fire-related deaths in CCMED (i.e., 2,200 fire-related deaths) and was found to be comparable (see APPENDIX 1). The comparable distributions between the two datasets suggests a potential lack of linkage bias in the linked dataset.

In the following sections, the term 'linked dataset' will be used to refer to the 700 CCMED fire-related death records that linked to the 2006 or 2016 Census of Population or the 2011 NHS.

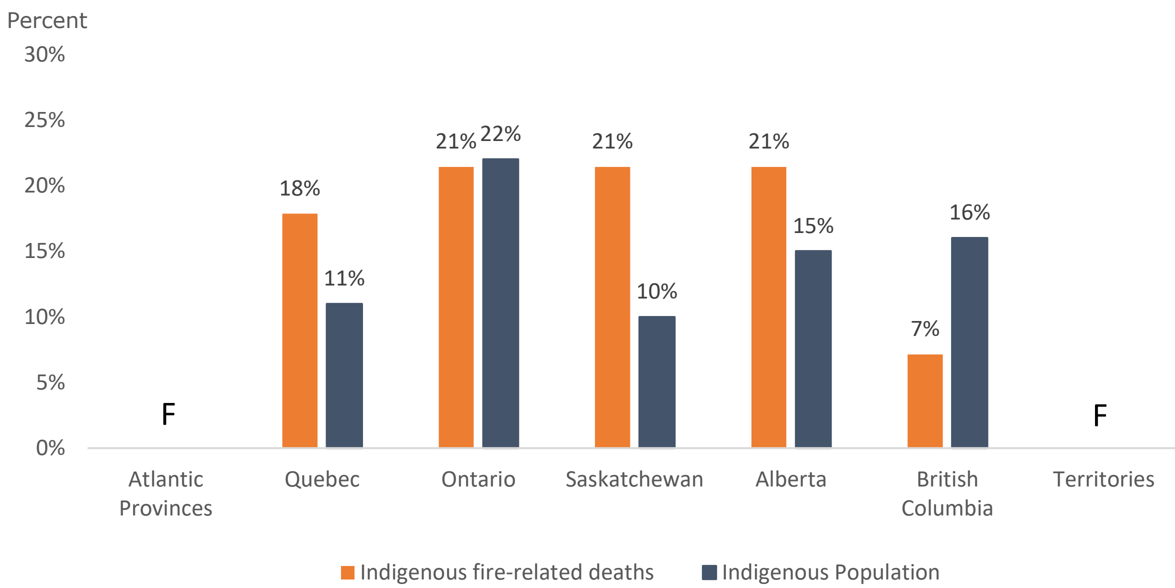
[iii] 100% of households on reserve and/or in the territories were sampled for the Census of Population and NHS compared to 20-30% of households off reserve in the provinces.

Provincial Overview

According to the 2016 Census of Population, the distribution of Indigenous people living in Canada varied by Province and Territory. While the distribution of fire-related deaths among Indigenous people also varied, it was not comparable to the Indigenous population distribution (Chart 1).

The proportion of fire-related deaths among Indigenous people was greater than the proportion of the Indigenous population in Alberta (21% of Indigenous deaths versus 15% of the Indigenous population), Quebec (18% versus 11%), and Saskatchewan (21% versus 10%), suggesting an overrepresentation of fire-related deaths in these Provinces. Underrepresentation was observed in British Columbia (7% versus 16%), where the proportion of fire-related deaths among Indigenous people was 2.3 times lower than its share of the Indigenous population. In Ontario, the proportion of Indigenous fire-related deaths (21%) was similar to the Indigenous population proportion (22%). Fire-related deaths for Manitoba were not available in the linked dataset and death proportions for Atlantic Canada and the Territories were suppressed to meet Statistics Canada's confidentiality requirements.

Chart 1
Distribution of Indigenous fire-related deaths compared to the distribution of the Indigenous population, 2011 – 2020



Notes: Data for Manitoba were not available in the linked dataset. Data for the Atlantic Provinces and Territories were suppressed to meet Statistics Canada's confidentiality requirements .
Source: Statistics Canada, linked dataset integrating the 2006 and

Who is at greatest risk?

Fire-related fatalities were more common among males

For both Indigenous and non-Indigenous populations from the linked dataset, fire-related fatalities were more prevalent among males than females. Approximately 3 in 5 (61%) individuals who died in a fire were male, and 2 in 5 (39%) were female.

Fire-related fatalities were most common among younger Indigenous people

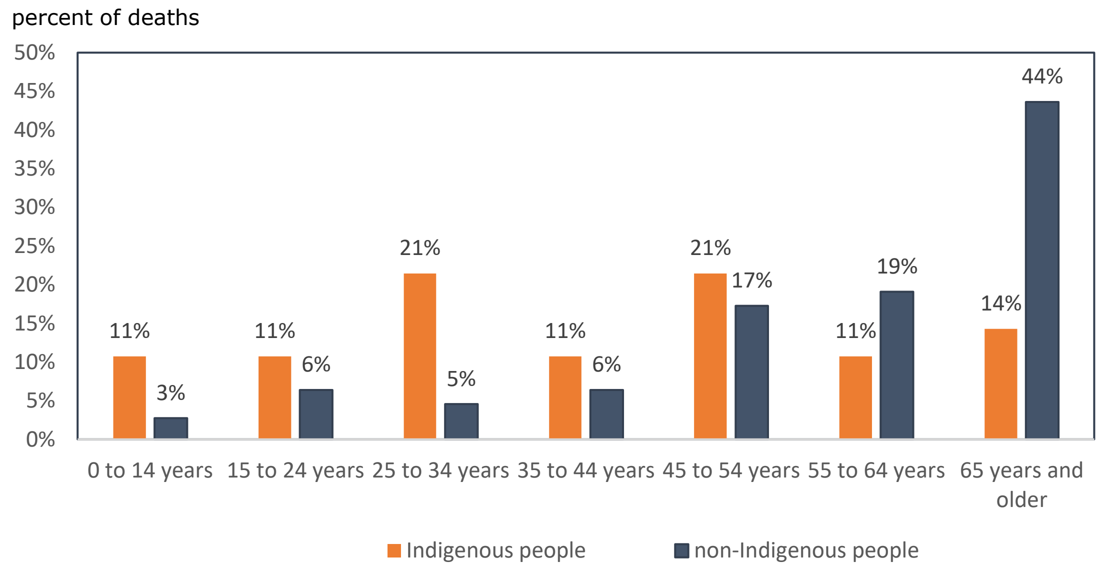
The age distribution of fire-related fatalities from the linked dataset varied by population group. Indigenous people who died from a fire-related event were younger on average (mean age of 39 years) compared to non-Indigenous people (mean age of 59 years).

From 2011 to 2020, 75% of Indigenous people who died in a fire were younger than 55 compared to 37% of non-Indigenous people. The difference was even more notable among those aged 0 to 14 and 25 to 34 years, where the proportion of fire-related deaths was 3 to 4 times higher among Indigenous people in these age groups compared to non-Indigenous people (Chart 2).

Of note, the Indigenous population is younger than the non-Indigenous population. According to the 2016 Census of Population, 83% of Indigenous people were younger than 55, compared with 69% of non-Indigenous people.[4]

According to a previous Statistics Canada analysis on fire-related deaths in Canada, seniors were at greater risk of fire-related death than their younger counterparts.[2] This finding is consistent with the trend for non-Indigenous people. Among non-Indigenous people who died in a fire, the proportion of deaths involving seniors was greater than any other age group and more than three times higher than among Indigenous seniors (14%).

Chart 2
Proportion of fire-related deaths among Indigenous and non-Indigenous people, by age group, Canada, 2011 to 2020



Notes: 'Age' refers to age at death. No weights were used in calculating these estimates.
Source: Statistics Canada, linked dataset integrating the 2006 and 2016 Census of Population, the 2011 National Household Survey and the Canadian Vital Statistics - Death database (2011-2020) with the Canadian Coroner and Medical Examiner Database (2011 to 2020).

What is happening? – Manner and cause of fire-related deaths

Most fire-related deaths were classified as accidents

In Canada, most fire-related deaths were classified as unintentional (accidents).[2] From 2011 to 2020, 82% of deaths from the linked dataset were classified as unintentional among Indigenous people who died in a fire, compared with 77% among non-Indigenous people. The proportion of fire-related deaths classified as suicide was two times lower among Indigenous people (7%) than among non-Indigenous people (16%). Other manners of death (e.g., homicide, undetermined) accounted for 11% of deaths among Indigenous people who died in a fire and 7% among non-Indigenous people.

Most fire-related deaths were a result of smoke inhalation

Most fire-related deaths in Canada were the result of smoke inhalation.[2] This finding was true for both Indigenous and non-Indigenous people. Among Indigenous people who died in a fire, over two-thirds (68%) of deaths were a result of smoke inhalation alone, while 14% were due to burns alone and 14% were caused by both smoke inhalation and burns. Among non-Indigenous people who died in a fire, the patterns were similar (60 % due to smoke inhalation alone, 24% due to burns alone, and 9% due to smoke inhalation and burns). A small percentage of fire-related deaths among both population groups were due to blunt force trauma from a jump, fall or falling debris, or had causes of death which were unknown or unspecified.

What are the other factors or circumstances surrounding fire-related deaths?

The coroner or medical examiner may include additional circumstance information in the reports submitted to the CCMED, but the level of detail provided in the report varies by death investigator and by jurisdiction. In some cases, the circumstance information is very limited.

In addition to providing information on demographics and causes of death, the findings more commonly reported by coroners and medical examiners investigating fire-related deaths include the date of death, the location of the fire, the source of ignition, and presence of working smoke alarms.

The presence of a risk factor is considered "not specified" when the information is missing from the coroner or medical examiner report, while the absence of a risk factor can only be considered when the coroner or medical examiner has indicated that a given factor was not present or involved in the death.

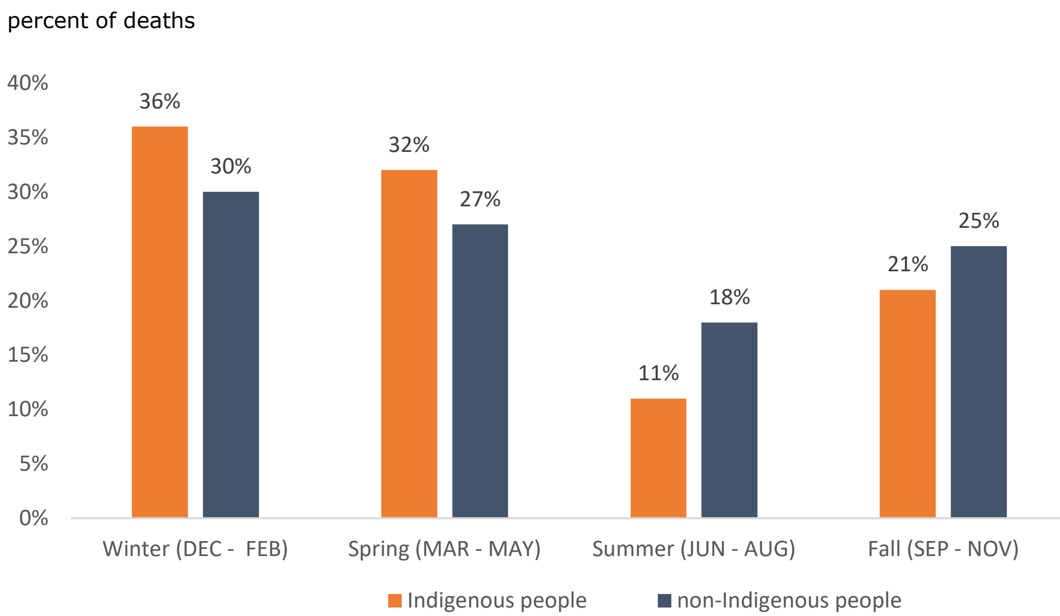
Corners and medical examiners may include information on alcohol or drug use prior to fatal events in reports submitted to CCMED. Information on alcohol and drugs (presence or non-presence) was less often included in CCMED fire-related death reports among non-Indigenous people than among Indigenous people. For this reason, proportions of fire-related deaths involving alcohol or drugs cannot be compared between the two population groups.

Most fire-related deaths occur in the colder months

In Canada, most fire-related deaths occur in the colder months.[2] From 2011 to 2020, among both Indigenous and non-Indigenous people, the largest proportion of fire-related deaths occurred in the winter months, followed by spring, fall and summer (Chart 3). During the colder months, there is increased usage of heaters and wood-burning stoves. In addition, people may remain indoors for longer periods of time, leading to an increased potential for indoor smoking and use of candles.

The proportion of fire-related deaths occurring in the summer and fall months was lower among Indigenous people (32%) than among non-Indigenous people (43%), while the proportion of fire-related deaths occurring in the spring and winter was higher among Indigenous people (68%) than among non-Indigenous people (57%).

Chart 3
Proportion of fire-related deaths among Indigenous and non-Indigenous people, by season, Canada, 2011 to 2020



Notes: No weights were used in calculating the estimates.
Source: Statistics Canada, linked dataset integrating the 2006 and 2016 Census of Population, the 2011 National Household Survey and the Canadian Vital Statistics - Death database (2011-2020) with the Canadian Coroner and Medical Examiner Database (2011 to 2020).

Residential fires account for the large majority of fire-related deaths

Residential fires accounted for the large majority of fire-related deaths among Indigenous people (89%) and non-Indigenous people (86%) identified in the linked dataset. This is consistent with previous studies showing that residential fires accounted for a substantial proportion of fire incidents and an even greater proportion of fire-related deaths.[2,13]

Cooking, electrical, and heating devices the most common sources of fatal fire among Indigenous people

A previous Statistics Canada release found that fires ignited by a cigarette, cigarette lighter, pipe or other smoking materials were reported in at least 20% of unintentional residential fire-related deaths.[2]

From 2011 to 2020, the source of the fire was not always specified in coroner and medical examiner reports submitted to the CCMED. The initial source of fire was more often unspecified or undetermined in fatal fires involving Indigenous deaths (72%) compared to non-Indigenous deaths (55%) identified in the linked dataset. Information on ignition source is more likely to be undetermined or unknown when there is significant damage to a structure.

Cooking, electrical and heating devices (14%) were reported to be the most common sources of fatal fire among Indigenous people, followed by cigarettes (7%) and candles or other open flames (7%). Among non-Indigenous people, fires were more often ignited by cigarettes (16%), cooking, electrical and heating devices (15%), and candles or open flames (14%).

Nearly 1 in 8 residential fire-related deaths among Indigenous people occurred in residences without a working smoke alarm

The risk of fire-related injury or death can be significantly reduced by having the recommended number of functional smoke alarms correctly placed in the home.[14]

From 2011 to 2020, information on smoke alarms was often unspecified in the coroner and medical examiner reports submitted to the CCMED. The information on smoke alarms was either not specified, unknown or not applicable for 80% of fire-related deaths among Indigenous people and 78% among non-Indigenous people. The presence or functionality of a smoke alarm cannot always be confirmed following an investigation where the damage to the home is significant.

The coroners and medical examiners reported missing or non-functional smoke alarms in 1 in 8 (12%) residential fire-related deaths among Indigenous people and 11% among non-Indigenous people identified in the linked dataset. The findings are consistent with a previous Statistics Canada release on unintentional residential fire-related deaths using data from the CCMED, which found that at least 14% of unintentional residential fire-related deaths from 2011 to 2020 occurred in a home without a working smoke alarm.[2]

Where did the deceased person live? A focus on usual place of residence

The next sections provide information on where the deceased lived prior to their death (i.e., their usual place of residence). Geographic detail (i.e., population centre size) for the deceased's usual residence at death was collected from the CVSD. Additional information on place of residence (e.g., condition of dwelling) was collected from the census closest to and preceding the date of death. Although most fire-related deaths occurred on or around residential property, it is not possible to determine whether the fatal fire occurred in the usual residence at time of death, in the residence lived in on Census Day, or in another residence (e.g., deceased may have moved or may have been staying with a friend). The linked dataset did not include detailed information on the location of the residential fire. Instead, the deceased person's usual place of residence will be used as a proxy for the location of residential fire.

The majority of people who died in a residential fire lived in single-detached houses

According to the 2006 and 2016 Census of Population and 2011 NHS data from the linked dataset, more than three quarters (76%) of Indigenous people and more than half (56%) of non-Indigenous people who died in a residential fire lived in single-detached houses.

The repair status of these houses and other residence types varied by population group. About 56% of Indigenous people who died in a residential fire lived in residences that needed major repairs, that is residences with defective plumbing, electrical wiring and or requiring structural repairs. In comparison, 13% non-Indigenous people who died in a residential fire lived in residences needing major repair. According to 2016 Census of Population, 19.4% of the Indigenous population lived in a dwelling that required major repairs compared to 6% for the non-Indigenous population.[15]

The average number of people living in a household was two times higher among Indigenous people who died in a residential fire than among non-Indigenous people

Analysis of data collected from the Census closest to and preceding death showed that the average number of people living in a household was two times higher among Indigenous people (5.0 people) who died in a residential fire than among non-Indigenous people (2.5 people). The average number of rooms and bedrooms in the residence was similar for Indigenous and non-Indigenous people who died in a residential fire.

According to the 2016 Census of Population, close to one-fifth of the Indigenous population lived in crowded housing that was considered not suitable for the number of people who lived there.[15] An overcrowded household may increase risk of fire-related death as exits or pathways may be blocked with personal belongings, and an increase in personal belongings could cause the fire to spread more quickly.

A bigger household may also lead to a higher number of people dying in a single residential fire. CCMED data showed that the proportion of residential fire-related deaths where a residential fire caused two or more deaths was nearly three times higher among Indigenous people (20%) than among non-Indigenous people (7%).

Two-thirds of Indigenous people who died in a residential fire lived in rural areas

Rural areas are more likely to experience significant fires and fire-related fatalities due to the absence of nearby fire-stations and hospitals. Two-thirds (68%) of Indigenous people who died in a residential fire lived in rural[iv] areas, 20% in small population centres (population between 1,000 to 29,999) and 12% in medium-to-large urban population centres (population 30,000 or more). In comparison, most non-Indigenous people who died in a fire lived in medium-to-large urban areas (50%), followed by rural areas (34%) and small population centres (16%).

Rural areas tend to be farther from fire stations and paramedic services resulting in increased response times, longer burn times, and faster spreading fires. In addition, volunteer firefighters are often first on the scene of rural fires, influencing the size of potential suppression forces.[16]

[iv] According to the Census of Population, 'rural and small population centres' is defined as the population living in towns and municipalities outside the commuting zone of larger urban centres (i.e., outside the commuting zone of centres with populations of 10,000 or more).

Chart 4
Proportion of residential fire-related deaths among Indigenous and non-Indigenous people, by population centre size, Canada, 2011 to 2020

Notes: No weights were used in calculating the estimates.
Source: Statistics Canada, linked dataset integrating the 2006 and 2016 Census of Population, the 2011 National Household Survey and the Canadian Vital Statistics - Death database (2011-2020) with the Canadian Coroner and Medical Examiner Database (2011 to 2020).

Conclusions

The objective of this study was to examine, present, and compare the circumstances surrounding fire-related deaths among Indigenous people to those among non-Indigenous people. Although there were several similarities between the two population groups, such as sex distribution, manner, cause of death, and presence of smoke alarms, there were some important differences related to demographic and socioeconomic risk factors.

Most notably, Indigenous people who died in a fire were younger on average than non-Indigenous people and the proportion of fire-related deaths occurring in rural areas and in housing needing major repair was higher among Indigenous people who died in a fire. Additionally Indigenous people who died in a fire were more often involved in residential fires causing two or more deaths than non-Indigenous people.

It is recommended that a future study about fire-related deaths consider additional socioeconomic factors such as food security, cost of living, and household income.

Data Sources and Methodology

This study uses data from the Canadian Coroner and Medical Examiner Database (CCMED) and the Canadian Vital Statistics - Death database (CVSD) linked to the 2006 and 2016 Census of Population and the 2011 National Household Survey (NHS). The 2011 to 2020 CCMED data used for this report were extracted in March 2023.

The Canadian Coroner and Medical Examiner Database (CCMED)

The Canadian Coroner and Medical Examiner Database (CCMED) was developed at Statistics Canada in collaboration with the 13 provincial and territorial Chief Coroners and Chief Medical Examiners and the Public Health Agency of Canada. The CCMED contains data on deaths investigated by coroners and medical examiners from all provinces and territories, except Manitoba. It contains information on demographics (e.g., age, sex, date of death, province/territory), causes of death, related health conditions, and circumstances of death. More information on the CCMED can be found at the following link: Surveys and statistical programs - Canadian Coroner and Medical Examiner Database (CCMED) (statcan.gc.ca).

The CCMED does not consistently contain information on population groups. In order to obtain information on Indigenous identity, the database was linked to the Census of Population and NHS. To maximize the number of fire-related deaths from 2011 to 2020 with census information, the CCMED was linked to the 2006 and 2016 Census of Population and 2011 NHS using a pooled approach. About one-third of the 2,200 fire-related deaths identified in the CCMED from 2011 to 2020 had census information. The CCMED records with census information were also linked to the CVSD in order to obtain more complete residential postal code information.

The Canadian Vital Statistics Death Database (CVSD)

The Canadian Vital Statistics - Death database (CVSD) contains information on all deaths in Canada. Data are obtained regularly from provincial and territorial vital statistics registries. The CVSD includes information on basic demographics and causes of death. The underlying cause of death information in the CVSD is coded using the 10th revision of the *International Classification of Diseases and Related Health Conditions* (ICD). Data for Yukon have not been received since 2017. More information on the CVSD can be found at the following link: Surveys and statistical programs - Statistics Canada, Canadian Vital Statistics - Death database (CVSD) (statcan.gc.ca)

Postal Code Conversion File (PCCF+)

The Postal Code Conversion File Plus (PCCF+) provides a link between six-character postal codes produced by Canada Post, standard 2016 census geographic areas (such as dissemination areas, census subdivisions, and census tracts) produced by Statistics Canada, and supplementary administrative areas and neighbourhood income quintiles.

Postal codes do not respect census geographic boundaries and may be linked to more than one standard geographic area or assigned to more than one set of coordinates. Therefore, one postal code may be represented by more than one record. The PCCF+ product, produced by Statistics Canada, provides links between postal codes and all recorded matches to census geography. In this analysis, PCCF+ was generated using the place of residence postal code from the CVSD.

The Census datasets

The Census of Population is designed to provide information about people and housing units in Canada by their demographic, social and economic characteristics.

Information on the 2006 Census can be found here: Surveys and statistical programs - Census of Population (statcan.gc.ca). The 2006 Census was held on May 16th, 2006. In 2006, there were 22 incompletely enumerated reserves and settlements in the census.

Information on the 2011 Census and NHS can be found here: [Surveys and statistical programs - Census of Population (statcan.gc.ca)] and [Surveys and statistical programs - National Household Survey (NHS) (statcan.gc.ca)], respectively. The NHS was a voluntary survey which replaced the long-form census in 2011. The 2011 NHS was held on May 10th, 2011. In 2011, there were 36 incompletely enumerated reserves and settlements in the NHS.

Information on the 2016 Census can be found here: [Surveys and statistical programs - Census of Population (statcan.gc.ca)]. The 2016 Census was held on May 10th, 2016. In 2016, there were 14 incompletely enumerated reserves and settlements in the census.

Information about the linkage

The CCMED, CVSD and census datasets were linked in Statistics Canada's Social Data Linkage Environment (SLDE) using variables such as: surname, given names, birthdate, and geography (province, city, postal code). Within SDLE, population data files for social analysis are linked to the Derived Record Depository (DRD), a dynamic relational database containing only basic personal identifiers (surname, given names, birthdate, and geography (province, city, postal code)). Survey and administrative data are linked to the DRD using a generalized record integration software that supports deterministic and probabilistic integration. The linkage was conducted in accordance with the Policy on Record Linkage[17]and approved by Statistics Canada's Executive Management Board. Statistics Canada ensures respondent privacy during linkage and subsequent use of linked files.

Variables

From the CCMED:

- Demographic variables such as age, sex, date of birth, date of death, province/territory
- Causes of death and related health conditions
- Multiple deaths for a given event
- Circumstances of death and coroner/medical examiner narrative report

From the CVSD:

- Postal codes for usual place of residence
- Underlying cause of death

From PCCF+:

- Population centre and rural area classification

From the Census:

- Indigenous identity population (First Nations people, Metis, Inuit, those with Registered or Treaty Indian Status, those with membership in a First Nation or Indian band) and the non-Indigenous population
- Usual place of residence: Residence type
- Usual place of residence: State of repair of residence
- Number of people in the household

Limitations

The CCMED includes data from 12 provinces and territories. Data for Manitoba are not currently included in the database. All data are considered preliminary and include only closed cases. Closed cases refer to those whose investigation or inquest is complete and whose cause and manner of death are final.

CCMED data coverage varies from one variable to another. Coroners and medical examiners may include additional circumstance information in the reports submitted to the CCMED, but the level of detail provided in the report varies by death investigator. When there is no detail or information provided for a given circumstance, the information is considered 'not specified' and results for that circumstance should be interpreted with caution.

About one-third of the 2,200 (700) fire-related deaths identified in the CCMED from 2011 to 2020 linked to at least one of the three sample surveys (2006 or 2016 Census of Population or 2011 NHS). The linked dataset may not be representative of all fire-related deaths in Canada. That is, the proportions presented in this article may not reflect the true distribution of fire-related fatalities considering only a subset of fire-related deaths linked to the census datasets. Caution should be exercised when interpreting the results. In addition, the results should not be extrapolated to the entire population of Indigenous and non-Indigenous people in Canada.

Indigenous people living on reserve and in the territories were overrepresented among Indigenous people sampled for the 2006 and 2016 Census of Population and the 2011 NHS. The analysis excludes institutional and collective dwelling populations and excludes those living on incompletely enumerated reserves and settlements. Furthermore, Indigenous identity was self-reported, which may have led to underestimation or overestimation of the mortality proportions in some Indigenous groups. The proportions of fire-related fatalities for small areas and small subgroups of the population may experience substantial year-to-year random fluctuations since death is a relatively rare event, particularly death resulting from a fire.

While the article used place of residence information collected on the Census Day closest to but preceding death (May 16, 2006; May 10, 2011; May 10, 2016), it is possible that the individual was in a different residence during the fatal fire. Additionally, the deceased's family composition at the time of their death may differ from the information collected on Census Day (i.e., older child may have moved out of the home, deceased married or began living in a common-law relationship etc.).

While a distinction-based approach to acknowledge the unique histories, interests and priorities of First Nations people, Métis, and Inuit is important, such an approach was not feasible due to the small sample size of Indigenous people in the linked dataset.

To ensure the confidentiality of the results, a controlled rounding process was used. Counts were rounded to a neighbouring multiple of five.

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Appendix 1

Comparing the total population of fire-related deaths in CCMED from 2011 to 2020 (2200 deaths) to the total number of fire-related deaths from the linked dataset (700 deaths), by select characteristic.

Variable Name	Description	Percent distribution of fire-related deaths in CCMED (2200) (%)	Percent distribution of fire-related deaths in the linked dataset (700) (%)
Select demographic information			
Sex	Male	63%	62%
	Female	36%	38%
Age group	0 - 45 years	29%	28%
	45 years and older	71%	72%
Province*	Quebec	25%	23%
	Ontario	36%	34%
	Saskatchewan	5%	7%
	Alberta	13%	14%
	British Columbia	12%	12%
Some select circumstances information			
Season	Winter (DEC - FEB)	32%	31%
	Spring (MAR - MAY)	28%	28%
	Summer (JUN - AUG)	18%	17%
	Fall (SEP - NOV)	22%	24%
Cause of death**	Smoke Inhalation	63%	62%
	Burns	21%	22%
	Smoke inhalation and burns	10%	10%
Manner of death	Accident	81%	78%
	Suicide	12%	15%
	Other	7%	7%
Location of death	Residential	87%	87%
	Non-residential	8%	7%
	Not specified	5%	6%

Note(s): * select provinces with majority of fire-related deaths

** select causes of death

Circumstances surrounding fire-related suicides, 2011 to 2020

Released at 8:30 a.m. Eastern time in The Daily, Tuesday, October 11, 2022

Fatal fires are tragic events that are devastating to individuals, families, and communities. From 2011 to 2020, there were on average 220 fire-related deaths in Canada each year. While the majority of fire-related deaths were classified as unintentional, 1 in 6 were classified as intentional (i.e., suicide or homicide). Unlike unintentional fire-related deaths, intentional fire-related deaths result from an individual creating fire with intent to harm oneself and/or others.

Coroners and medical examiners investigate deaths that are sudden and unexpected, including intentional fire-related deaths. Although the circumstances or details surrounding these tragic events are not always determined, insights can be obtained from the investigation findings. The results in this report are based on new insights released today from the Canadian Coroner and Medical Examiner Database (CCMED) from 2011 to 2020. This report follows a previous analysis on the circumstances surrounding unintentional fire-related deaths released on June 16, 2022.

Fire-related suicides account for more than 3 in 4 intentional fire-related deaths

From 2011 to 2020, coroners and medical examiners investigated on average 26 fire-related suicides (i.e., suicide by smoke, fire, and flame) each year. While fire-related suicides accounted for more than three-quarters of intentional fire-related deaths during this same reference period, they accounted for less than 1% of overall suicides in Canada.

Suicide is a complex issue involving multiple factors and is a major cause of premature and preventable death. Previous studies have found that suicide often results from the interaction of various factors including mental illness, substance use, stressful life events, terminal illness, trauma and family history of suicide. If you or someone you know is struggling with thoughts of suicide or suicide-related behaviour, help is available from Talk Suicide Canada (1-833-456-4566). If you or someone you know is in immediate danger, please call 9-1-1.

The factors that influence a person's choice of suicide method (e.g., hanging, poisoning, firearm, fire-related) are not well understood. Some of the factors may include accessibility (i.e., access to a means of suicide), anticipated nature of a death or dying experience, sociocultural acceptance or media portrayal of suicide. The following sections will provide an overview of the coroner or medical examiner reported circumstances surrounding fire-related suicides.

The majority of fire-related suicides are a result of smoke inhalation

Most fire-related suicides were a result of smoke inhalation (52%), while another 12% were caused by a combination of smoke inhalation and burns, and 29% were due to burns alone (e.g., by self-immolation). Smoke inhalation leads to asphyxia, a condition where the body's supply of oxygen is deprived. Unlike deaths due to smoke inhalation, which are often immediate, deaths reported to be caused by burns often involved the individual surviving the fire but succumbing later to complications of the burns (e.g., infection, sepsis, organ failure). Other or multiple causes of death (e.g., blunt force trauma or drug toxicity occurring as part of a fire incident) were reported in 4% of fire-related suicides (the cause of death was not specified in 3% of fire-related suicide deaths).

Accelerants are involved in over 2 in 5 fire-related suicides

Accelerants are substances used to spread a fire. From 2011 to 2020, coroners and medical examiners reported the use of accelerants (e.g., gasoline or kerosene) in 42% of fire-related suicides. In another 8% of fire-related suicides, accelerant containers were found at the scene, but the investigation was not able to conclude whether a substance was used. Reports of accelerant use varied by cause of death. Coroners and medical examiners reported that an accelerant was used in more than half of burn-related suicides (53%), while its use was less frequently reported in suicides related to smoke inhalation (36%).

In 2% of fire-related suicides, accelerants were not used to spread the fire. Meanwhile, information on accelerants was either unknown, not specified, or not applicable for 48% of fire-related suicides.

Most fire-related suicides occur on residential properties

Fire-related suicides occurred both indoors and outdoors on residential (61%) and non-residential (33%) properties. General location information was not provided in 6% of fire-related suicides.

Nearly 1 in 6 residential fire-related suicides occurred outside (13%) (e.g., backyard or driveway) or in a vehicle parked on the property (3%), while the majority of residential fire-related suicides occurred indoors, including inside a house (38%), multi-unit dwelling (13%) (e.g., apartment building, hotel, or a long-term care facility), barn or shed (4%), moveable dwelling (1%), or in an unspecified indoor residential location (20%). The residential location (whether indoor or outdoor) was not specified in 8% of cases.

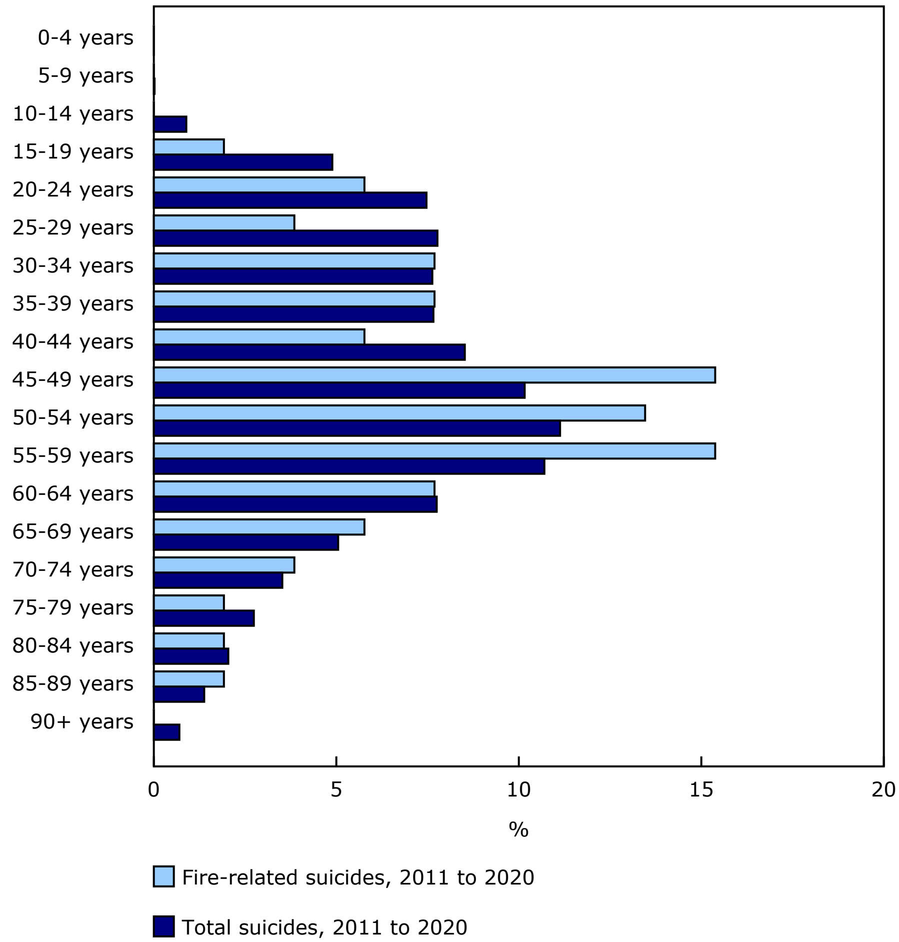
Unlike residential fire-related suicides, the majority of non-residential fire-related suicides occurred in a parked vehicle (65%) (e.g., located in a parking lot or on the side of a road) or outdoors in public areas (29%), while 6% occurred indoors (e.g., workplace).

The rate of fire-related suicide is higher among men

From 2011 to 2020, men (10.9 deaths per 1,000,000 population) were over three times more likely than women (3.6 deaths per 1,000,000 population) to die in a fire-related suicide. Methods of suicide tend to vary by sex. Generally, men are more likely to use violent methods such as hanging or firearms, while women are more likely to use less violent methods like poisoning. However, regardless of method, the suicide rate for men in Canada has been higher than the suicide rate for women since the 1950s.

Middle-aged adults were also overrepresented among fire-related suicides. From 2011 to 2020, 44% of fire-related suicides in Canada involved people aged 45 to 59, while this same age group represented 32% of overall suicides. While this pattern (of middle-aged adults being overrepresented) was also noted for poisoning suicides, the rates of suicide by hanging were higher among younger adults and the rates of suicide by firearm were higher among older adults.

Chart 1
Percentage distribution of fire-related suicides compared with the distribution of total suicides, by age group



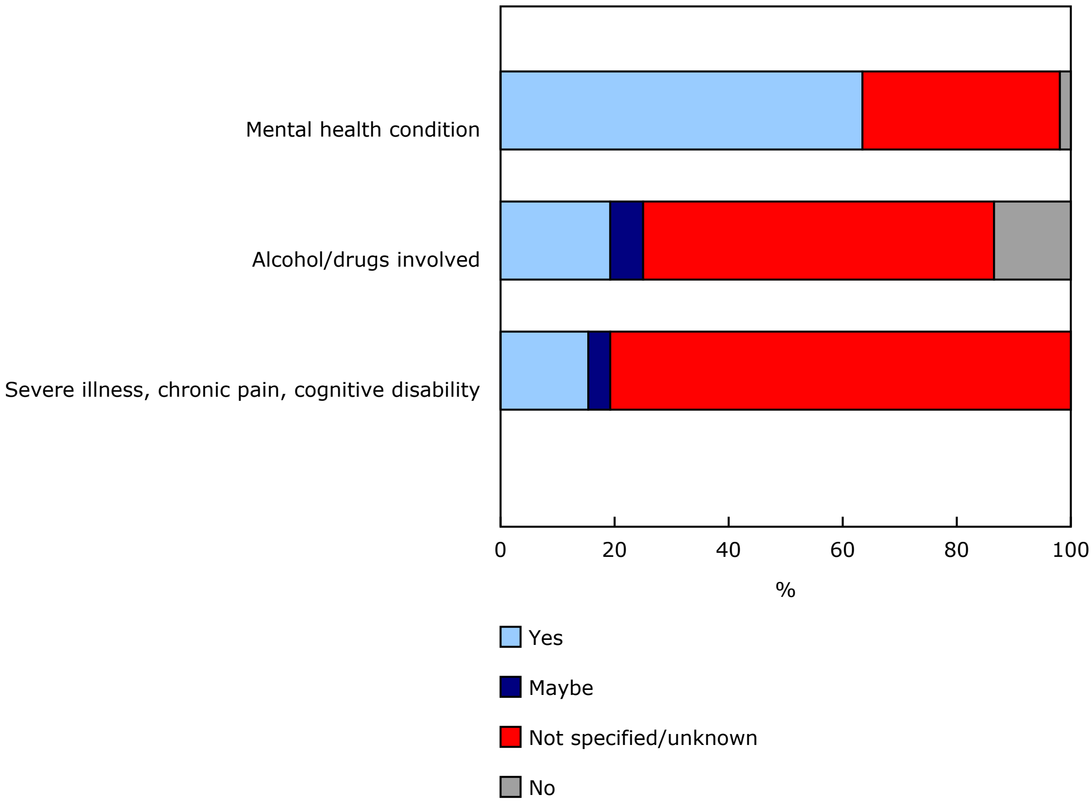
Note(s): Data were not available for all jurisdictions for all years (see Note to readers)
Source(s): Canadian Coroner and Medical Examiner Database (5125) and table 13-10-0394-01.

Additional circumstances surrounding fire-related suicides

Coroners and medical examiners may include information on additional circumstances in the reports submitted to the CCMED, but the level of detail provided in the report varies by death investigator and by jurisdiction. In addition to providing information on demographics and causes of death, the circumstances more commonly reported by coroners and medical examiners investigating fire-related suicides include mental health conditions, the potential role of alcohol or drugs, and severe illness, chronic pain or cognitive disabilities. These circumstances may be relevant for suicides more generally, and not necessarily specific to those that are fire-related.

The presence of a risk factor is considered "not specified" when the information for a given risk factor is missing from the coroner or medical examiner report, while the absence of a risk factor can only be considered when the coroner or medical examiner has indicated that a given factor was not present.

Chart 2
Presence of select factors more commonly reported by a coroner or medical examiner investigating fire-related suicides



Note(s): "Mental health condition" was indicated when the coroner or medical examiner (C/ME) reported that the decedent had a confirmed mental health condition. "Alcohol/Drugs involved" was indicated when the C/ME reported that the decedent had consumed alcohol or drugs prior to the event. "Severe illness, chronic pain, cognitive disability" was indicated when the C/ME reported that the decedent had a confirmed severe illness, chronic pain, or a cognitive disability. Data were not available for all jurisdictions for all years (see Note to readers)
Source(s): Canadian Coroner and Medical Examiner Database (5125).

A coroner or medical examiner reported that the deceased individual suffered from a mental illness in nearly two in three fire-related suicides. In another 2% of fire-related suicides, it was reported that the individual did not have a mental illness. Information on mental health conditions was unknown or not specified in 35% of fire-related suicides.

Alcohol or drug consumption was reported in nearly one in five fire-related suicides. In another 6% of fire-related suicides, it was reported that the deceased individual may have consumed alcohol or drugs (e.g., open containers found on the scene). Alcohol or drug consumption may impair judgment, decrease inhibition, and increase impulsivity. In 13% of cases, it was reported that the deceased individual had not consumed any alcohol or drugs. The consumption of alcohol or drugs was not specified in 62% of fire-related suicides.

Finally, coroners and medical examiners reported a severe illness, chronic pain or cognitive disability in nearly one in six fire-related suicides. These conditions were not specified in 81% of fire-related suicides.

Note to readers

The Canadian Coroner and Medical Examiner Database (CCMED) was developed at Statistics Canada in collaboration with the 13 provincial and territorial Chief Coroners and Chief Medical Examiners and the Public Health Agency of Canada. Currently, it combines data from all provincial and territorial databases, with the exception of Manitoba.

For the provinces and territories included in the report, data are not available for all years. Data for Nova Scotia, New Brunswick, Quebec, Ontario, Saskatchewan, Alberta, British Columbia, Yukon, and the Northwest Territories are available from 2011 to 2020. Data for Prince Edward Island are available from 2011 to 2019, data for Nunavut are available for 2011 to 2018 and data for Newfoundland and Labrador are available for 2020. All data are considered preliminary and include only closed cases. Closed cases refer to those whose investigation or inquest is complete, and the cause and manner of death are final. Data for this report were extracted in October 2021.

At the time this report was written, 2,190 fire-related deaths were documented in the CCMED from 2011 to 2020. Of these, 260 were classified as suicides. This value was used for reporting on the circumstances surrounding fire-related suicides. CCMED data coverage varies from one variable to another.

The number of records for more recent years will be lower than what may be expected as only closed cases are published. Moreover, as the source of non-response and the completeness of the available information varies both between and within jurisdictions, users are advised to exercise caution when comparing data between years and across provinces and territories.

The risk factors for suicide come from the Health Canada article "Suicide in Canada: update of the report of the Task Force on Suicide in Canada" and the page Suicide: risks and prevention on the Government of Canada website.

Acute alcohol use as a risk factor for suicide comes from the following article: "Acute alcohol consumption, alcohol outlets, and gun suicide," in Substance Use and Misuse, 2011.

Information on reasons for choosing a method of suicide come from the following articles: "Influences of the media on suicide," in the British Medical Journal, 2002; "Factors influencing the decision to use hanging as a method of suicide: qualitative study," in The British Journal of Psychiatry, 2010; "Factors associated with choice of high lethality methods in suicide attempters: a cross-sectional study," in the International Journal of Mental Health Systems, 2014; "Changes in rates of suicide by car exhaust asphyxiation in England and Wales," in Psychological Medicine, 2001.

Effects of alcohol come from the page About alcohol on the Government of Canada's website.

Counts referenced in this report were rounded to a neighbouring multiple of five.

Definitions, data sources and methods: survey number 5125.

For more information, or to enquire about the concepts, methods or data quality of this release, contact us (toll-free 1-800-263-1136; 514-283-8300; **infostats@statcan.gc.ca**) or Media Relations (**statcan.mediahotline-ligneinfomedias.statcan@statcan.gc.ca**).

Circumstances surrounding unintentional fire-related deaths, 2011 to 2020

Released at 8:30 a.m. Eastern time in The Daily, Thursday, June 16, 2022

Fatal fires are tragic events that are devastating individually, to families and within communities. From 2011 to 2020, there were approximately 220 fire-related deaths in Canada each year. The vast majority of these fire-related deaths were classified as unintentional (accidents) (81%). Smaller proportions of these deaths were classified as either intentional (15%), such as suicides and homicides, or were undetermined (4%), where the classification of the manner of death (i.e., accident, homicide or suicide) could not be determined following investigation.

Understanding the circumstances surrounding unintentional fire-related deaths in Canada is a valuable starting point towards implementing preventative measures that can reduce harm to Canadians. Although the circumstances or details surrounding the death are not always known, insights can be obtained from findings reported by coroners and medical examiners who investigate these tragic events. The results in this report are based on new insights released today from the Canadian Coroner and Medical Examiner Database (CCMED) covering the period from 2011 to 2020.

Residential fires are the leading type of unintentional fire-related death in Canada

Residential fires are the leading type of unintentional fire-related death in Canada. While the proportion of all fires that occur in residential structures is relatively small (31%) according to the National Fire Information Database, fire-related deaths occurring in private homes, long-term care facilities, temporary dwellings (e.g., hotels, trailers, tents) or elsewhere on residential property (92%) represented the vast majority of all unintentional fire-related deaths from 2011 to 2020.

According to previous research, the risk factors for fatal residential fires are different than those associated with nonfatal residential fires. While nonfatal residential fires were commonly linked to cooking or fires starting in the kitchen and electrical failure, some of the risk factors most often associated with fatal residential fires, according to previous studies, are the consumption of drugs or alcohol, improperly discarded cigarettes, living alone, being asleep at the time of the fire, older age, male sex, and the fire occurring in a mobile home. In order to prevent injury and death from fires, Health Canada recommends having a clear and well-practised escape plan, a suitable number and placement of smoke alarms in working order, and a working fire extinguisher in the home.

Males and adults aged 45 and older are more likely to die in a residential fire

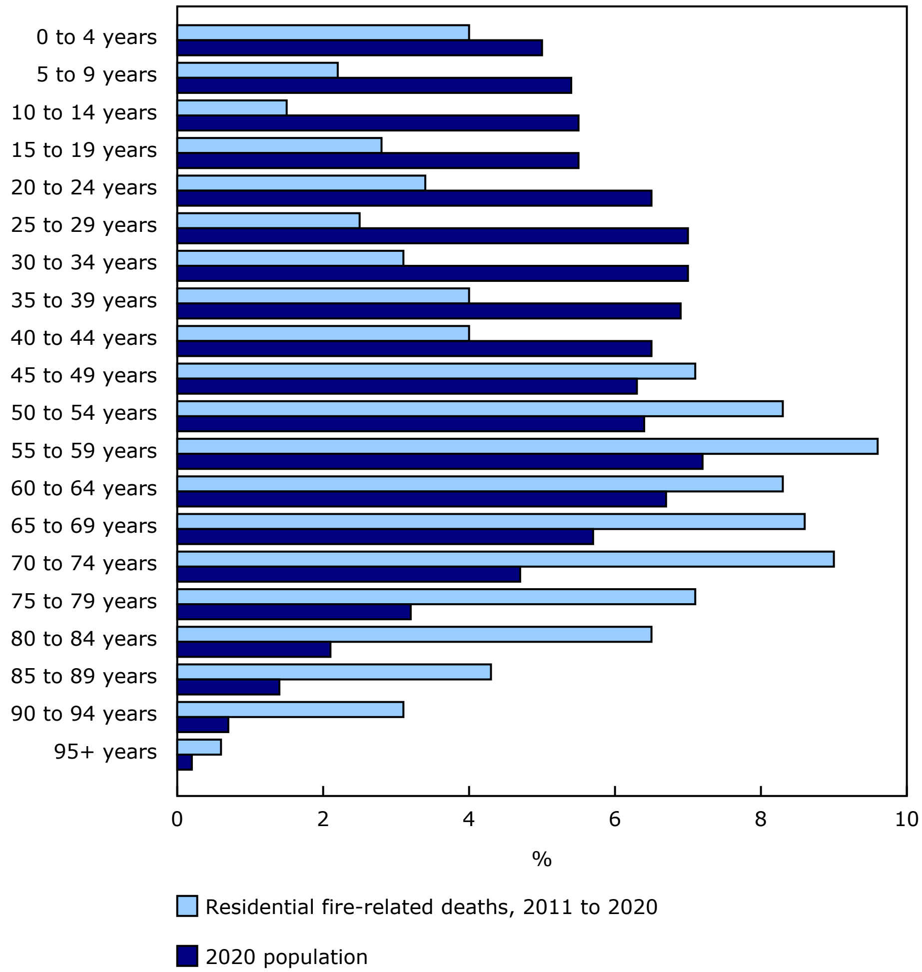
Unintentional residential fire-related deaths affect people of both sexes and all ages, however, men and older adults are overrepresented. From 2011 to 2020, males were 1.5 times more likely than females to die in an unintentional residential fire. This trend is consistent with previous research on fire-related death rates in Canada and internationally.

Older adults are also at a greater risk of fire-related death than their younger counterparts. From 2011 to 2020, the rates of unintentional residential fire-related death were higher than the Canadian average (4.3 deaths per 100,000 people) in each selected age group above 44 years.

According to previous research, older persons are at greater risk of residential fire-related death. Results from the CCMED show that nearly one-third of unintentional residential fire-related deaths in Canada involved people 70 years and older, while this same age group represented one-eighth of the population in 2020. Findings from the 2017 Canadian Survey on Disability indicate that disabilities (e.g., cognitive disabilities, mobility disabilities) are more common among seniors. These disabilities may affect a person's ability to react to or escape from a fire.

From 2011 to 2020, a coroner or medical examiner reported a mobility-related (e.g., use of crutches, wheelchair or other) or cognitive (e.g., dementia) impairment in 14% of unintentional residential fire-related deaths. In just over half of these cases, the individual was aged 70 and older.

Chart 1
Proportion of unintentional residential fire-related deaths compared to the proportion of the population, by age group

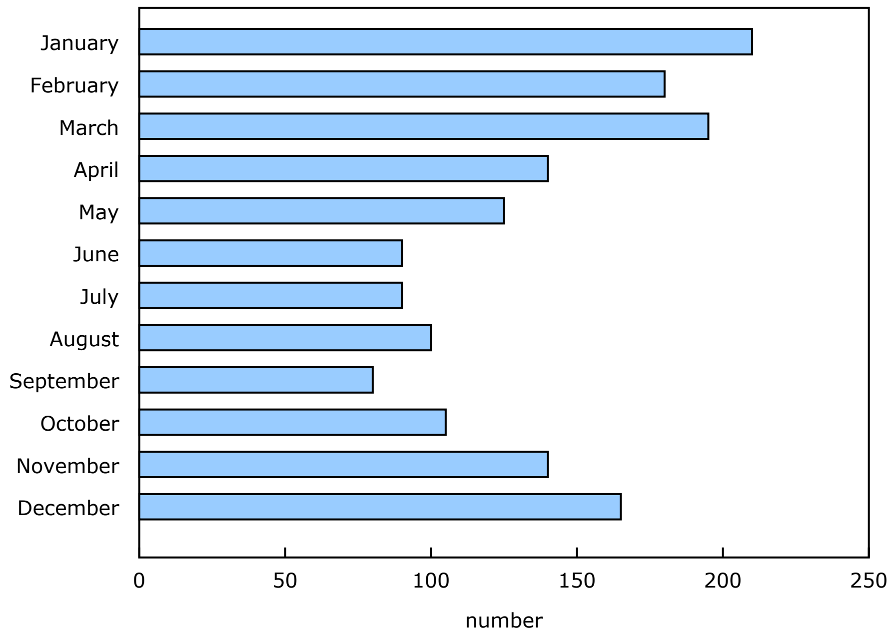


Note(s): Data were not available for all jurisdictions for all years (see Note to readers).
Source(s): Canadian Coroner and Medical Examiner Database, 2011 to 2020 (5125), and table 17-10-0005-01.

The colder months saw more than twice as many unintentional residential fire-related deaths as the warmer months

Unintentional residential fire-related deaths are more common in the winter. During the 2011 to 2020 period, the number of residential fire-related deaths tended to increase in the early fall, peaking in the winter months, subsequently decreasing in early spring. The four-month period from December to March saw over twice as many residential fire-related deaths as the four-month period from June to September. During the colder months, there is increased use of heaters and wood-burning stoves. Additionally, people remain indoors for longer periods of time, leading to an increased frequency of indoor smoking and use of candles.

Chart 2
Average number of unintentional residential fire-related deaths by month, 2011 to 2020



Note(s): Data were not available for all jurisdictions for all years (see Note to readers).
Source(s): Canadian Coroner and Medical Examiner Database, 2011 to 2020 (5125).

The majority of unintentional residential fire-related deaths were a result of smoke inhalation

The majority (68%) of residential fire-related deaths were a result of smoke inhalation alone, while 10% were reported to be caused by both smoke inhalation and burns, and 17% were due to burns alone. Smoke inhalation leads to asphyxia, a condition where the body's supply of oxygen is deprived. Unlike deaths due to smoke inhalation which are often immediate, deaths reported to be caused by burns often involved the individual surviving the fire, but succumbing later to complications of the burns (e.g., infection, sepsis, organ failure). In 2% of fatal residential fires, the death was attributed to another cause, such as blunt force trauma from falling debris, a jump, a fall, or an explosion. The cause of death was unknown or not specified in 3% of deaths.

At least one modifiable risk factor was present in approximately half of unintentional residential fire-related deaths

Coroners and medical examiners may include additional circumstance information in the reports submitted to the CCMED, but the level of detail provided in the report varies by death investigator and by jurisdiction.

In addition to providing information on demographics and causes of death, the findings more commonly reported by coroners and medical examiners investigating residential fire-related deaths include: residence type, source of ignition, consumption of alcohol or drugs, and presence of working smoke alarms. From 2011 to 2020, at least one of these more commonly reported modifiable risk factors (i.e., alcohol/drug consumption prior to the event, non-functional smoke alarm, and cigarette smoking as a source of ignition) was reported in approximately half of unintentional residential fire-related deaths investigated by a coroner or medical examiner.

The presence of a risk factor is considered "not specified" when the information for a given risk factor is missing from the coroner or medical examiner report, while the absence of a risk factor can only be considered when the coroner or medical examiner has indicated that a given factor was not present.

Unintentional residential fire-related deaths occurred in various residence types or outdoors on residential property

Unintentional residential fire-related deaths occurred in both permanent and temporary residence structures or outdoors on residential property. From 2011 to 2020, 46% of residential fire-related deaths occurred in a house (e.g., single, semi-detached, row house, cottage, or mobile home), 23% in a multi-dwelling unit (e.g., apartment building, long-term care facility or hotel), 4% in a moveable dwelling (e.g., recreational vehicle, trailer), and 3% in other types of temporary shelter (e.g., tent) or outdoors on residential property.

At least 1 in 7 unintentional residential fire-related deaths occurred in residences without a working smoke alarm

Smoke alarms save lives. From 2011 to 2020, at least 14% of unintentional residential fire-related deaths occurred in homes where the smoke alarm was either missing (8%) or non-functional (6%). It's possible these percentages are even higher since the presence or functionality of a smoke alarm could not always be confirmed following an investigation if the damage to the home was too significant. Overall, from 2011 to 2020, information on smoke alarms was either not specified, unknown or not applicable in 71% of unintentional residential fire-related fatalities submitted to the CCMED. According to Health Canada, having the recommended number of functional smoke alarms in the correct places in a home can significantly reduce the risk of fire-related injury or death.

At least 1 in 5 unintentional residential fire-related deaths were caused by cigarettes or other smoking materials

A dropped cigarette is a risk factor for unintentional residential fire-related deaths. According to a Health Canada report using data collected by the Canadian Association of Fire Chiefs, fires started by cigarettes resulted in more deaths than fires started by other sources.

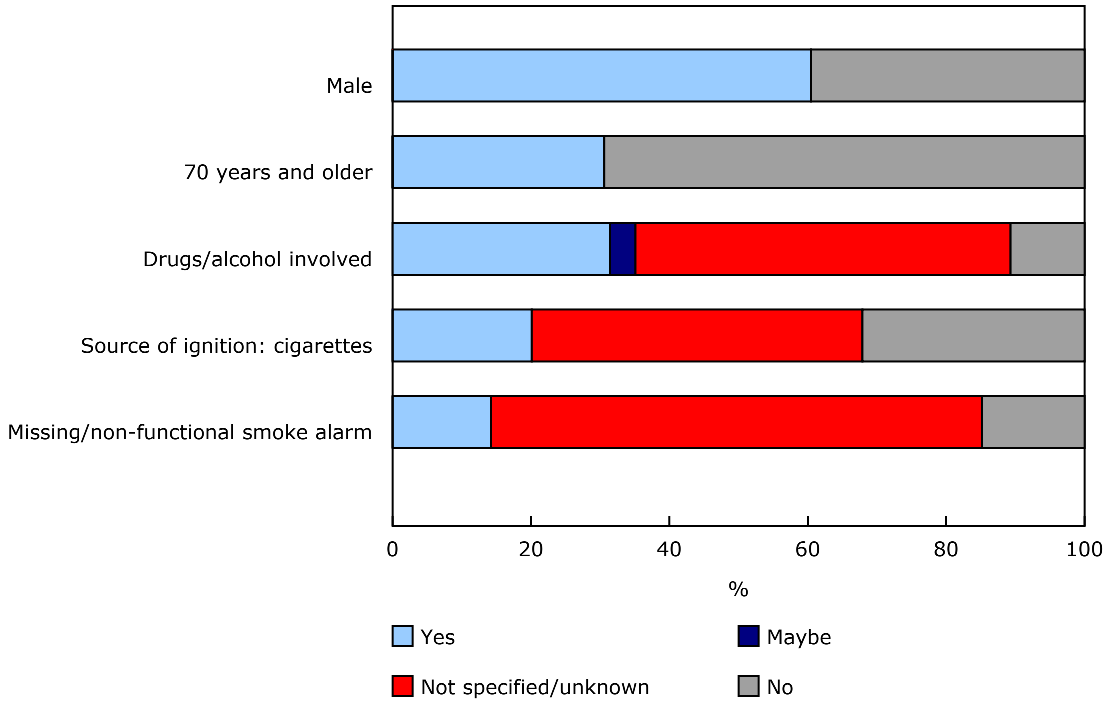
From 2011 to 2020, the coroner or medical examiner reported that the fire was ignited by a cigarette, cigarette lighter, pipe or other material used for smoking in at least 20% of residential fire-related deaths. Other fatal residential fires were caused by a cooking (10%) or electrical (8%) incident, candles or other open flames (7%), a heating device (5%), or from other sources (2%). The initial source of fire was undetermined or unspecified in 48% of cases. This information is more likely to be undetermined or unknown when there is significant damage to a structure.

The consumption of alcohol, cannabis, or illicit drugs was reported in nearly one-third of unintentional residential fire-related deaths among persons aged 15 and older

The consumption of alcohol or drugs is a risk factor for residential fire-related death. In 31% of unintentional residential fire-related deaths among persons aged 15 and older, the coroner or medical examiner reported the consumption of alcohol, cannabis or illicit drugs. In 4% of deaths, the coroner or medical examiner reported the presence of open containers of alcohol or drug-related paraphernalia at the scene of the fire. Alcohol or drug intoxication may impair judgment and coordination, which may increase the risk of unintentionally starting, or of having difficulty reacting to (e.g., ability to wake up) and escaping from a fire. The consumption of substances was more commonly reported among males (37%) than females (22%).

In 11% of residential fire-related deaths, there were no reports of alcohol or drug consumption. The consumption of alcohol or drugs was not specified in 54% of cases.

Chart 3
Select factors more commonly reported by a coroner or medical examiner investigating unintentional residential fire-related deaths



Note(s): "Drugs/Alcohol involved" was indicated when the coroner or medical examiner (C/ME) reported that the decedent had consumed alcohol or drugs prior to the event. "Source of ignition: cigarettes" was indicated when the C/ME reported that the source of ignition for the event was a cigarette or other smoking materials. "Missing/non-functional smoke alarm" was indicated when the C/ME reported that the smoke alarm was either missing or non-functional. Data were not available for all jurisdictions for all years (see Note to readers).
Source(s): Canadian Coroner and Medical Examiner Database, 2011 to 2020 (5125).

Snapshot of unintentional fire-related deaths occurring on non-residential property

Non-residential fire-related deaths occurring in parked cars, workplaces, public spaces and rural areas represented less than 5% of all investigated unintentional fire-related deaths in Canada from 2011 to 2020. As with residential fire-related deaths, non-residential fire-related deaths were more common among males (80%) than females (20%). However, unlike residential fire-related deaths, non-residential deaths were less frequent among older adults. Instead, persons aged 30 to 59 represented the majority (73%) of non-residential fire-related deaths from 2011 to 2020. This age group represented less than 40% of the population in 2020. This trend can be explained in part by this age group accounting for the majority of persons in the workforce. At least 33% of non-residential fire-related deaths were reported to have occurred in a workplace.

Unlike residential fire-related deaths which were largely due to smoke inhalation, the leading cause of non-residential fire-related deaths was burns. Among these deaths, 47% were caused by burns, 33% by smoke inhalation, 7% from a combination of both, and 7% by blunt force trauma (e.g., an explosion or due to a fall). The consumption of alcohol or drugs was reported in over 27% of non-residential fire-related deaths, and in another 7% of deaths, coroners or medical examiners indicated that alcohol or drugs may have been consumed (e.g., open containers at the scene). Finally, the source of ignition for non-residential fire-related deaths varied and included open flames, cigarettes, a heating mechanism, electrical, and work-related equipment (e.g., grinders, engines).

Being aware of fire safety recommendations is important to reducing the risk of death or harm. A subsequent publication with information on intentional fire-related deaths and criminal incidents will be made available later this year.

Note to readers

The Canadian Coroner and Medical Examiner Database (CCMED) was developed at Statistics Canada in collaboration with the 13 provincial and territorial Chief Coroners and Chief Medical Examiners and the Public Health Agency of Canada. Currently, it combines data from all provincial and territorial databases, with the exception of Manitoba.

For the provinces and territories included in the report, data are not available for all years. Data for Nova Scotia, New Brunswick, Quebec, Ontario, Saskatchewan, Alberta, British Columbia, Yukon, and the Northwest Territories are available from 2011 to 2020. Data for Prince Edward Island are available from 2011 to 2019, data for Nunavut are available for 2011 to 2018 and data for Newfoundland and Labrador are available for 2020. All data are considered preliminary and include only closed cases. Closed cases refer to those whose investigation or inquest is complete and the cause and manner of death are final. Data for this report were extracted in October 2021.

Fire-related deaths in this report include deaths resulting from explosions and exclude deaths occurring from a transport-related event (moving vehicle). At the time this report was written, 2,190 fire-related deaths were documented in the CCMED from 2011 to 2020. Of these, 1,770 were classified as unintentional. This value was used for reporting on the circumstances surrounding unintentional fire-related deaths. CCMED data coverage varies from one variable to another. The location of the fire was not specified in 4% of fire-related deaths.

The number of records for more recent years will be lower than what may be expected as only closed cases are published. Moreover, as the source of non-response and the completeness of the available information varies both between and within jurisdictions, users are advised to exercise caution when comparing data between years and across provinces and territories.

The risk factors for nonfatal and fatal fires comes from an article in the Fire Safety Journal, "Comparative investigation of 'survival' and fatality factors in accidental residential fires" by Lin Xiong, Dorothy Bruck and Michelle Ball (Volume 73, April 2015, Pages 37-47). Another article, outlining risk factors for fatal fires, comes from the journal Injury Prevention: "House fire injury prevention update. Part 1. A review of risk factors for fatal and non-fatal house fire injury" by Lynn Warda, Milton Tenenbein and Michael E K Moffatt.

The proportion of fires that occur in residential structures comes from the National Fire Information Database (2014).

Safety recommendations to reduce injuries and death from fire come from the following Health Canada website: Fire safety in your home.

Information on disabilities among seniors comes from the 2017 Canadian Disability Survey.

Information on cigarettes as the leading cause of fire-related death comes from a Health Canada report using data from the Canadian Association of Fire Chiefs.

Counts referenced in this report were rounded to a neighbouring multiple of five.

Definitions, data sources and methods: survey number 5125.

For more information, or to enquire about the concepts, methods or data quality of this release, contact us (toll-free 1-800-263-1136; 514-283-8300; **infostats@statcan.gc.ca**) or Media Relations (**statcan.mediahotline-ligneinfomedias.statcan@statcan.gc.ca**).

Fire and at risk populations in Canada

Analysis of the Canadian National Fire Information Database

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December 2017

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Executive Summary

1. This research examines the Canadian National Fire Information Database (NFID) to understand more about At Risk Populations (Area of Focus #5 as per the Request for Proposal documentation). The broad focus was to explore what we know about fire-related casualties in Canada and what the protective influences of working life safety systems are. The analysis focused on residential structure fires reported to the NFID between 2005 and 2015, reported by Alberta, British Columbia, Manitoba, Ontario, and Saskatchewan. With a focus on non-firefighter casualties, the sample of residential fires included 830 deaths and 4,656 injuries

2. Prior research indicates: (a) elevated risk for older residents (65 years and over), children under 5 years, and Indigenous populations, (b) present, functioning life safety systems also reduce the likelihood of deaths from residential fires, and (c) houses that experience residential fires are less likely to have working life safety systems in place.

3. There was approximately 7,130 residential fires per year with an average injury rate of 70.8 injuries per 1,000 fires and an average death rate of 10.9 deaths per 1,000 fires.

4. Fire-related deaths and injuries were more likely to involve males and older residents were much more likely to have died in fires (relative risk of 65 to 79 year olds dying 1.6 times above the population rate and 80 years and over 2.4 times greater than the population overall).

5. Almost one-third of fatalities were asleep at the time of fire, 31% were impaired by alcohol, drugs, or medication, and 21% were awake with no physical/mental impairments. Almost two-thirds of injuries involved a casualty who was awake with no physical/mental impairments at the time of the fire and one-quarter were asleep at the time of the fire.

6. Approximately half of deaths resulted from rapidly spreading fire/smoke, 14% resulted from high flame spread of combustible interior finish, and only 7% of the known reasons for failure to escape were as a result of age and/or other physical limitations.

7. About one-third of non-firefighter fatalities occurred while the casualty was attempting to escape, 29% did not act, and 14% experienced a loss of judgement or panic. Half of the cases resulting in injury involved the person entering/remaining for rescue, firefighting, or saving personal property.

8. Residential fires that were contained to the room of origin (44%) resulted in 57% of injuries and 24% of deaths, at a rate of 79.2 injuries and 3.8 deaths per 1,000 fires. In comparison, fires that extended beyond the room and (as far as beyond the property of origin, 22%) resulted in 28% of injuries and 59% of deaths (75.9 injuries and 28.4 deaths per 1,000 fires, respectively).

9. Residential fires that required fire department intervention (37%) resulted in 34% of injuries and 63% of deaths (at a rate of 18.5 deaths per 1,000 fires). In comparison, when fires were extinguished using hand held extinguishers or makeshift firefighting aids (17.0% of fires) there was a death rate of 1.7 per 1,000 fires.

10. Across the period of analysis the average rate of activation of working smoke alarms was 309.4 per 1,000 fires (with 2015 figures noticeably below this). There has also been a steady year-on-year increase in the presence of sprinkler protection in residential buildings, increasing to 72.5 per 1,000 fires in 2015.

11. Relatively few residential fires (4%) had complete sprinkler protection and two-thirds of these fires had no sprinklers. Comparing between these two groups, death and injury rates were much lower in the presence of complete sprinkler protection (1.3 deaths per 1,000 fires, compared to 11.3 deaths per 1,000 fires with no sprinkler protection).

12. The relative death rates per 1,000 fires was significantly lower for the 31% of fires when the smoke alarm was activated (6.8 per 1,000 fires), compared to fires where the alarm was not activated or was not installed (14.1 and 10.2 per 1,000 fires, respectively). As with previous research, the injury rate was highest in the presence of a working smoke alarm: consistent with casualties fighting fires.

13. When aggregating fire safety system presence and looking at fire outcomes, the following main findings were produced:
    a. Just over two-thirds of these residential fires had no present, functioning life-safety systems and these fires resulted in 80% of the deaths in this sample.
    b. Relative to fires with no life safety systems in place, fires with either a working smoke alarm or complete sprinkler protection are much less likely to result in a death, less likely to require fire department intervention, and less likely to extend beyond the room of origin.
    c. The compound effect of both sprinkler protection and a working smoke alarm resulted in only 4 deaths, required the least amount of fire department intervention, and the fires did not extend beyond the room of origin 94% of the time.

14. These findings are consistent with previous research and should be used to implement targeted fire prevention campaigns, building on Census data to identify at-risk populations. Given the aging population in Canada and the elevated risk of fatality for older citizens in the event of residential fires, this should be a priority for the Canadian emergency first responders and governments into the future. Based on these findings, the researchers urge the Canadian fire service to adopt a proactive, partnership-based, prevention focus to maximise the potential for elderly residents to remain living safely in their own homes for longer. In addition to targeting preventable fires, this initiative could also attempt to reduce the risks of trips/falls and crime victimisation. Given the consistency of findings relating to the elevated risk for this sub-section of the population, it is unacceptable to fail to act.

Research aim

This report summarises an analysis of the Canadian National Fire Information Database (NFID) to understand more about **At Risk Populations** (Area of Focus #5 as per the Request for Proposal documentation). In broad terms this research examines the extent to which the NFID can give additional insight into the uneven distribution of risk for fire across the Canadian population. The specific research questions that this research explores are:

1. What do we know about casualties (injuries and deaths) that have resulted from residential fires in Canada? This will focus on examination of:
    a. The demographic characteristics of casualties.
    b. What is known about the behavior of individuals who became fire casualties?
    c. What is known about the fires that led to these casualties?

2. What is the protective influence of working fire safety systems (smoke alarms and sprinkler systems)?
    a. What is the coverage of these life safety systems nationally?
    b. What are the longitudinal trends with respect to coverage of these life safety systems?
    c. How do fire-related casualties vary as a consequence of coverage of these life safety systems?

The answer to these questions will directly impact policy and practice decision making processes for the delivery of fire prevention services across Canada. Best-practice research clearly indicates that fire risk is unevenly distributed across time, space and individuals. Further to this, targeted prevention is possible, when founded on appropriate evidence-based analysis. This research will provide much-needed insight into the non-random distribution of risk across Canada. This knowledge will better-arm the fire service to proactively reduce fire risks for at risk populations, working in a targeted, prevention-focused, sustainable manner.

What do we know already? A short summary of relevant literature

This section of the report briefly summarizes what is already known about populations who are at risk from residential fire. Fires that occur in residential buildings are the leading cause of fire-related death and injury [1]. In 2007, 42,753 fires occurred in Canada resulting in the deaths of 224 civilians [2]. Thirty percent of these fires occurred in residential structures yet they accounted for 73% of deaths. Similarly, in the United States of America (U.S.), residential fires represented 28.6% of fires overall and caused 78% of deaths and 71% of injuries, in 2015 [3]. Not all residential fires are fatal, or require fire department intervention, yet various risk factors exist that, when present, can increase the likelihood of fire-related death or injury. Indeed, research has found significant differences among fatal and survived house fires [4]. In broad terms, it is important to understand the significance of individual characteristics, household characteristics, and area characteristics for their influence on residential fire outcomes. These outcomes are also mediated by the presence of functioning life safety systems such as smoke alarms and residential sprinklers.

AT-RISK POPULATIONS

Men, older adults (65+ years), children under 5 years, and Indigenous populations are over-represented among residential fire casualties [5]. Men are consistently more likely to die or become injured in a house fire than women [6]. This could be because men are more likely to be under the influence of drugs or alcohol and engaged in dangerous behaviors such as trying to fight the fire and attempting a rescue, when injured [1, 7]. Older adults, children and Indigenous communities are at increased risk for a number of reasons; further discussed below.

Older adults (aged 65 and over)

In the U.S., more than 1,000 older adults die in residential fires each year and another 2,000 are injured [6]. Internationally, older adults are consistently at greater risk of fire-related death than any other age group and the risk increases with age [8-12]. Indeed, research has found that for adults aged 65-74 years the relative risk of dying in a residential fire is 1.9 times higher than the general population and 4.6 times higher for those aged over 84 years [11]. Almost one-third of home fire victims are aged 65 years and over, yet this demographic only represent 13% of the American population [11].

Carelessly or inappropriately discarded smoking materials are the leading cause of ignition in fatal residential fires, especially those with elderly victims [1]. From 2007-2011 in the U.S., 46% of residential fire fatalities caused by smoking materials, were aged 65 years or older [1]. Fatal fires caused by heating units were also prevalent among this population with older adults accounting for 38% of these deaths. Holborn et al. [8] found that a significant number of house fire deaths among this demographic involved the ignition of clothing, followed by bed linens and upholstered furniture. When ignited, these materials could be more likely to result in fatality as it is possible they would be in close proximity to the victim. Almost half of elderly victims were located in the bedroom when injured (fatally and non-fatally) [6].

Older adults are at increased risk of casualty for a number of reasons. First, health declines with age and as a result the elderly are more likely than the general population to suffer from diminished sensory ability, mobility and mental capacity disorders. Secondly, the elderly are more likely to live below the poverty line which in itself creates a number of additional risk factors for casualty. Diminished sensory ability is a normal part of the ageing process, yet it also leads to increased risk in cases of fire [6]. According to the U.S. Fire Administration (2013a), a decrease in two or more of the senses can lead to a substantial increase in risk of fire-related casualty.

- **Vision.** Sight arguably plays the most important role in fire safety. Individuals with poor/no vision are less likely to notice when combustibles are placed too close to a heat source or smoking materials are not discarded correctly [6]. Diminished vision may also increase the risk of older adults falling on top of heating units or falling during escape, further increasing the risk of casualty.

- **Sound.** As mentioned above, many fire-related deaths occur when people are asleep, yet having a working smoke alarm can significantly reduce the risk of casualty. In fact, the auditory system is the only sensory system that remains active while an individual is asleep [13]. However, one in three older adults suffers from hearing loss and the number increases with age [14]. Age-related hearing loss most commonly affects an individuals' ability to hear high-pitched noises and the average residential smoke alarm emits a high-frequency signal [15]. Research has found that people with mild to moderately severe hearing loss are less likely to respond to the average residential smoke alarm when sleeping [16, 17], leaving a large proportion of older adults at greater risk during this time.
- **Touch.** As people age they experience changes in their skin (such as thinning and wrinkling), because of this older adults can experience a diminished sense of touch [18]. Higher tactile thresholds can mean that older adults have trouble sensing heat or pain and have slower reaction to various stimuli [18]. Changes such as these could lead to an increase in burn severity, as during a fire, grabbing a hold of something (such as a door handle) could cause serious damage to the skin, especially when the individual does not immediately notice/react to the heat.
- **Smell.** Along with sight, olfaction can aid us in quickly determining the presence of a fire. However, research has found that smell is not consistently capable of waking people from a deep sleep [19, 20]. As mentioned above, many victims of house fires are overcome whilst asleep. Indeed, from 2007-2011, 40% of fatalities died from smoke inhalation alone, in the U.S. [1]. Considering smell is unlikely to wake people from sleep in general and olfaction decreases with age, the chances of older adults waking from the smell of smoke alone are presumably even less than the general population.

Older adults are also likely to suffer from physical disabilities that restrict their ability to fulfil daily activities. In fact, 38.7% of older Americans reported having at least one physical or mental disability, with the most common being; serious difficulty walking or climbing stairs [21]. Research has found that people with physical disabilities/limited mobility are at greater risk of dying in residential fires [22]. Not only could limited mobility/physical disability limit a person's reaction time and their ability to escape, but they may also be unable to adequately install/maintain smoke alarms within their homes [23].

The elevated likelihood of an elderly person dying in the event of a residential fire is also influenced by incidents of diminished mental capacity in this cohort. In the U.S., 9% of men and 11% of women aged 65 years and over living among the public have a diagnosis of dementia [24]. Dementia, as well as other forms of severe decrease in mental capacity, can lead to an increased risk of fire-related casualty [11, 12]. As well as a possible reduction in reaction time, diminished mental abilities can lead to an increased likelihood of engaging in dangerous fire-related behaviors [11, 12]. They may also be less likely to recognize a hazard or comprehend the need to escape in certain situations.

Finally, the elevated risk for elderly residents is also influenced by characteristics of the living arrangements for this group. According to FIFARS (2016), in the U.S., 36% of women and 20% of men over the age of 65 years live alone and 39% of older American adults reported having housing problems. Furthermore, as the majority of older adults are not actively participating in the labor force, many rely on social security/retirement savings as their main form of income [24]. Ten percent of older adults in the U.S. live below the poverty line and 23% on a low income (FIFARS, 2016). People aged 65 years and over living below the poverty line are also twice as likely to smoke cigarettes [24] and households with at least one regular smoker are at greater risk of residential fire injury and less likely to have a working smoke alarm [25, 26]. In combination across these research findings, older adults that live alone are less likely to have working smoke alarms in their homes and are at increased risk of fire-related death [4, 27]. This relative disadvantage is also likely linked to the findings from Coty et al.'s [23] research, in which many of the participants (older adults) relied on free smoke alarm distribution from local fire departments.

Young Children (aged 5 and under)

In the past, along with older adults, young children have been over-represented among house fire casualties [28]. Fire-related death and injury among children under 15 decreases with age, with children under the age of 5 years accounting for the highest fire-related child deaths and injuries (Ahrens, 2014). However, research has found that the risk of fire-related casualty among young children has steadily been decreasing [1]. From 1980-2011, in the U.S., the percentage of home fire fatalities aged 5 years and under dropped from 18% down to 6%. Indeed, the U.S. Fire Administration's [12] study concluded that the relative risk for young children dying in a house fire was 10% less than the general population, in 2010. This decrease in child fire-related casualties is believed to be attributed to the introduction of child-resistant lighters in 1994 [1]. Yet, even though young children are now at less risk, they still remain vulnerable compared to older children as they are less likely to be able to understand the need to act quickly in certain situations and escape without the help of another [1].

Fire-play (or playing with a heat source) is the leading cause of fire-related death among children [1]. In fact, 80% of the people killed and 40% injured by house fires caused by fire-play were under the age of 15. Furthermore, 61% of these deaths were children aged 5 and under. It is important to note however, that child fatalities of fire-play are not always directly involved in the ignition. In their study of child victims of fire-play, Harpur et al. [29] found that the fatalities under the age of 2 years were the result of fire-play by an older sibling in the house. Matches and lighters were the most commonly cited sources of ignition in fires that resulted in child casualty [30, 31]. Fires caused by fire-play can spread out of control very quickly, especially in instances where bed linens or clothing were ignited [29]. As most children are directly involved with the ignition, many are injured/die from burns rather than smoke inhalation [29], which is the most common cause of residential fire-related casualty in general [1]. Indeed, in Harpur et al.'s [29] study 86% of children were located in the room of fire origin at the time of ignition, a significant risk factor in fatal fires. Most fires caused by fire-play also began in the bedroom or lounge room, another significant risk factor. Besides the risk factors associated with fire cause and location among this population, various household characteristics that increase risk also exist.

Risk factors for child fire-related casualty often depend on the child's home and family environment. Single parent, low SES households, the presence of a regular smoker and inadequate supervision are all major risk factors for child fire-related fatality [12, 29]. Single parent families are more likely to live below the poverty line or in low income households [32]. Low SES households already present a certain number of risks (as mentioned above for the elderly), however, low SES, single parent households are at additional risk. Single parents often rely on a sole income and are less likely to have access to child care services and as a result, may be unable to adequately supervise their children at all times. As the majority of child fire-related casualties are due to fire-play, supervision of the child could have a substantial impact on the probability of a fire occurring. Indeed, research has found that fire-play often occurs in the absence of a guardian or in the presence of a guardian that is incapable of preventing the fire (in another room/not in close enough proximity to prevent injury or incapacitated by drugs or alcohol) [22, 33].

Indigenous Populations

Internationally, Indigenous populations have consistently higher risk for fire-related casualty than Caucasian people. In New Zealand, Māori people are three times more likely to die in a residential fire than the general population [10]. First Nation's citizens in British Columbia, Canada, were also at greater risk, with statistics showing higher risk among every age group [34]. Overall, the risk of fire-related fatality for First Nation's people in British Columbia was 9.4 times higher than the general population. In the U.S., African Americans account for 13.3% of the overall population [35], yet they are twice as likely to die in a residential fire, with the highest death rates among young children and older adults [1]. Compared to Caucasian children (aged 0-4), African American children had 2.4 times higher risk of fatality [11]. Indeed, 29% of child fire-related deaths were African American. Much like the general older population, the risk of house fire casualty increases with age among the older African American population [6]. However, the increase in risk occurs at a substantially higher rate. Male African Americans aged 85 and over have the highest relative risk of house fire fatality than any other group in the U.S.; more than 19 times the risk of the general population and 4 times the general elderly population [11]. It is likely that Indigenous people are more likely to be at increased risk as they are more likely to live below the poverty line or on a low income. In America, both African American and American Indian populations specifically are more likely to live below the poverty line, smoke cigarettes, report having poorer overall health and older African American adults are also more likely to live alone; all significant risk factors in cases of residential fire [11, 24, 36-38].

AT-RISK AREAS AND HOUSEHOLDS

Relative risk within houses

Research has shown there are a range of factors associated with the area of original of a residential fire that are significantly associated with the likelihood of residential fire fatalities, including;

- Room of fire origin,
- Cause of ignition,
- Awareness of the occupant/s at the time of ignition,
- Location of the occupant/s at the time of ignition, and
- Absence of a smoke alarm [4, 39, 40].

Residential fires are most likely to occur in areas of high daily occupancy such as the bedroom, lounge room or kitchen [10, 41]. However, fires that begin in the bedroom or lounge room are more likely to result in fatalities than those that occurred in the kitchen [4]. Fires that begin in the kitchen are also less likely to require fire department intervention or spread beyond the room of fire origin [42]. This is likely to be related to the cause of ignition and awareness of the occupant/s at time of ignition.

Fires caused by inappropriately discarded smoking materials only account for 5% of residential fires, yet are the leading cause of fire-related death [1]. Fires caused by smoking materials and combustibles placed too close to a heat source are more likely to result in a fatality than cooking or electrical fires [4]. Cooking fires, however, are the most common cause of house fires and the leading cause of non-fatal fire-related injury [1]. It is likely that cooking fires may be less fatal because the occupants are likely to be awake, giving them more time to escape. In fact, occupants that are awake at the time of ignition and unimpaired by alcohol, drugs or disability are 12.9 times more likely to survive than those who are asleep [4].

The risk of casualty is significantly increased when the occupant is in the room of fire origin at the time of ignition [4]. Fires caused directly by human involvement are more likely to result in death than those that were not [4]. This is likely to be because fires spread out of control quickly and people are likely to be overcome within a short period of time, therefore making escape less likely when in close proximity to the fire [10]. Human activity during a fire can have a significant impact on ones risk of casualty. Most fatal fires occur at night during hours when people are likely to be asleep [41]. In fact, being asleep or having a physical disability are the most common factors contributing to death in house fires [41]. In addition to the above risk factors, certain areas are also at increased risk of fire-related casualty.

Area-level variation in risk of residential fire

It has been evident for some time that residential fire risk is not evenly distributed among society. Indeed, particular areas are at substantially higher risk than others. Research has found that rural areas, or areas with high proportions of older housing, vacant properties, unemployment/low income and Indigenous populations are more likely to experience residential fire [1, 43, 44]. In addition to at-risk areas, households that are rented, overcrowded, have children under 15 years, non-English speaking residents, or people who regularly smoke cigarettes/drink alcohol are also at increased risk [26, 44-46].

Rural areas are at increased risk for residential fire casualty. The smallest communities in the U.S. have the largest overall fire rates and fire-related fatality per capita [47]. The number of fires per 1,000 population and the frequency of fire incidents is higher in communities with a population of less than 5,000 [3]. Indeed, the rate of fire-related death in these communities is significantly higher than in communities with larger populations [3]. Rural areas are likely to be at increased risk for a number of reasons. First, these regions are more likely to have volunteer fire fighters, influencing factors such as response times and size of potential suppression forces [48]. Research comparing the differences in fire safety between rural and suburban communities has also found that rural residents are more likely to be on a low income and be over the age of 65; both risk factors for house fire casualty [49]. Finally, rural households are also less likely to own a smoke alarm or a telephone (to alert the fire department, should a fire occur) and twice as likely as suburban homes to use a space/gas heater as opposed to central heating.

With respect to disadvantage and low-SES areas, research has consistently found an increased occurrence of residential fire in areas with high proportions of low income/poverty. Indeed, Wuschke, Clare and Garis [50] found residential fire significantly clustered in areas with high levels of social disadvantage. Furthermore, Ducic and Ghezzo [45] found that house fires were more likely to occur in low income census tracks that had higher proportions of older housing. High income households are more likely to invest in fire safety equipment [51]. Furthermore, for low income households the purchase, use and maintenance of fire safety equipment may be postponed while income is limited [47]. In fact, individuals who live below the poverty line are less likely to have housing and appliances that meet fire safety standards and working smoke alarm/s within their homes [11, 12, 26]. One determinant of neighborhood decline and increased fire risk is the proportion of vacant properties within an area [46].

There is also an elevated risk of residential fire as a consequence of building occupancy, with house fires that occur in vacant properties account for 7% of residential fires overall in the U.S. [52]. On average, 25,000 vacant property fires occurred annually from 2010-2012, resulting in 60 deaths and 225 injuries per year. While the fire-related casualty rate among these properties is lower than occupied houses, these fires result in substantially more property damage, with the fire sometimes extending to surrounding properties. Vacant property fires also pose considerable risk to firefighters and nearby residents. Indeed, as mentioned by the U.S. Fire Administration [52], without knowing the state of the building, or whether or not there are people inside, entering a vacant property that is on fire can be particularly dangerous for firefighters. Furthermore, Schachterle et al. [48] found that the risk of fire in an area increases with each vacant property and the risk is heightened for households within 10 metres. From 2010-2012, in the U.S. approximately 11% of vacant house fires spread to nearby properties and while 89% stayed confined to the vacant household, 53% involved the entire house, compared to 14% of occupied house fires [52]. As well as at-risk areas and households, certain individuals are at significantly higher risk of dying/being injured in house fires than others.

LIFE SAFETY SYSTEMS

Internationally, smoke alarm use has increased substantially since the late 1970's – early 1980's [53]. Since smoke alarms have become widely available, many countries have made it mandatory by law to install smoke alarms in newly constructed households [54-56]. Today, research on the ownership and maintenance of smoke alarms is somewhat inconsistent. In the U.S., national research indicates that approximately 96% of households report having at least one smoke alarm [53]. As mentioned by Ahrens [57], this means that almost 5 million households in the U.S. remain unprotected by smoke detectors. However, research done at a county level found only 60.6% had at least one smoke alarm [49]. When considering the presence of smoke alarms in cases of residential fire, the research shows a substantial amount of fire-related deaths are occurring in houses with no functional smoke alarm present [57]. In fact, Garis and Clare [42] found that 74.3% of the house fires in their study had no present, functional smoke alarm. Indeed, whilst many households report owning a smoke alarm, the amount that own smoke alarms that actually work is much smaller. For example, Ahrens [58] found that 41% of residential fires in the U.S. occurred in houses with either no smoke alarm or no *functional* smoke alarms, 40% of deaths occurred in houses with no smoke alarm, whilst 23% of fatalities had a smoke alarm, but it was not working. Similarly, Zhang et al. [27] found that 83.6% of older adults in their study owned a smoke alarm, yet only 72% had working smoke alarms. Disconnected/dead batteries was the most commonly cited reason for inoperative smoke alarms [57]. Ahrens [57] found that smoke alarms were most likely to be disabled due to nuisance alarms which are usually triggered due to cooking or smoking cigarettes.

Many households also do not have adequate smoke alarm protection [59]. According to Ahrens [57], 12% of the fires in their study did not trigger the smoke alarm as the fire was too small. Similarly, 1% of U.S. house fire deaths occur in houses with working smoke alarms that were not triggered by the fire. Smoke alarms need to be placed/maintained as per recommendations (such as the National Fire Protection Association recommendations) in order to ensure the entire house is fully protected [59]. When correctly placed and functioning at the time of fire, smoke alarms can provide enough warning for the occupants to escape and contact fire services, limiting the spread of the fire and resulting in significantly less damage [40]. In cases, where working smoke alarms were present but people still died, the victims were most likely;

- In the room of origin,
- Involved in ignition,
- Asleep,
- Unable to act (due to disability or time),
- Over the age of 65,
- Overcome by the fire (clothing ignited), or
- Under the influence of alcohol [1, 8, 29].

Other life safety systems, such as wet pipe sprinklers, while not as common, are even more effective at reducing fire-related casualty (both death and injury) and property damage [42].

FIRE RISK WITH AND WITHOUT PROTECTION OF LIFE SAFETY SYSTEMS

House fires with present, functioning smoke alarms are less likely to result in death and require fire department intervention than house fires without functional smoke alarms [42]. Indeed, houses with at least one functional smoke alarm are 49% less likely to result in fatality in the event of a fire [58]. While house fires that had a present, functional smoke alarm resulted in less fatality, they had higher overall injury rates than houses without smoke alarms [42]. This is likely to be because the smoke alarm alerted the resident to the fire and they began to engage in firefighting behavior when they experienced the fire-related injury.

Sprinkler protection, while more effective at reducing casualty, is less common [42]. In fact, Garis and Clare [42] found that only 1.6% of the house fires in their study had complete sprinkler protection. Residential fires that had sprinkler protection resulted in considerably lower fire-related casualty than residential fires overall. These households were also less likely to require fire department intervention and the fire was more likely to be contained to the room of fire origin.

Owning functional fire safety equipment can significantly reduce the risk of fire-related casualty [57]. However, the use/maintenance of fire safety equipment (such as smoke alarms), like fire itself, is also not uniformly distributed across society.

At-risk households and smoke alarm ownership/use

Households with children are more likely to have working smoke alarms installed [26]. However, the protective factors associated with smoke alarms are also lessened among this demographic. Children have higher auditory thresholds than adults when asleep and research has found that many children are likely to sleep through a standard residential smoke alarm [15-17]. Furthermore, children are also more likely to spend longer periods in stage 4 sleep than adults, putting them at further risk of sleeping through the alarm [15]. Only 12% of the children in Bruck and Thomas' [16, 17] studies were awoken by a smoke alarm in their house and of these, 49% did not know that the sound that woke them was in fact, a smoke alarm. Compared to all other fire causes, smoke alarms had no protective effect for intentionally set fires and fires caused by fire-play [30]. As children are involved in the ignition in cases of fire-play and are most likely to be injured/die from burns, it would suggest that the victims may be overcome by the fire before the smoke alarm is triggered or a guardian is able to intervene.

Analytical strategy and expectations

Based on this prior research and maintaining a focus on at risk populations in Canada, the current research uses the NFID information to examine residential fire outcomes. Particular attention is paid to demographic characteristics of residential fire fatalities and the presence of functioning life safety systems.

Residential fires as a sub-set of all reported incidents

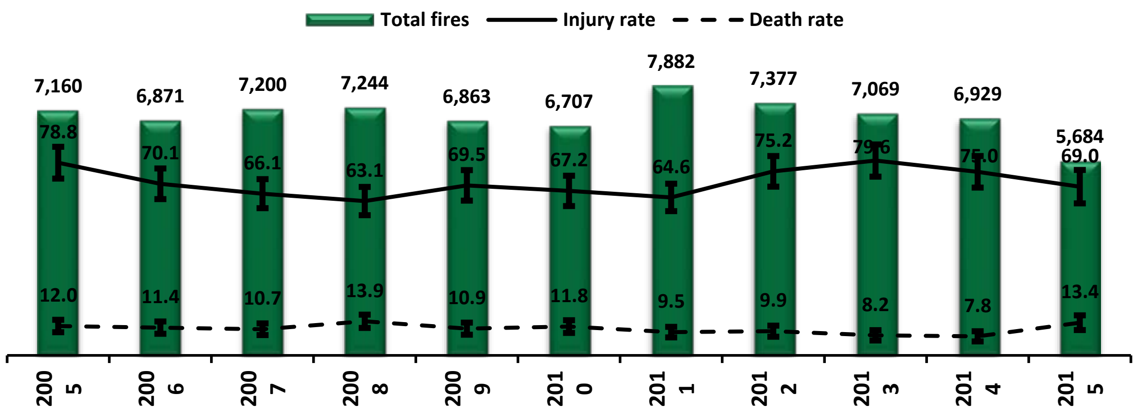
The complete NFID contains 467,929 fire incidents that resulted in 1,927 deaths and 13,399 injuries. Over 300,000 of these incidents (64.3%) were coded as having occurred in an 'unknown' or 'undetermined' occupancy group. For the remainder of fires (167,087, resulting in 1,038 deaths and 8,743 injuries)) fires that occurred in buildings identified as having a residential use accounted for 52.3% of fires and resulted in 82.4% of deaths and 64.9% of injuries. Given the focus of this research is on at risk populations, the remainder of this analysis will focus on this subset of the overall NFID. These fires were reported by Alberta, British Columbia, Manitoba, Ontario, and Saskatchewan.

Annual trends for residential fires and fire-related casualties

Figure 1 shows the annual trends for residential fires and fire-related casualties across the 11 years of data included in the NFID. With the exception of 2015, the number of reported residential fires each year was relatively stable (avg. 7,130 per year). The total number of residential fires in 2015 was 20.6% lower than the number reported in 2005. The rates of injuries (solid black line) and deaths (broken black line) per 1,000 fires each year are also displayed in Figure 1, along with 95%

confidence interval error bars for each annual rate estimate. These trends indicate there is year-to-year variation in the rate of these casualties, but the overall trends are relatively stable, with an average of 70.8 injuries and 10.9 deaths per 1,000 fires.

FIGURE 1. ANNUAL RESIDENTIAL FIRE COUNTS WITH INJURY AND FIRE RATES PER 1,000 FIRES (PLUS 95% CONFIDENCE INTERVALS)



Demographic details of residential fire casualties

Table 1 provides some age and sex information about the fire related casualties from the 11-years' of residential fires included in the NFID. Consistent with prior research, males were more likely to have been injured and killed in residential fires, relative to females. Also as expected, older adults were more likely to have been killed as a result of residential fires

TABLE 1. NON-FIREFIGHTER CASUALTY DEMOGRAPHIC INFORMATION (COUNTS AND RATES PER 100,000 PEOPLE) AND RELATIVE RISK OF CASUALTY FROM RESIDENTIAL FIRES

Demographic category	Deaths	Injuries	Death rate per 100,000 people	Injury rate per 100,000 people	Relative risk death (compared to whole population)	Relative risk injury (compared to whole population)
Male	549	2,815	4.6	23.4	1.3	1.2
Female	281	1,793	2.3	14.4	0.7	0.8
12 and under	79	994	2.2	27.7	0.7	1.5
13 to 18 years	24	173	1.5	10.5	0.4	0.6
19 to 64 years	482	2,086	3.2	13.7	0.9	0.7
65 to 79 years	160	250	5.5	8.5	1.6	0.4
80 years and over	84	96	8.1	9.3	2.4	0.5
Age unknown	1	1,057	NA	NA	NA	NA
Total	**830**	**4,656**	**3.4**	**19.0**		

NB. Population rates were based on 2016 Census age/sex population estimates published at http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/dt-td/Index-eng.cfm and residential fires were filtered to exclude incidents where the sprinkler presence was classified as 'blank' and 'not applicable – e.g., vehicle, outdoor, person'. This filter applies throughout the report.

Given the focus on at risk populations, all casualties involving firefighters have been excluded from the majority of this analysis. There were two fatalities of firefighters resulting from residential fires included in this sample. In comparison, there were 790 injuries sustained by firefighters, the severity of which are displayed in Table 2, relative to the severity of injuries sustained by non-firefighters. With respect to injuries, it is clear that overall, the majority of all injuries captured by the NFID were minor or light (85.4% of firefighter injuries vs. 78.5% for non-firefighters).

TABLE 2. RELATIVE SEVERITY OF INJURIES SUSTAINED BY FIREFIGHTERS AND NON-FIREFIGHTERS AS A CONSEQUENCE OF RESIDENTIAL FIRES

Injury severity	Firefighters		Non-firefighters	
	# injuries	% injuries	# injuries	% injuries
Minor injury (less than one day hospital or off work)	546	69.1%	2,622	56.3%
Light injury (hospitalised 1-2 days and/or off work 1-15 days)	129	16.3%	1,034	22.2%
Serious injury (hospitalised 3+ days and/or off work 16+ days)	89	11.3%	815	17.5%
Injury - seriousness unknown	0	0.0%	25	0.5%
Unknown/Undetermined/Other	26	3.3%	160	3.4%
Total	**790**	**100.0%**	**4,656**	**100.0%**

Behaviors of residential fire casualties

This section examines what is known about the behavior of the non-firefighter residential fire casualties. Table 3 shows the condition of each casualty and it is clear that there is a large amount of uncertainty relating to this variable: 44.2% of deaths and 25.7% of injuries were 'unclassified' or 'unknown'. Analysis of corrected percentages that excluded these uncertain cases revealed that 32.6% of fatalities were asleep at the time of fire, 30.9% were impaired by alcohol, drugs, or medication, and 21.4% were awake with no physical/mental impairments. For injuries, almost two-thirds (61.1%) of cases involved a casualty who was awake with no physical/mental impairments at the time of the fire and one-quarter (24.2%) were asleep at the time of the fire.

TABLE 3. CONDITION OF CASUALTY FOR NON-FIREFIGHER CASUALTIES FROM RESIDENTIAL FIRES

Non-firefighter condition of casualty	# Deaths	% Deaths	# Injuries	% Injuries
Hearing impaired	2	0.2%	0	0.0%
Visually impaired	1	0.1%	0	0.0%
Asleep at time of fire	151	18.2%	838	18.0%
Bedridden or other physical handicap	42	5.1%	81	1.7%
Impairment by alcohol, drugs or medication	143	17.2%	320	6.9%
Awake and no physical or mental impairment at the time of fire	99	11.9%	2,113	45.4%
Under restraint or detention	1	0.1%	3	0.1%
Too young to react to fire emergency	8	1.0%	57	1.2%
Mental handicap - includes senility	11	1.3%	22	0.5%
Child left unattended	5	0.6%	24	0.5%
Condition of casualty - unclassified	48	5.8%	240	5.2%
Condition of casualty - unknown	319	38.4%	958	20.6%
Total	**830**	**100.0%**	**4,656**	**79.4%**

Once again, when examining the cause of failure to escape for non-firefighter casualties, a lot of incidents were classified as 'unknown' (Table 4): with two-thirds (62.5%) of deaths and over 90% of injuries coded this way. Analysis of corrected percentages that excluded these uncertain cases revealed that 51.1% of deaths resulted from rapidly spreading fire/smoke, 14.5% resulted from high flame spread of combustible interior finish, and only 7.4% of the known reasons for failure to escape were as a result of age and/or other physical limitations. Being trapped by fire/smoke was also a major cause of failure to escape resulting in non-firefighter injuries (49.4% of known injuries) and explosion accounted for 20.3% of known injuries. In comparison, 41.3% of the 727 firefighter injuries resulted from falling debris, 22.2% from rapid spreading fire/smoke, and 12.7% from building collapse (NB: values for firefighter injuries are not shown in Table 4).

TABLE 4. CAUSE OF FAILURE TO ESCAPE FOR NON-FIREFIGHER CASUALTIES FROM RESIDENTIAL FIRES

Cause of failure to escape	# Deaths	% Deaths	# Injuries	% Injuries
Trapped by rapid spreading of fire/smoke - vertical openings, stairways, elevators	53	6.4%	112	2.4%
Trapped by rapid spreading of fire/smoke - through horizontal openings	106	12.8%	110	2.4%
High flame spread of combustible interior finish	45	5.4%	68	1.5%
Building collapse	1	0.1%	2	0.0%
Falling debris	2	0.2%	3	0.1%
Explosion	17	2.0%	91	2.0%
Exit blocked, locked, or obstructed	19	2.3%	35	0.8%
Outdoor fire - includes forest/brush fires	1	0.1%	14	0.3%
Fell, slipped or tripped	0	0.0%	1	0.0%
Exposure to fire products	8	1.0%	10	0.2%
Trapped (or caught) - type of openings unknown	31	3.7%	2	0.0%
Exposure to hazardous materials of toxic fumes	0	0.0%	0	0.0%
Exposure to hazard, type unknown	0	0.0%	0	0.0%
Age and/or other physical imitation	23	2.8%	0	0.0%
Multiple Causes	0	0.0%	1	0.0%
Not applicable - escaped	1	0.1%	0	0.0%
Not applicable - suicide	4	0.5%	0	0.0%
Unknown	519	62.5%	4,207	90.4%
Total	**830**	**100.0%**	**4,656**	**100.0%**

The final avenue of insight into the behaviors of the non-firefighter residential fire casualties was the classification of the action taken by each casualty (Table 5). Once again, there were a large number of 'unknown' incidents with respect to this variable: 58.3% of deaths and 24.5% of injuries. With these records removed, the corrected percentages indicated that one-third (36.4%) of fatalities were attempting to escape, one-quarter (28.6%) did not act, and 14.2% experienced a loss of judgement or panic. When the action of the casualty was known for injuries, 50.4% of cases involved the person entering/remaining for rescue, fire fighting, or saving personal property. The remainder of cases involved injuries sustained when trying to escape (26.8%), a loss of judgement (11.4%), or a failure to act (6.9%). In comparison, 94.8% of the 727 firefighter injuries were sustained while entering/remaining for rescue (7.9%), fire fighting (86.3%), or saving personal property (0.6%, with values for firefighter injuries not shown in Table 5).

TABLE 5. ACTION OF CASAULTY FOR NON-FIREFIGHER CASUALTIES FROM RESIDENTIAL FIRES

Action of casualty	# Deaths	% Deaths	# Injuries	% Injuries
Civilian attempted suppression	5	0.6%	0	0.0%
Fire setter	4	0.5%	0	0.0%
Injured while attempting to escape	126	15.2%	941	20.2%
Over-exertion, heart attack	5	0.6%	15	0.3%
Entered or remained for rescue purposes	17	2.0%	215	4.6%
Entered or remained for firefighting/extinguishment	12	1.4%	1375	29.5%
Entered or remained to save personal property	8	1.0%	180	3.9%
Loss of judgement or panic	49	5.9%	401	8.6%
Received delayed warning	21	2.5%	66	1.4%
Did not act	99	11.9%	322	6.9%
Unknown	484	58.3%	1141	24.5%
Total	**830**	**100.0%**	**4,656**	**100.0%**

Residential fires that result in casualties

To understand more about the residential fires that did result in casualties, this section examines how fire casualties were influenced by (a) the extent of fire spread (Table 6), and (b) the method of fire control (Table 7). Consistent with previous research, Table 6 indicates that the death rate from residential fire increased along with the extent of fire spread. Fires that were contained to the room of origin (43.6%) resulted in 56.9% of injuries and 23.6% of deaths, at a rate of 79.2 injuries and 3.8 deaths per 1,000 fires. In comparison, fires that extended beyond the room and as far as beyond the property of origin (22.3%) resulted in 27.9% of injuries and 58.7% of deaths (75.9 injuries and 28.4 deaths per 1,000 fires, respectively).

TABLE 6. EXTENT OF FIRE SPREAD AND CASUALTIES CAUSED BY RESIDENTIAL FIRES

Extent of fire spread	Total Fires	% fires	Injuries	% injuries	Deaths	% deaths	Injury rate	Death rate
Confined to object of origin	15,203	19.8%	687	14.8%	39	4.7%	45.2	2.6
Confined to part of room/area of origin	13,687	17.9%	1,359	29.2%	87	10.5%	99.3	6.4
Confined to room of origin	4,564	6.0%	603	13.0%	70	8.4%	132.1	15.3
Confined to floor level of origin	3,052	4.0%	445	9.6%	103	12.4%	145.8	33.7
Confined to building of origin	10,719	14.0%	690	14.8%	339	40.8%	64.4	31.6
Extended beyond property of origin	3,359	4.4%	165	3.5%	45	5.4%	49.1	13.4
Confined to roof/attic space	780	1.0%	5	0.1%	0	0.0%	6.4	0.0
Other*	25,311	33.0%	702	15.1%	147	17.7%	27.7	5.8
Total	**76,675**	**67.0%**	**4,656**	**100.0%**	**830**	**100.0%**	**60.7**	**10.8**

NB. ‘Other’ here combines ‘not applicable’, ‘unclassified’, ‘unknown’, and ‘not available’.

Also consistent with previous research, Table 7 demonstrates the relationship between method of fire control and fire casualties. Fires that required fire department intervention (36.8%) resulted in 33.7% of injuries and 62.8% of deaths (at a rate of 18.5 deaths per 1,000 fires). In comparison, when fires were extinguished using hand held extinguishers or makeshift fire fighting aids (17.0% of fires) there was a death rate of 1.7 per 1,000 fires.

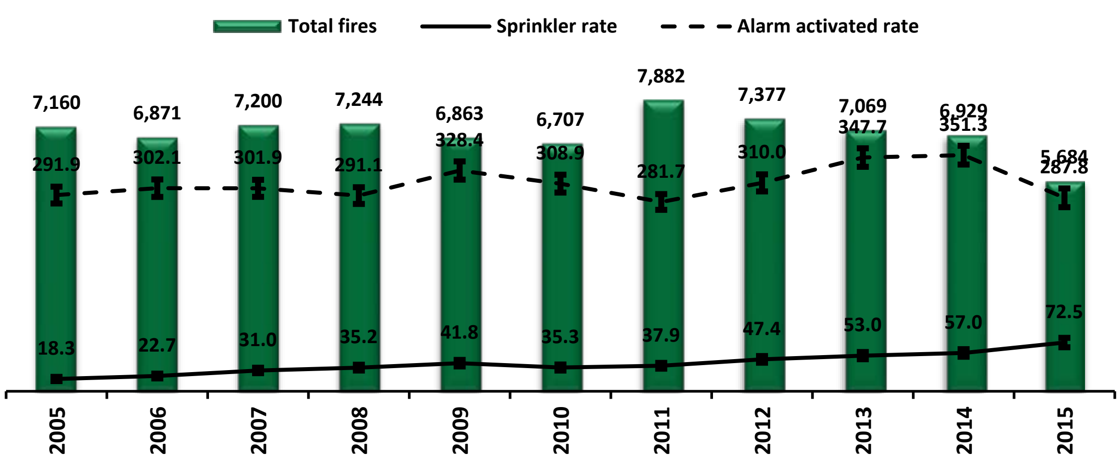
TABLE 7. METHOD OF FIRE CONTROL AND CASUALTIES CAUSED BY RESIDENTIAL FIRES

Method of fire control	Total fires	% fires	Injuries	% injuries	Deaths	% deaths	Injury rate	Death rate
Hand held extinguisher	5,763	7.5%	336	7.2%	8	1.0%	58.3	1.4
Standpipe and hose systems	756	1.0%	46	1.0%	12	1.4%	60.8	15.9
Makeshift firefighting aids	7,264	9.5%	497	10.7%	14	1.7%	68.4	1.9
Fire Department - water application	26,490	34.5%	1,524	32.7%	503	60.6%	57.5	19.0
Fire Department - other than water	1,742	2.3%	45	1.0%	18	2.2%	25.8	10.3
Sprinkler protection	833	1.1%	61	1.3%	3	0.4%	73.2	3.6
Fixed system other than sprinklers	111	0.1%	9	0.2%	0	0.0%	81.1	0.0
Burned out	6,285	8.2%	226	4.9%	37	4.5%	36.0	5.9
Miscellaneous method of fire control/extinguishment	3,610	4.7%	123	2.6%	3	0.4%	34.1	0.8
10. Cannot be determined	23,821	31.1%	1,789	38.4%	232	28.0%	75.1	9.7
Total	**76,675**	**100.0%**	**4,656**	**100.0%**	**830**	**100.0%**	**60.7**	**10.8**

Cumulative protective influence of life safety systems

This section examines the cumulative influence of life safety systems on reducing the likelihood of death as a result of residential fire. Figure 2 shows the annual trends with respect to complete residential sprinkler protection (solid black line) and smoke alarm activation (broken black line) as rates per 1,000 fires each year (with 95% confidence interval error bars). With some fluctuation from year-to-year, the average rate of activation of working smoke alarms was 309.4 per 1,000 fires (with 2015 figures below this). In comparison, there has been a steady year-on-year increase in the presence of sprinkler protection in residential buildings, increasing to 72.5 per 1,000 fires in 2015.

FIGURE 2. ANNUAL RESIDENTIAL FIRE COUNTS WITH FIRE SAFETY SYSTEM PRESENCE AS A RATE PER 1,000 FIRES (PLUS 95% CONFIDENCE INTERVALS)



Comparisons between the provinces that submitted data for analysis in the NFID indicates there was a wide range of fire safety coverage across areas in Canada (averaged over the full time period, Table 8).

TABLE 8. RELATIVE COVERAGE OF COMPLETE SPRINKLER PROTECTION AND ACTIVATED SMOKE ALARMS BY PROVINCE

Province	# fires	% sprinkler	% smoke alarm
Alberta	18,939	3.3%	17.0%
British Columbia	24,375	8.8%	33.9%
Manitoba	13,710	2.5%	29.0%
Ontario	18,070	0.0%	45.6%
Saskatchewan	1,581	0.0%	7.1%
Total	**76,675**	**4.1%**	**31.1%**

With respect to fire safety systems and the presence of sprinklers, Table 9 shows patterns consistent with prior research. Relatively few fires (4.1%) had complete sprinkler protection and two-thirds of fires had no sprinklers. Comparing between these two groups, death and injury rates were much lower in the presence of complete sprinkler protection (1.3 deaths per 1,000 fires, compared to 11.3 deaths per 1,000 fires with no sprinkler protection).

TABLE 9. SPRINKLER PROTECTION AND CASUALTIES CAUSED BY RESIDENTIAL FIRES

Sprinkler protection	Total fires	% fires	Injuries	% injuries	Deaths	% deaths	Injury rate	Death rate
Complete sprinkler protection	3,120	4.1%	181	3.9%	4	0.5%	58.0	1.3
Partial sprinkler protection	1,054	1.4%	75	1.6%	10	1.2%	71.2	9.5
No sprinkler protection	51,106	66.7%	3,220	69.2%	575	69.3%	63.0	11.3
Sprinkler protection unclassified	2,957	3.9%	287	6.2%	1	0.1%	97.1	0.3
Cannot be determined	18,438	24.0%	893	19.2%	240	28.9%	48.4	13.0
Total	**76,675**	**100.0%**	**4,656**	**100.0%**	**830**	**100.0%**	**60.7**	**10.8**

Table 10 shows the impact of smoke alarms on casualty outcomes. As expected, the relative death rates per 1,000 fires was significantly lower for the 31.1% of fires when the smoke alarm was activated (6.8 per 1,000 fires), compared to fires where the alarm was not activated or was not installed (14.1 and 10.2 per 1,000 fires, respectively). As with previous research, the injury rate was highest in the presence of a working smoke alarm: consistent with casualties fighting fires.

TABLE 10. SMOKE ALARM PROTECTION AND CASUALTIES CAUSED BY RESIDENTIAL FIRES

Smoke alarm status	Total fires	% fires	Injuries	% injuries	Deaths	% deaths	Injury rate	Death rate
Alarm activated	23,810	31.1%	2,114	45.4%	163	19.6%	88.8	6.8
Alarm not activated	6,292	8.2%	512	11.0%	89	10.7%	81.4	14.1
Not enough smoke to activate smoke alarm	1,400	1.8%	57	1.2%	8	1.0%	40.7	5.7
No smoke alarm installed	19,456	25.4%	706	15.2%	199	24.0%	36.3	10.2
Cannot be determine/not applicable*	25,717	33.5%	1,267	27.2%	371	44.7%	49.3	14.4
Total	**76,675**	**100.0%**	**4,656**	**100.0%**	**830**	**100.0%**	**60.7**	**10.8**

* Combined ‘not applicable’, ‘unknown’, and ‘not available’.

Table 11 summarizes the findings from this section. This table presents the relative trends as a function of the combination of life safety systems that were in place for each residential fire. Table 11 also provides 95% confidence intervals for the estimates of death rates, fire department intervention, and the extent of fire spread for each of these combinations of life safety systems. The main findings from Table 11 include:

- Just over two-thirds of these residential fires had no present, functioning life-safety systems and these fires resulted in 80.4% of the deaths in this sample.
- Relative to fires with no life safety systems in place, fires with either a working smoke alarm or complete sprinkler protection are much less likely to result in a death, less likely to require fire department intervention, and less likely to extend beyond the room of origin.
- The compound effect of both sprinkler protection and a working smoke alarm resulted in only 4 deaths, required the least amount of fire department intervention, and the fires did not extend beyond the room of origin 94% of the time.

TABLE 11. RESIDENTIAL FIRES, FIRE-RELATED CASUALTIES, FIRE DEPARTMENT INVOLVEMENT, AND EXTENT OF FIRE SPREAD BY COMBINATIONS OF LIFE SAFETY SYSTEMS

Smoke alarm	Sprinkler	Fires (% total)	Injuries (% total)	Injury rate (95% CI)	Deaths (% total)	Death rate (95% CI)	% Fire department extinguish (95% CI)	% Beyond room of origin (95% CI)
Yes	Yes	1,808 (2.4%)	108 (2.3%)	59.7 (48.5, 71.0)	4 (0.5%)	2.2 (0.0, 4.4)	15.8% (13.9%, 17.6%)	5.8% (4.6%, 7.0%)
No	Yes	1,312 (1.7%)	73 (1.6%)	55.6 (42.9, 68.4)	0 (0.0%)	0.0 (0.0, 0.0)	28.3% (25.3%, 31.2%)	16.5% (14.2%, 18.8%)
Yes	No	22,002 (28.7%)	2,006 (43.1%)	91.2 (87.2, 95.2)	159 (19.2%)	7.2 (6.1, 8.3)	39.6% (38.6%, 40.7%)	18.0% (17.3%, 18.7%)
No	No	51,864 (67.6%)	2,469 (53.0%)	48.1 (45.7, 49.5)	667 (80.4%)	12.9 (11.9, 13.8)	43.1% (42.6%, 43.7%)	42.9% (42.2%, 43.6%)
Total		***76,675 (100.0%)***	***4,656 (100.0%)***	***60.7 (59.0, 62.5)***	***830 (100.00%)***	***10.8 (10.1, 11.6)***	***41.5% (41.0%, 41.9%)***	***33.9% (33.4%, 34.4%)***

Policy implications of these findings

In aggregate, and in light of previous similar research, there are no real surprising findings from this analysis of fire related casualties from the NFID. Overall, there is an elevated risk for males and older residents, and there are protective benefits of life safety systems when they are in-place. There is also a notable absence of fire safety systems in a large proportion of the properties that experienced residential fires. According to the U.N. [52], almost every country in the world is experiencing an ageing population, with figures estimating the number of adults aged 60+ years worldwide will grow by 56% from 2015-2030. Considering this, if preventative measures are not put in place it is likely the amount of fire-related casualties among this demographic will only increase with time.

With these trends in mind, the researchers would encourage the relevant Canadian agencies to commence targeted problem-prevention strategies to increase coverage of working smoke alarms for vulnerable residents. These interventions could build on frameworks that have been demonstrated as effective in reducing other non-random social problems (such as disease and crime). The key components to these strategies usually involve clear definition of the problem (i.e., what needs to change), analysis of available data to give insight into the non-random nature of the problem, inter-agency collaboration to implementation interventions designed to reduce the problem, and solid evaluation to ensure the interventions have been implemented and are effective. Without being clear about what your problems are, it is not possible to design and implement effective, targeted interventions that have the greatest likelihood of success. The findings outlined here (in combination with the summary from the available literature in this area) provide an excellent platform for locally-specific, data-driven, targeted interventions to reduce risk for the most vulnerable populations in Canada. Furthermore, given the large number of 'unknown' responses captured in the NFID, to date, the researchers would also implore the relevant agencies to do all they can to improve data collection (training and recording) to reduce this issue into the future.

In conclusions, we urge the Canadian fire service to adopt a proactive, partnership-based, prevention focus to maximise the potential for elderly residents to remain living safely in their own homes for longer. In addition to targeting preventable fires, this initiative could also attempt to reduce the risks of trips/falls and crime victimisation. Given the consistency of findings relating to the elevated risk for this sub-section of the population, it is unacceptable to fail to act.

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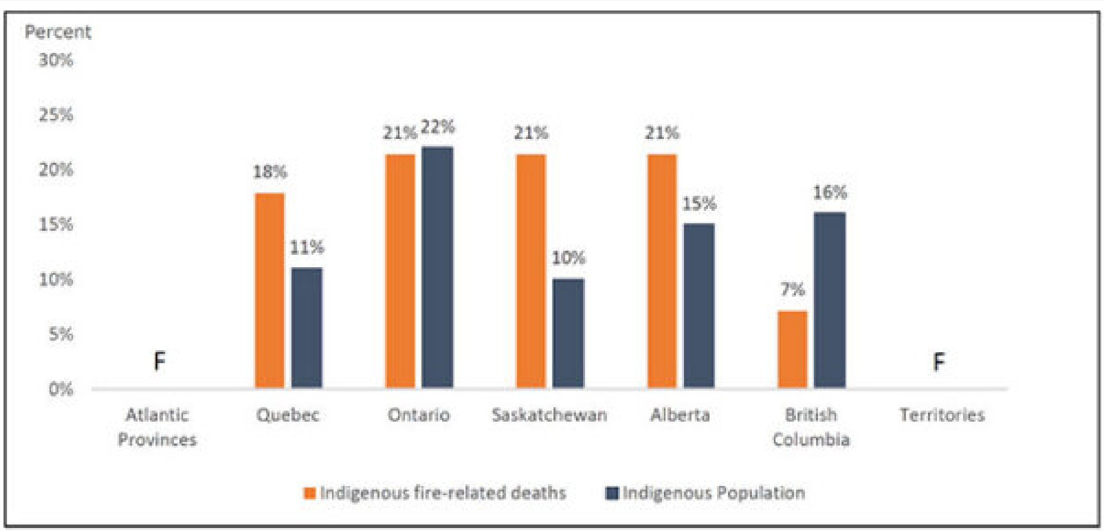
Features

Learning from fire death data

Ten years of coroner data reveals the factors behind escalated Indigenous fire risk in Canada

September 6, 2024

By Len Garis and Mandy Desautels



The proportion of fire-related deaths among Indigenous people compared to population percentage.

Photo: Canadian Coroner and Medical Examiner Database and Statistics Canada

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A new study of Canadian coroner data suggests that unsafe homes, lack of working smoke alarms and lack of attention to correcting major housing repairs needed are among the factors in why Indigenous people in Canada die in fires more often than non-Indigenous people.

The National Indigenous Fire Safety Council (NIFSC) released a new Statistics Canada study delving into the circumstances surrounding fire deaths in Canada from 2011 to 2020, based on the Canadian Coroner and Medical Examiner Database (CCMED) and Canadian Vital Statistics death data.

Titled *Circumstances Surrounding Fire-related Deaths among the Indigenous People in Canada, 2011 to 2020*, the report was commissioned by NIFSC, which is funded by Indigenous Services Canada. The study not only reinforces earlier research showing that fire-related deaths and injuries are significantly higher for Indigenous than non-Indigenous people but sheds new light on the contributing factors.

The study data suggests that Indigenous people are four times more likely than non-Indigenous people to die in a fire in Canada, and that the risk is highest for those who live in rural areas with underfunded fire services, in homes that need major repairs, and in provinces without ongoing and widespread smoke alarm education and installation programs.

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"Study after study has shown us that Indigenous people in Canada die in residential fires at a much higher rate than non-Indigenous people, but this new data helps fill in the gaps as to why that is happening," said Blaine Wiggins, senior director of the NIFSC. "With this compelling new evidence, we urge decision-makers across Canada to acknowledge the factors that increase this risk and to take immediate and appropriate steps to address them."

Study approach

Fires are the fourth most common cause of unintentional death and injury worldwide. In Canada, an average of 220 people died in fires each year from 2011 to 2020.

A total of 2,200 deaths were reported to the CCMED during that time, but the study sample was about one-third of that number, limited to 700 deaths that could also be linked to the 2006 and 2016 long-form censuses and the 2011 National Household Survey (NHS) in order to select people who identified as Indigenous and gain valuable location information.

While the study sample may not represent all fire-related deaths in Canada, the study's key findings are based on data that was consistent between the sample and the total fire deaths: place of death, sex and age. It should be noted that the number of deaths reported may be lower than expected because only closed cases are published in the CCMED.

Key insights

Key results related to individual risk are as follows:

- Indigenous people made up 20 per cent of fire deaths from 2011 to 2020 but, based on 2016 census data, represent 4.9 per cent of the total population.
- Indigenous people who died in fires were on average 41 per cent younger than non-Indigenous people (mean age of 39 versus 59). This may be explained in part

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by their younger age profile; 83 per cent are under age 55 compared to 69 per cent for non-Indigenous people.
- Alberta, Saskatchewan and Quebec had the highest proportion of Indigenous fire deaths based on their Indigenous populations, while Ontario and British Columbia had the least.

Results related to the circumstances surrounding fire deaths are as follows:

- For both Indigenous and non-Indigenous people, most fire deaths occurred in residential fires, most often in a single-detached home and in the winter. Fire deaths were more prevalent among men than women for both groups.
- Indigenous people who died in a fire were 4.5 times more likely to live in homes needing major repairs than non-Indigenous people (about 56 per cent versus 13 per cent).
- Twice as many Indigenous people who died in a fire lived in rural areas compared to non-Indigenous people (two-thirds versus one-third). Rural areas tend to be further from fire stations and paramedic services and served by volunteer firefighters.
- Cooking, electrical and heating devices were the most common sources of fatal fires for both Indigenous and non-Indigenous people, followed by cigarettes and candles or other open flames. However, ignition sources were less often specified in Indigenous fires. This may point to a reduced level of fire service in rural areas, either related to data collection or response times that resulted in damage too extensive to identify the source.
- Nearly one in eight (12 per cent) Indigenous fire deaths were reported in homes without a working smoke alarm, similar to non-Indigenous people. Noting smoke alarms was either not specified, unknown or not applicable for 80 per cent of fire-related deaths among Indigenous people.

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The risk factors for Indigenous people are combined with other known vulnerabilities that increase the danger of fire-related injury and death, including lower education and income, overcrowded living conditions, and limited access to healthcare in rural areas.

Provincial overview

According to the 2016 Census of Population, the distribution of Indigenous people living in Canada varied by province and territory. While the distribution of fire-related deaths among Indigenous people also varied, it was not comparable to the Indigenous population distribution.

The proportion of fire-related deaths among Indigenous people was greater than the proportion of the Indigenous population in Alberta (21 per cent of Indigenous deaths versus 15 per cent of the Indigenous population), Quebec (18 per cent versus 11 per cent), and Saskatchewan (21 per cent versus 10 per cent), suggesting an overrepresentation of fire-related deaths in these provinces. Underrepresentation was observed in British Columbia (seven per cent versus 16 per cent), where the proportion of fire-related deaths among Indigenous people was 2.3 times lower than its share of the Indigenous population. In Ontario, the proportion of Indigenous fire-related deaths (21 per cent) was similar to the Indigenous population proportion (22 per cent). Fire-related deaths for Manitoba were not available in the linked dataset and death proportions for Atlantic Canada and the territories were suppressed to meet Statistics Canada's confidentiality requirements.

Using what was learned

The new report provides direction for interventions to reduce fire risk for Indigenous people:

- **Home maintenance:** Home disrepair has been identified as a risk factor in fire deaths. Census data shows that 19.4 per cent of Indigenous people live in a

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dwelling requiring major repairs, compared to six per cent of non-Indigenous people.

- **Smoke alarms:** Research has shown working smoke alarms significantly reduce the risk of fire injuries and deaths. The provinces with the lowest proportion of Indigenous fire deaths based on population, Ontario and British Columbia, have ongoing smoke alarm education and installation programs with a focus on vulnerable populations.
- **General fire education:** A report by the Ontario chief coroner identified that education on topics such as fire escape, fire safety and home maintenance is key to reducing fire fatalities in First Nations.
- **Information gathering:** Data related to Indigenous-specific fire deaths was lacking in a number of areas and topics. Fire services continue to be encouraged to report data to the National Fire Information Database to support the development of evidence-based interventions.

"This new study has brought important insights to aid in our efforts to reduce Indigenous fire-related deaths and injuries in Canada," said Michelle Vandervord, president of the National Indigenous Fire Safety Council. "By pinpointing the circumstances leading to fatal fires, we can help ensure that investments in Indigenous fire safety are being directed to the most promising interventions. We would like to see this data translated into tangible actions across the country."

In terms of future research, potential next steps could involve expanding the study to look into the impact of some of the socio-economic factors (such socio-economic standing, food security, cost of living, overcrowded living conditions and household income), funding for housing structures, the allocation of funds to meet community needs, the role of fire and building codes, and the status of home maintenance on fire-related deaths among Indigenous communities in Canada.

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View *Circumstances Surrounding Fire-related Deaths among the Indigenous People in Canada, 2011 to 2020* at https://assets.ctfassets.net/5izjgsoqhaa4/17RcvYpMggzHUl5vZWb9uZ/01988dfd4f0aa45867586abf1897859a/Report_Indigenous_Fire_Deaths_NIFSC.pdf.

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CANADIAN
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Suicide accounts for more than 3 in 4 intentional fire deaths: StatsCan

By CFF Staff October 12, 2022

Oct. 11, 2022, Canada – Suicide made up more than three in four of intentional fire-related deaths between 2011 and 2020, shows new data from Statistics Canada. Of the over 200 fire-related deaths reported annually, one in six are classified as cases of intentional, meaning by suicide or homicide.

The findings are based on new insights released from the Canadian Coroner and Medical Examiner Database (CCMED).

From 2011 to 2020, coroners and medical examiners investigated, on average, 26 fire-related suicides each year. While these deaths accounted for more than three-quarters of intentional fire-related deaths, they accounted for less than one per cent of overall suicides in Canada.

Fifty-two per cent of fire-related suicides were a result of smoke inhalation, while 12 per cent were caused by smoke inhalation and burns, and 29 per cent were caused by burns alone. Other causes of death such as blunt force trauma or drug toxicity were a

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factor in four per cent of fire-related suicides. Three per cent were not specified. Accelerants were used in 42 per cent of fire-related suicides.

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Most fire-related suicides occurred on residential property, accounting for 61 per cent.

Most of the fire-related suicides that took place in non-residential structures occurred in a parked vehicle on the property, accounting for 65 per cent of deaths. Twenty-nine per cent happened in public areas and six per cent happened indoors.

The report found that men were three times more likely than woman to die in a fire-related suicide. Middle-aged adults were overrepresented, with those aged 45 to 59 comprising 44 per cent of fire related suicides. This same group represents 32 per cent of overall suicides in Canada.

At the time of this report, 2,190 fire-related deaths were documented. Of these, 260 were classified as suicides. In a news release, Statistics Canada stated that the number recorded recent years is lower than expected as only closed cases are published.

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