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A Review of International Research Efforts Related to Occupant Pre-movement Behaviour and Response Times in Fire

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Preface

This is the first stage in a human behaviour research programme into the pre-movement component of fire evacuations. Pre-movement is the period of time measured from when occupants receive the first fire cues to when they actively commence evacuation. The time taken in pre-movement activity can vary enormously between individuals and scenarios, and can represent a substantial proportion of the total time taken to complete evacuation from a building.

The accurate prediction of pre-movement is an essential element in the validation of fire engineering assumptions and to generally assist performance-based fire engineering designs in New Zealand. One of the objectives of this first stage was to publish a comprehensive summary of current national and international research and published literature containing pre-movement data. A matrix was developed to highlight future research requirements and to provide a resource for fire engineering by identifying specific pre-movement data sources.

Recommendations have been made about future research requirements for New Zealand specific pre-movement data, and for the use and applicability of international data sets in the fire engineering of New Zealand buildings.

Acknowledgments

This work was funded by the Building Research Levy.

Note

This report is intended for fire engineers, regulators and others conducting human behaviour in fire research.

A REVIEW OF INTERNATIONAL RESEARCH EFFORTS RELATED TO OCCUPANT PRE-MOVEMENT BEHAVIOUR AND RESPONSE TIMES IN FIRE

BRANZ Study Report SR 143 **P.N. Whiting**

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KEYWORDS

Human behaviour, evacuation, pre-movement, occupant, response times, fire, fire incidents, trial evacuation, research

ABSTRACT

The report is structured to provide an introduction to human behaviour associated with the "pre-movement" phase of fire evacuation. Relevant research on human behaviour in fires is discussed and a considerable number of pre-movement data sources are reviewed. They comprise research work, actual fire incident reports and reports from experimental work including trial evacuations from around the world. A matrix is used to identify the same data sources by country of origin. This is important where cultural differences may lead to modification of the response actions. The ongoing international research effort is briefly described, and recommendations for further work are proposed.

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1. INTRODUCTION

The purpose of this study is to identify the kind of human behaviour information required for the purposes of fire safety engineering our future built environment. In the present building regulation environment, there is enormous scope for fire engineered solutions to be tailored to one-off projects rather than simply applying a standard set of pre-approved solutions taken from the relevant Acceptable Solutions (DBH 2005). The Acceptable Solutions provide a prescriptive solution for almost all building types and are one means of compliance with the New Zealand Building Code (NZBC). To accommodate a very broad spectrum of building types, they offer both generic and conservative pre-approved solutions.

The performance-based building regulations have been introduced primarily to encourage innovation and provide a greater scope for tailor-making buildings to more closely meet client requirements. In particular, there is great potential for specifically engineering the fire safety design to exactly match the needs of the client while also satisfying NZBC performance requirements.

Fire engineering is a very recent discipline when compared with the likes of structural engineering. As a result, many of the assumptions made in the course of fire engineering an Alternative Solution are based on limited data sets, and the quality and reliability of these is still being developed and refined.

The issue is summarised as follows: “Fires are a product of buildings, users, contents, ignition sources and public and private responses. Only some parts of these systems are outputs of traditional engineering principles. Fire protection engineers usually define performance-based analysis in terms of fire physics, chemistry and toxicology. But almost all the key variables involved in performance-based analysis involve the interpretation of the effects of intentional human decisions.” (Brannigan and Smidts 1998). Their conclusion is that human behaviour data can at best be included as “estimates”, otherwise uncertainties will have to be treated as conditions of the modelling.

Our building codes are primarily concerned with the life safety of the building occupants, and the life safety of those in close proximity to the affected building i.e. neighbouring building occupants and emergency services personnel who may attend the building. This paper is only concerned with the human behaviour of occupants in the affected building.

To validate the fire design of a building, the fire engineer is asked to demonstrate that the life safety of the occupants can be assured during any fire incident. Traditionally this has comprised modelling fire scenarios and comparing the available safe egress time (ASET) with the required safe egress time (RSET). The ASET is the time up to the point when the fire conditions within the building become untenable for remaining occupants and the RSET is the required time for occupants to complete evacuation to a safe place. Assumptions made about typical human behavioural traits are central to a reliable prediction of RSET values. Human behaviour data and the subsequent assumptions made may not always be appropriate for the application. It then falls to the reviewer and approval authority to determine the suitability of such assumptions.

The field of human behaviour in fire encompasses many distinctly different areas of study. These range from the mechanics of ambulatory motion, to recognition and response actions of occupants, and extend to the toxicological effects of the by-products of fire. Of all these areas, the recognition and response actions of the occupants to a fire, otherwise known as “pre-movement”, is presently the least able to be quantified with any degree of confidence. It is also then the area of study most required for any prediction of human behaviour in fire to be credible.

The aims of this study are to provide a comprehensive summary of current research and published literature on the "pre-movement" component of human behaviour in fire, and identify the present position in terms of the data available for use in the prediction of the pre-movement component. In addressing this, a further question that must be answered is how relevant is the existing international research and data to application in New Zealand fire engineering design. Finally, in order to move forward, it is important to identify any gaps in the present data and to highlight where future research is required.

A resource of pre-movement data is a key component to assist with validation of fire engineering assumptions and to generally assist performance-based fire engineering designs in New Zealand.

2. PRE-MOVEMENT AND HUMAN BEHAVIOUR IN FIRE

Early studies concentrated on the basic mechanics of human movement, such as the physical dimensions of people, the average area occupied and characteristics associated with movement (for example swaying. Determinations based on these parameters can be further refined by taking account of crowd density, speed of travel, width and length of escape routes, age and physical ability of the occupants. While this is perceived to be the major component in evacuation, the actual time required for evacuees to travel the specified distance to the exit is only one part of the total time required to complete the evacuation. A study looking at sensitivity analysis of modelling evacuations (Crawford 1999), found that in terms of evacuation success or failure, the occupant speed is insignificant when compared with the time to un-tenability, occupant response time (pre-movement), and the time taken until the fire is detected.

The RSET begins with the occupants receiving the first cues to evacuate. Such cues can include an automated fire alarm signal, verbal instructions, consensus amongst fellow occupants, or first-hand observations of a fire and/or smoke. On receiving and processing the first cues, many different reactions have been recorded ranging from deciding to evacuate to not responding at all. All of this activity undertaken before actually starting to evacuate is to be taken into account when determining pre-movement time. It can be a significant contributing factor to the overall time required to complete the evacuation process. Because every individual has the capability of making their own decisions, the pre-movement time is very difficult to predict. By default then, it is a critical element in the overall validity of fire engineering designs in which the life safety of occupants relies on the analysis of evacuation performance.

The major sources of data on the pre-movement phase come from interviews with real event evacuees, and from unannounced trial evacuations, although the suitability of data from the latter is debatable.

The pre-movement phase can itself be broken down into distinctly separate components. In this report, the following sub-headings and their definitions are those used in the human behaviour chapter of the *Fire Protection Handbook* (NFPA 1997). The list is selective, including only those that may have an influence over the human behaviour assumptions used in fire engineered designs. In order these are:

- Awareness of the fire
- Decision process of the individual
    - Recognition
    - Validation
    - Definition
    - Evaluation

Commitment
Reassessment

- Behaviour actions of occupants
  First actions
  Convergence clusters
  Panic behaviour
  Re-entry behaviour
  Occupant fire fighting
  Occupants movement through smoke.

The definition for these components are paraphrased from the *Fire Protection Handbook* (NFPA 1997), and these are the same headings that are used in the matrix breakdown table in Section 5.

2.1 Awareness of the fire

The cues by which occupants become aware of a fire are many and may include one or a combination of: automatic or manually operated fire alarm system, direct observation of the fire and/or the smoke, smell, noise of the fire, announcement via a public address system, or informed by other occupants.

2.2 Decision processes of the individual

The response of occupants to the fire cues will vary depending on many factors such as past experience, the degree of perceived or real threat posed by the fire, whether the cues are ambiguous or not, and the reaction of other occupants. The process can be broken down into a series of sub-actions that aim to describe the decision process, in the order in which they can be expected to occur.

2.2.1 Recognition

Recognition is the perception of cues that indicate a threatening fire. The action of recognising a threat and the adaptive behaviour that follows is important for fire protection. Insufficient or incorrect recognition of cues could lead to delays in building evacuation and eventual suppression of the fire.

2.2.2 Validation

Validation attempts by individuals to determine the seriousness of the threat cues. This occurs when cues are ambiguous and the occupants attempt to obtain additional information.

2.2.3 Definition

Definition is an attempt by the occupants to relate the information about the threat to some of the variables such as the qualitative nature of the threat, the magnitude of deprivation of the threat and the time context. Stress and anxiety are related to the ability of the occupant to apply a structure or meaning to a situation. In a physical sense, definition relates primarily to the generation, intensity and propagation of smoke, flames and thermal exposure.

2.2.4 Evaluation

Evaluation is the process involved in the decision to fight or take flight. This decision is also related to the perceived time available, the immediate environment, the location relative to egress routes, other people and their behaviour. During this phase an occupant is susceptible to the actions and suggestions of others. The resulting behaviour can range from mimicking that of others, mass adaptive or mass non-adaptive, to selective and individualised.

2.2.5 Commitment

Commitment is the act of initiating the actions arrived at in the evaluation process. This will lead to either success or failure. If it is the latter, this immediately results in the next process of Reassessment and further Commitment to a new course of action.

2.2.6 Reassessment

Reassessment follows a previous failure, and results in increased stress and anxiety levels. More effort goes into behavioural reactions, the choice of response is less selective, the risk of injury increases and the probability of success reduces.

2.3 Behaviour actions of occupants

The physical actions selected by the occupants have been arrived at in the above decision-making process. These actions are a vital element in determining success or failure. Typically there is a standard set of actions performed by occupants of buildings on fire; however the order in which these occur can vary.

2.3.1 First actions

Some of the most commonly recorded first actions have been: notification of others, searching for fire, fighting the fire, calling the fire brigade, and leaving the building. Studies have shown that the order of these actions can vary significantly depending on the occupant's sex, age and nationality. For example, males are more likely to engage in fire fighting while females are more likely to engage in warning and evacuation activities. As for nationalities, in a USA study (Bryan 1977) the most common first five actions were: "notified others", "got dressed", "got family", "left building", and "entered building". This contrasts with a British study (Wood 1972) that reports the first actions as "fought fire", "went to fire area", closed door to fire area", "pulled fire alarm", and "turned off appliances". Both the order of these and the specific nature of the actions undertaken could clearly have a major impact on the overall success or failure of an evacuation.

2.3.2 Convergence clusters

The term 'convergence cluster' is used to describe occupants gathering in a location for real or perceived refuge. This behaviour can significantly reduce stress and anxiety of occupants. "Group formation can have a significant impact on a range of evacuation parameters such as response times, travel speeds, way finding, and overall evacuation efficiency and time" (Galea and Blake 2004).

2.3.3 Panic behaviour

Panic is defined as "a fear-induced flight behaviour which is non-rational, non-adaptive, and non-social, which serves to reduce the escape possibilities of the group as a whole." (Shultz 1968). It is now considered to occur very rare, if at all. In most instances it can easily be described as an entirely rational response to a very rare and threatening situation, even if from the perspective of a remote observer it may appear illogical and hence described as panic.

2.3.4 Re-entry behaviour

After completing an evacuation, some occupants re-enter a building. As noted above in discussing "First Actions", there can be a very different focus on the reasons for re-entry behaviour, perhaps depending on the nationality of the occupants. Some of the reasons recorded are to: fight the fire, save personal effects, observe the fire, call fire brigade, rescue pets, and notify others. This action not only re-exposes an otherwise safe occupant to risk from the fire, but may also hinder the efficient and effective evacuation of others through the same means of egress.

2.3.5 Occupant fire fighting behaviour

Occupant fire fighting is predominantly a male action. It is most prevalent when the occupant has economic or emotional attachment to the building.

2.3.6 Occupants' movement through smoke

In many incidents occupants reported they travelled considerable distances through smoke. Principal factors that influence this action are familiarity with the exit system and therefore travel distance, appearance and density of the smoke, and the presence or absence of heat.

2.4 Other behavioural responses

Occupants tend to adapt their response according to the surrounding occupants and situation. In public spaces, social inhibition and diffused responsibility is common, leading to occupants simply adopting the cues for behaviour from others. The degree of association between those present, and/or lack of any hierarchy amongst fellow participants are contributing factors.

Altruistic behaviour is very commonly recorded in fire incidents and occurs almost independently of the degree of association between the occupants. This behaviour extends to searching for other occupants and providing assistance to others, particularly those less mobile.

Another variable that can have a time implication is the human decision-making process when it comes to selecting an exit route. Typically, we are most comfortable in using the same exit as was used to enter the building. However in many situations this is neither the safest nor the most efficient. Many evacuation models simply assign the building occupants to the closest exit, or split the population evenly amongst the exits. In practice this would rarely occur, resulting in queuing and possible overcrowding of a preferred exit.

Occupants often deny their senses and do not react immediately. In general terms, people tend to under-estimate the dangers of fire and overestimate their own abilities (Rushbridge 1999).

3. RELEVANT NEW ZEALAND STUDIES ON HUMAN BEHAVIOUR IN FIRE

In New Zealand, most fire in buildings research has been conducted into the physical properties of fires to answer specific NZBC related questions, and to improve the level of our ability to more accurately predict fire behaviour and/or building response. Very little has been directed at how the behaviour of New Zealand occupants may influence their ability to survive a fire.

The NZ Fire Service have funded a considerable number of research projects across a broad range of topics from fire safety to factors relating to fire service operation. One in particular reviews human behaviour contributing to unintentional residential fire deaths in New Zealand (Miller 2005). The study covers 131 unintentional fire deaths that occurred in 108 fire incidents between 1997 and 2003, all of which occurred in residential dwellings. A number of the cases are described from the coronial reports giving detail on the pre-movement actions of the victims, and in some instances the actions of survivors too. In most cases, the fires are attributed to carelessness on the part of an occupant, often the victim, with intoxication or incapacitation through substance abuse affecting the cognitive response being a contributing factor to the fire death.

In response to the New Zealand Māori population being disproportionately represented in the fire statistics, the Fire Service have initiated research specifically targeting Māori. The research conducted to date addresses education and partnership with the Fire Service, and fire safety strategies, with no reference to pre-movement activities.

The University of Canterbury's Masters of Fire Engineering program includes a paper on human behaviour, and some research papers have been prepared on various aspects of evacuation and human behaviour. However, none to date specifically cover the pre-movement phase of an evacuation.

One research paper considered evacuation movement through different building components (Holmberg 1997). The experimental work collected data on walking velocities, twisting rates and flow rates. The findings indicated similar results to previous research into movement velocity as a function of the occupant densities.

The University of Canterbury has been developing an evacuation model 'EvacuatioNZ'. It is a coarse network, probabilistic evacuation model which has the option to incorporate human behaviour. Two research papers (Teo 2001 and Sing-Yen Ko 2003) have been prepared to date on the validation of components of this model.

Human behaviour aspects have been incorporated into the model with the inclusion of two input files (Teo 2001). The first, a "Person Type" file allows the maximum potential travel to be set, and the second, an " Exit Behaviour" file, allows the user to influence how the occupants may select from several exit paths that may be available. The options have probabilities that can be assigned based on human behaviour research results. The report concludes that the basic components of movement are working satisfactorily when compared to other calculated values, and that simple scenario testing showed the components worked adequately well, but with some discrepancies due to different assumptions made. Most importantly, it recommended that the current version 1.0e should not be used for design purposes as it still requires further work.

Further validation work was carried out (Sing-Yen Ko 2003) by comparing the computer-based evacuation models of EvacuatioNZ (version 1.01) and Simulex with observations and data collected from actual trial evacuations. It was found that the EvacuatioNZ predicted evacuation performances close to the actual trial evacuation data, while Simulex indicated a faster pedestrian flow rate but was capable of more accurately modelling the actual travel distances. One of the report's conclusions was that pre-movement times are a critical element to be factored into any evacuation modelling.

In separate research evaluating the effect of safety factors on evacuation modelling (Crawford 1999), it was found that the occupant response time was the most critical factor in an evacuation and the occupant travel speed the least.

In an earlier Masters research paper, the responsiveness of occupants to fire alarms had been considered (Grace 1997). This was essentially a literature review of international work in this field. Typically, the highest proportion of fire fatalities occur in domestic dwellings. In New Zealand, as in the USA and Australia, the peak period is between 1am and 4am. The report concluded that people were least responsive to a fire alarm during the deepest stage of sleep, and that younger people have a longer deep sleep stage than do the elderly. The overall response level was due to many factors including the volume of the alarm, background noise, familiarity with the alarm, age of the respondent, the stage of sleep, and the influence of drugs and alcohol. It also concluded that it is possible to improve the response with motivation and/or training, and a universal fire alarm signal would eliminate confusion. The 75 dBA sound level at the bed-head was found to be adequate for awakening occupants, and that the installation should also consider background noise levels.

These findings, in particular those relating to recognition of the alarm sound being a fire alarm signal have been further confirmed in a similar study conducted in Canada (Proulx *et al* 2001).

The Canadian study simply asked participants to identify a selection of alarm type sounds including a car horn, a reversing bleeper and an industrial warning buzzer. The report concluded that more community education was required to improve recognition and therefore response.

While Grace's research utilised international work, the findings are consistent with those of Duncan (Duncan 1999) in which the effectiveness of the domestic smoke alarm signal was studied. Duncan conducted experimentation on a number of New Zealand volunteers from the higher risk groups of students, Māori and the elderly. The report concluded that the alarm signal was 85% reliable at alerting occupants, and that children aged under 10 years and adults whose sleep was influenced by the effects of alcohol were not reliably woken by the alarm. This work is consistent with that reported in Australia (Bruck 1998). In the Australian study, it was found that 85% of the children did not awaken over two separate nights that the experiment was conducted.

Recognising and responding to cues indicating that there is a fire is one component; the subsequent actions of the occupants another. These subsequent actions can in part depend on what an occupant understands about fire. A survey was conducted to assess people's awareness of fires in domestic dwellings (Rusbridge 1999). The survey was returned primarily by mid-income New Zealanders of European descent. The findings showed that there was a sound basic knowledge, but that a large proportion of the respondents under-estimated the rate of fire growth and would undertake wrong or ill-advised actions. Many of these actions could be modified with education, such as could be given through media campaigns. The presence of other family members, including children, was enough for a very high proportion to consider re-entering the building on fire to attempt rescue. Other findings were that very few had a planned and practiced escape route, and that the house owner was prepared to undertake more risky behaviour than a person renting.

These findings are consistent with those from a study conducted by the Melbourne Fire Brigade in which the victims of residential fires were interviewed and surveyed (Metropolitan Fire and Emergency Services Board 2003). This study considered the impact of fire safety education programs, the actions of victims and the influencing factors of those actions, and how a fire incident may have influenced their attitude towards fire. In summary, general education on changing smoke detector batteries and how to protect yourself in a fire were understood. There was, however, a considerable lack of understanding of fire, its development and prevention, and few had extinguishers or fire blankets available. In terms of actions on discovery of a fire, people generally finished their activity before responding to a fire cue or evacuating with less than half evacuating immediately. Few contacted the fire brigade immediately, most often the call was made after their own fire fighting attempts, usually with the garden hose, had failed. Most occupants had made on-the-spot decisions rather than following a pre-plan. Most occupants under-estimated the danger of fire, more influenced by protection of either the home or household members. Interestingly, most occupants were indifferent about improving the fire safety in their homes in the future, and were more likely to mention reactive measures than preventive measures.

In another University of Canterbury research report *Design for Escape from Fire* (Garrett 1999), the main focus was to propose a design procedure for safe escape from fire with reference to the NZBC Acceptable Solutions and actual occupant densities. Much of the supporting research data relating to pre-movement was taken from overseas work including that of Wood (Wood 1972) and Bryan (Bryan 1977).

An evacuation study was carried out in three Canterbury University buildings comprising two multi-storey buildings housing offices, libraries, study rooms and lecture theatres, and a single level building housing three lecture theatres (Olsson and Regan 1998). The study compared the results from a simulated fire emergency in the buildings with predicted evacuation times determined using the Simulex evacuation model. It was found that the model could be used with confidence to simulate travel times when the observed occupant numbers and measured pre-movement times were used. The predicted pre-movement times presented in the literature were shown to be very conservative when compared to the measured pre-movement times. The measured pre-movement times for occupants who were alerted to evacuate by pre-recorded PA information were shorter than those alerted by siren alarms alone.

One paper examined the impact of estimating distributions of pre-movement times on simulated evacuation performance within the Simulex computer model (Spearpoint 2004). The estimation of pre-movement time should be a distribution of times, and simply adding the maximum pre-movement time to the movement time was found to over-estimate the total evacuation time. Different distributions of pre-movement times were modelled. The findings were that when the distribution of the range of pre-movement time was small, the travelling and queuing effects dominated the simulated evacuation time. When the distribution of the range of pre-movement time was large, then travel and queuing effects were not so important and the pre-movement times dominated.

A model for the estimation of occupant pre-movement and/or response times and the probability of their occurrence is proposed by MacLennan, Regan and Ware (MacLennan *et al* 1999). This work does not present any hard pre-movement data; rather it concentrates developing a method for the application of such data into the overall determination of the RSET value.

Essentially very little work in New Zealand can be directly used as a source of pre-movement data. While much can point to general behavioural traits and some responses, there is very little analysis of occupant pre-movement actions in response to real fire incidents other than on specific occasions such as when required by a coronial court.

4. PRE-MOVEMENT DATA

As discussed previously, pre-movement data is an essential component in compiling realistic predictions of building evacuation performance. This section reviews and summarises the current research and data sets available. Where possible, it has been subdivided by building and occupancy types in line with the broad purpose group classifications used in the NZBC Acceptable Solution C/AS1. These purpose groupings are: Sleeping, Crowd and Working. In many cases, a single piece of research may cover many building and occupancy types. In these instances, and where the findings cannot conveniently be separated, discussion of the research findings has been retained in the section headed General.

4.1 General

The delay time or pre-movement time prior to starting to evacuate is a major component in the overall success of an evacuation. Realistic delay time input data, suitable for modelling evacuations, was the driver for a review of five evacuation case studies (Proulx and Fahy 1997). The case studies themselves covered apartment and office buildings ranging from mid-rise (more than three storeys but less than 36 m in building height) to high-rise (greater than 36 m). The trial evacuations were comprehensively video recorded and, after the event, all occupants received a survey to complete. The occupants of the apartment buildings had received a memo advising that a trial evacuation would take place without giving the exact day and time. The two office buildings included in this review were six to seven storeys high with a mix of open plan and enclosed offices. Unlike the apartment building trial evacuations, those in the office buildings were completely unannounced. The review was complemented with data from two real fire evacuations, that of the 30 storey Forest Laneway apartment building (Proulx *et al* 1995 discussed further in Section 4.2) and the 1993 bombing of the World Trade Center (WTC) (Fahy and Proulx 1997 discussed further in Section 4.3).

In the trial evacuations, video cameras accurately identified the delay in the occupant response times. The very quick and efficient response of the office occupants demonstrated the benefits of good alarm audibility, training and the presence of fire wardens. The response in the apartment buildings was significantly slower. The alarm audibility varied enormously to the extent that some occupants were only made aware by others or the sirens of the fire engines. Typically, the pre-movement activities were more extensive and included: gathering valuables, getting dressed, finding children and/or pets, and moving to the balcony. In comparison, the pre-movement activities of the office building occupants were limited to little more than gathering valuables. The two “real fire” incidents illustrate that even timelines from real situations have to be used with caution. In the Forest Laneway incident, the occupants were surveyed up to three weeks after the event and the respondents illustrated a tendency to round-off times to multiples of five minutes and in some cases the nearest half an hour. In any evacuation of the WTC, occupants on hearing the alarm were to gather at the central core on their floor and await further instructions over the public address system. The bomb in 1993 destroyed the emergency control centre rendering the alarm system silent and the public address system inoperative. Occupants then had to decide for themselves when, or even if, to commence evacuation. In Tower 1 the times recorded for commencing evacuation ranged from 0 to more than 4 hours, and in Tower 2, from 0 to just over 3 hours. The mean times were 11 minutes and 25 minutes for Towers 1 and 2 respectively.

This research into delay times was continued (Fahy and Proulx 2001) and the number of fire incidents and unannounced trial evacuations reviewed was expanded. The aim was towards creating a database of delay times. The building and occupancy types in this study now included high-rise hotels, high and mid-rise office buildings, department stores, and high and mid-rise apartment buildings. The database of delay times clearly demonstrates that for the unannounced trial evacuations, it is possible to achieve very short delay times with an apparent degree of consistency, and perhaps therefore some predictability. However, the same database also highlights just how unpredictable real fire events can be with a very large spread in the delay times recorded. The database as presented comprised some 21 evacuations, of which seven were from actual fire incidents.

In the United Kingdom a survey was undertaken of nearly 1,000 fire incidents, and the more than 2,000 people involved in them, based on the analysis of questionnaires administered by fire brigade personnel at the scene of the fires (Wood 1980). The data represented dwelling houses (50%), blocks of flats and other multi-occupancy dwellings (11%), factories (17%), shops (7%), and institutions such as schools and hospitals (4%). It is worth noting that this data is only from fires considered by occupants or observers severe enough incidents for the brigade to be called to attend. There are likely to be many more incidents in which occupant fire fighting was successful and the brigade was not called to attend. The analysis was very much generalised across all building and occupancy types, but some broad patterns were worthy of note.

The first actions of occupants on discovering a fire, in decreasing order of preference were:

1. fire fighting
2. contact fire brigade
3. investigate fire
4. warn others
5. do something to minimise danger
6. evacuate oneself
7. evacuate others.

A higher proportion of occupant fire fighting as a first activity occurred in the factories (25%), whereas in domestic dwellings it was less than 10%. The greater affiliation between the occupants in a dwelling situation is likely to move the fire fighting activity from being the first action. Occupant fire fighting activity was inversely proportional to the perceived seriousness of the fire.

Other general findings were:

- Familiarity of the layout did not lead to reduction in the pre-movement time.
- The more frequently occupants received training, the more likely they were to raise the alarm or organise evacuation as a first action.
- People who had been in previous fire incidents were no more likely to contact the fire brigade than those who had not. They were, however, more likely to attempt fire fighting and less likely to evacuate immediately.
- The first actions of female occupants were more likely to be: warn others, evacuate immediately, request assistance and/or evacuate their family. They were less likely to fight the fire and/or minimise the risk.
- Male occupants were more prepared to move through smoke, more so in the home rather than at work, and were more likely to re-enter the building after evacuating.

One study (Saunders 2001) specifically focussed on gender differences in fire incidents. The study comprised a questionnaire to be answered in response to viewing a film used to provide cues that were typical of a developing office fire emergency. The film paused when an actor experienced one of the cues, to enable participants to complete the questionnaire. The findings were consistent with those above – that females were more likely to investigate, alert/warn others and evacuate than males.

4.2 Sleeping

4.2.1 NZBC Acceptable Solution definition

In the NZBC C/AS1, there are several sub-classifications used to provide distinction between different types of sleeping accommodation. These are identified in NZBC C/AS1 Table 2.1, and the relevant section has been copied as Figure 1.

SLEEPING ACTIVITIES		
SC	Spaces in which *principal users* because of age, mental or physical limitations require special care or treatment.	Hospitals. Care institutions for the aged, children, *people with disabilities*.
SD	Spaces in which *principal users* are restrained or liberties are restricted.	Care institutions, for the aged or children, with physical restraint or detention. Hospital with physical restraint, detention quarters in a police station, prison.
SA	Spaces providing transient accommodation, or where limited assistance or care is provided for *principal users*.	Motels, hotels, hostels, boarding houses, clubs (residential), boarding schools, dormitories, halls, *wharenui*, community care institutions.
SR	Attached and multi-unit residential dwellings.	*Multi-unit dwellings* or flats, apartments, and includes *household units* attached to the same or other *purpose groups*, such as caretakers' flats, and residential accommodation above a shop. *Household unit firecells* may contain garages which are used exclusively by the occupants of that *household unit*.
SH	Detached dwellings where people live as a single household or family.	Dwellings, houses, being *household units*, or *suites* in *purpose group* SA, separated from each other by distance. Detached dwellings may include attached self-contained *suites* such as granny flats when occupied by a member of the same family, and garages whether detached or part of the same *building* and are primarily for storage of the occupants' vehicles, tools and garden implements.

Figure 1. NZBC C/AS1 Table 2.1 abridged – Sleeping purpose groups

4.2.2 Examples of evacuation studies

In an attempt to understand the behavioural responses to fires, a study in the United Kingdom was carried out on 14 domestic, eight multiple occupancy (e.g. hotels) and six hospital fires. The study (Canter 1980) interviewed 198 people involved in the fires about their decisions and actions from first being alerted to the fire to the end of their involvement. The collected data has been analysed and presented in decomposition diagrams which identify the connections between various actions and the strength of the associations. The report identifies that there are certain behavioural rules that are applied by occupants depending on the scenario. For example, in a domestic dwelling, the adults or parents are responsible for identifying and determining a response to the fire. In a hotel, the guest will not know if they are the prime discoverer of the fire or one of many individuals with similar experience. In a hospital, a natural organisational hierarchy exists and the actions of junior staff are guided by prior instructions, both through previous training and orders received during the incident. One of the key findings was that occupant actions and action sequences derive their behavioural significance from the position in the overall sequence at which they occur. The report concludes that while behaviour in fires is complex, the complexity does not preclude summary action sets for classes of fires. One of the major causes of non-standardised behavioural sequences is more a product of occupants attempting to cope with ambiguous and rapidly changing information.

There have been many reports written summarising the actions of occupant response to actual residential fires. In Victoria, Australia, the actions of both victims and survivors were studied (Brennan 1998a) in the 109 residential fire incidents in which there were fatalities from mid-1990 to 1995. The fires occurred in houses, apartments, hotels, hostels, cabins, huts and mobile homes and the source material comes from coronial inquests. Some of the findings include: a large proportion of the victims under five and 65 years and over were awake at the time of the incident, and for the under five's, the cause was playing with matches. Alcohol consumption was found to have impaired occupants' reasoning in a way that increased the danger to themselves. Most victims who moved at all were attempting to escape and were overcome by smoke. Three-quarters of those asleep. and half of those awake. did not move from the room in which they were originally located suggesting they never woke or responded too slowly. The key findings are that the common element in the response of both victims and survivors in fatal fires is late awareness of the fire, and that in many cases comparison of victim and survivor is not informative because fire conditions for survivors were quite different.

A source of raw data is contained in a Fire Code Reform Centre (FCRC) Technical Report FCRC TR98-03 (Brennan 1998b). The report contains brief accounts of fire incidents occurring in a range of sleeping purpose group buildings in Australia, where occupants were present in the room of fire origin. The accounts were collated to form the basis of a "Response in Fires" database project also funded by the FCRC. An earlier paper (Brennan and Doughty 1997) contains a similar, although more limited, selection of incident accounts but includes some analysis of the cues recorded by occupants in the events.

A terraced row of houses in Chester, United Kingdom became involved in a fire that started in an adjacent storage warehouse. An account of the evacuation was captured by questionnaires (Davis 1998) returned from 29 individuals. While this does represent a very small group, there are some general trends that are common to other fire incidents. Analysis of the replies indicates that occupants had received most of their fire safety knowledge from the workplace and to a lesser degree from the TV. In terms of the fire incident, 55% were alerted to the fire by noise, and 45% understood the situation to be extremely serious at that time. The fire began around 1:30am and, not surprisingly, 83% were in bed asleep at the time. The main "first actions" were to alert others (41%), evacuate (34%), and prepare to leave the house (28%). The highest proportion of occupants (69%) reported evacuating at least initially to the street, while for many they continued onwards to gather at the pub (52%).

High-rise residential accommodation represents quite a different scenario. Generally there is an overall management system for the building, fire safety features including alarms and sprinkler systems are more likely to be installed (sometimes with direct connection to the fire brigade), and for occupants the evacuation route is likely to be very long. There have been many fires in high-rise apartment buildings, including one in 1997 in a sixth floor apartment of a 25 storey apartment building in Ottawa, Canada. In this incident, the fire service attended promptly and extinguished the fire within 10 minutes of the notification call. On the orders of the fire department, the building voice communication system was used to advise all residents to evacuate immediately. A subsequent study of this event (Proulx 1998) was conducted, receiving a total of 213 completed questionnaires from 265 units. For 39% of the occupants the fire alarm was the first indication of the event, while 70% included the alarm with the instructions from the voice communication system. A total of 83% of the occupants attempted to evacuate the building, of which 82% took time to get dressed and collect other belongings. All respondents from above the fire floor reported encountering smoke during their evacuation attempt. Of the 83% who attempted to evacuate, only 54% managed to escape, with the remainder returning to their own apartment or seeking refuge in someone else's. It was indicated by 17% of the respondents that they made the decision to disregard the initial instructions of the fire department and remain in their own apartment. After their experiences, many of the occupants said they would not follow evacuation instructions over the voice communication system in future fire situations, preferring to stay in their apartments and defend in place.

Another is known as the “Forest Laneway fire” which occurred in 1995 in Toronto, Canada. This fire was caused by a carelessly discarded cigarette in an apartment on the fifth floor of a 29 storey apartment building. The results of an occupant survey questionnaire (Proulx 1995) found that 71% of the occupants decided to defend in place and not attempt to evacuate the building. All of these occupants had a look in the corridor or stairwell before making the decision to stay. Of the 64 occupants (the remaining 29%) who attempted to evacuate only 18 were successful, with the remainder returning because of smoke, either to their own apartment or seeking refuge in that of a friend or neighbour. The six fatalities were found towards the top of the stairs, suggesting they may have unsuccessfully attempted to seek refuge on the roof.

In 1996 in Hiroshima City, Japan, a fire occurred in a ninth floor apartment of a 20 storey apartment building, spreading very rapidly (within 30 minutes) to the 20th floor via external flame spread through balconies. The building complex contained about 3,000 households, and since its construction in 1972, had already experienced 69 fires including three which involved fire spread to upper floors (1980, 1985 and 1993). A similar research survey was conducted (Sekizawa 1998) and analysis carried out on a total of 77 responses from occupants who were at home at the time of the incident. As the fire occurred around 2:30pm, 72% of respondents were 60 years and over, and the gender split was 1:3 males to females. At the time of the fire, 40% were watching TV. A remarkably low 10% perceived the fire from the fire alarm sounding, while for 26% it was the siren of fire engines, and 55% were notified by neighbours. Most were very slow to begin evacuation. From past experience, most fires had been suppressed at an early stage. In this fire 47% used the elevators to evacuate, 42% the stairs and 7% a combination of both. The use of elevators, while contrary to evacuation instructions, was found to be proportional to the height of the floor being evacuated.

A fire incident in Australia (Brennan 1997) does not specifically deal with pre-movement but highlights some of the complexities involved in real evacuations that have to be considered when using models to predict evacuation performance. A fire broke out at approximately 3:30am in an apartment located on the third floor of an 18 storey apartment building. The fire was controlled by the occupant with assistance from the night manager prior to fire brigade attendance. The alarm was the first cue for most occupants, and it is worth noting that no evacuation drills had been practiced prior to the fire. Fewer than half of the estimated 200 occupants evacuated. Many waited more than 10 minutes before beginning to evacuate either in response to instruction from other occupants or from the fire brigade. In one case, the occupant heard a warning knock on the door from the fire brigade after around 12 minutes and eventually left after TV crews had arrived at the building some 18 minutes after the fire alarm sounded. Another occupant left the building, and on seeing the fire from the street returned to Level 11 using the lift to warn their partner before they both made their escape using the stairs. The response times ranged from one minute to more than 20 and this is stated to be comparable to that observed in trial evacuations conducted under similar conditions: fire alarm sounding, fire brigade in attendance, warnings from fire brigade and from others. Moreover, the wide range of times is evident even amongst those on the same floor, further demonstrating evacuation to be a more random process.

The area of care and detention facilities is a specific case of sleeping accommodation in its own right as the occupants require assistance to evacuate, either through their own physical condition, or because of their reduced freedom. The pre-movement activities are predominately going to be those of the staff assigned to take charge of the patients or detainees. In these situations, the staff have considerable authority and responsibility; the residents little or none.

A fire occurred in a clothing closet located on the fourth floor of a nursing home housing some 250 residents. A study of the evacuation was carried out (Edelman 1980) with the primary purpose relating the actions of the occupants to a proposed general model of behaviour. It is worthy of inclusion because it contains a comprehensive analysis of first-hand interviews with 22 of the occupants, all residents on the fourth floor. The initial cues included properties of the fire, the fire alarm and indications from others. The indication from others comprised notification by staff and hearing screaming. Given that only seven mentioned the alarm as the first indication of trouble, it clearly did not have its desired effect, and in one case an occupant closed the door to deaden the sound of the alarm. A number of false alarms in the past would have contributed to this response. The choice of first actions ranged from doing nothing (thinking it a false alarm) to leaving rooms immediately. A greater number of the occupants remained uncertain about the cues until they saw flames. All but six of the occupants (who were assisted by fire fighters or used the elevator) used the central stair. It was later noted that of the 85 fourth floor residents who escaped via the stairs, none were observed to use any of the other three exit stairs. For many this meant moving towards the fire to access the central stair rather than using a safer and closer exit. This response was concluded to be due to the residents knowing that using any of the emergency exits would activate the alarm system (for control of residents all had to pass the nurses station to get to the central stair), and this had caused problems in the past. The study concluded that increased and improved fire emergency training for both staff and residents was needed. This would decrease the time involved in detecting cues and defining the situation, and the training should extend to the use of all fire exits.

Another research study evaluated the human behavioural responses in three fires, one in each of a nursing home, a penal institution and a retirement home (Haber 1980). In all three incidents, the resident occupants required the assistance of staff for evacuation. In the nursing home incident, the fire which began in an unoccupied room was first detected by a staff member. After raising the alarm, considerable effort went into ineffectual fire fighting by staff. The lack of a door to one common room killed 21 people, whereas occupants located right next to the fire and behind a shut door survived. In the penal institution, one aggrieved inmate set fire to a mattress. This was witnessed by a fellow inmate who raised the alarm. With the assistance of other officers from another section of the prison, all affected inmates were removed to secure areas and the fire extinguished. The rest home fire resulted from the concerted effort of an arsonist setting fires using Molotov cocktails thrown into rooms on the ground, fourth and fifth floors. His actions were quickly discovered by staff who followed his trail and responded quickly, either removing the occupant or the burning object from affected rooms. Most importantly, the staff closed all doors to fire-affected rooms limiting the spread of fire and smoke. This incident points up the benefits of a highly effective team having received good fire-drill training and planning, in conjunction with good building design and fire protection. The three incidents demonstrate the necessity for efficient communication throughout such an incident, pre-planning, and in the case of the penal institution the need for secure refuge areas to house inmates in the event of an evacuation. It is interesting to note that in all three incidents the building occupants raised the alarm before any automated systems detected the fires.

An alternative source of pre-movement data is from experimentation rather than from real fire incidents. One approach is to conduct and study unannounced trial evacuations, although for ethical reasons, occupants may have to be informed before such an event, without being absolutely specific about when. Another approach is to conduct direct experimentation using willing participants. Both of these techniques have been applied to occupants of buildings classified within the "sleeping" purpose group category.

The Fire Safety Engineering Group at the University of Greenwich conducted an unannounced trial evacuation of a private hospital for the purposes of collecting pre-movement data (Gwynne *et al* 2003). The evacuation was limited to outpatients and associated staff. The exercise highlighted the dependence of patient safety on the response of the trained staff. In all instances, patients only began to evacuate after instruction to do so from staff. The pre-movement times recorded for the patients then directly related to the time at which they were reached by staff completing their sweeps of the building.

As discussed previously, two New Zealand studies (Grace 1997 and Duncan 1999) have involved work on the responsiveness of sleeping occupants to fire alarm signals (refer Section 3). In Australia, experimentation was carried out to study the recognition of fire cues during sleep (Bruck and Brennan 2001). The experiments comprised low-level cues designed to mimic the early presence of fire, sounds, flickering light and smoke odour. The findings indicated a high level of arousal to the sound cues (91% to a crackling sound and 83% to a shuffling sound), while 59% awoke to the smoke odour and 49% responded to the flickering light. A gender difference was evident only in regard to the smoke odour cue, with 80% of females responding verses 29% of males.

The building codes readily identify with and, where possible, make provisions for physically disabled occupants. However very little exists in relation to occupants with learning difficulties. In 1997, following concerns about the evacuation capabilities of people with learning difficulties, two residential care premises in Northern Ireland were subjected to unannounced trial evacuations (Shields 1998a). The two evacuations were conducted after 11:30pm and all residents had retired for the evening. The findings suggest that the concerns were well founded. In Residence 1, only three of the 10 evacuated, while in Residence 2, 10 out of 12 evacuated. The key findings were that: all of the evacuees from both residences concentrated on self-preservation i.e. they did not appear to warn others; the three who evacuated from Residence 1 demonstrated typical behavioural traits of seeking information and using familiar routes; and there was no transference of the evacuation skills acquired during day-time evacuation instruction to a night-time evacuation.

4.3 Working, business or storage

Generally the largest proportion of occupants present in buildings containing working, business and/or storage facilities are employees, and the remainder if not directly employed are likely to be assigned to or visiting employees. This provides a strong basis for the establishment of an efficient and effective pre-determined emergency response action plan.

4.3.1 NZBC Acceptable Solution definition

In the NZBC C/AS1, there are several sub-classifications used to provide distinction between different types of working, business and storage facilities. These are identified in NZBC C/AS1 Table 2.1, and the relevant section has been copied as Figure 2.

WORKING, BUSINESS OR STORAGE ACTIVITIES		
WL	Spaces used for working, business or storage – low *fire load*.	Manufacturing, processing or storage of *non-combustible* materials, or materials having a slow heat release rate, cool stores, covered cattle yards, wineries, grading or storage or packing of horticultural products, wet meat processing. Banks, hairdressing shops, beauty parlours, personal or professional services, dental offices, laundry (self-service), medical offices, business or other offices, police stations (without detention quarters), radio stations, television studios (no audience), small tool and appliance rental and service, telephone exchanges, dry meat processing
WM	Spaces used for working, business or storage – medium *fire load* and slow/medium/fast *fire* growth rates (e.g. <1 MW in 75 sec) **(Note 1)**.	Manufacturing and processing of *combustible* materials not otherwise listed, including bulk storage up to 3 m high (excluding *foamed plastics*).
WH	Spaces used for working, business or storage – high *fire load* and slow/medium/ fast *fire* growth rates (e.g. <1 MW in 75 sec) **(Note 1)**.	Chemical manufacturing or processing plants, distilleries, feed mills, flour mills, lacquer factories, mattress factories, rubber processing plants, spray painting operations, plastics manufacturing, bulk storage of *combustible* materials over 3 m high (excluding *foamed plastics*).
WF	Spaces used for working, business or storage – medium/ high *fire load* and ultra fast *fire* growth rates (e.g. >1 MW in 75 sec) **(Note 1)**.	Areas involving significant quantities of highly *combustible* and flammable or explosive materials which because of their inherent characteristics constitute a special *fire hazard*, including: bulk plants for flammable liquids or gases, bulk storage warehouses for flammable substances, bulk storage of *foamed plastics*.

Figure 2. NZBC C/AS1 Table 2.1 abridged – Working, business or storage activities purpose groups

This classification covers a very broad selection of working environments with the exception of retail premises. For the most part, the occupants in this purpose group are employees, there is a structured hierarchy of command, and all occupants should be familiar with the building layout, awake and alert. It is generally easy for researchers to identify the occupants for fires in this purpose group, providing a good source of "real" scenario data.

4.3.2 Examples of evacuation studies

One of the largest evacuations occurred following the 1993 bombing of the WTC complex. Six of the seven buildings were evacuated involving literally tens of thousands of occupants. Approximately 40,000 people worked in each of the two main towers and another 50,000 were estimated to visit the towers each day. A survey of the evacuation (Fahy and Proulx 1997; and Fahy 1995) was sent to 1,600 occupants (to each fire warden) from the two towers and resulted in more than 400 responses. As mentioned earlier, the bomb had knocked out the emergency control system leaving the building without the public address system (designed to inform occupants during such incidents), the power supply had failed and the phone system was down. The seat of the explosion was closest to Tower 1 and this explains the higher proportion of respondents who immediately recognised this cue to be a significant event on hearing/feeling the explosion. Surprisingly, for "trained" fire wardens, only a small proportion of the respondents attempted to contact the fire brigade and/or activate the manual pull alarms. Smoke had migrated through the buildings via the stairs and elevator shafts. A very high proportion reported that they tried to move through the smoke in the stairs with almost all having to seek refuge or turn back at some point during their evacuation. Two-thirds of those in Tower 1 and half of those in Tower 2 commenced evacuation without being told to do so by someone in authority. While all tenancies were required to conduct a trial evacuation every six months, 79% (Tower 1) and 90% (Tower 2) of the respondents had never practiced evacuating to another floor, let alone completely from the building. This omission led to a considerable amount of unfamiliarity with the stairs. The degree to which the fire wardens had been trained varied, and at least one reported being over-ruled by their manager, even though the manager had no better information. Analysis of the pre-movement actions was carried out, but no timelines for this were able to be drawn from the responses. The actions listed and the preferences given demonstrate a direct relationship with the strength of the cues, and therefore the level of threat, felt by the occupants.

In Australia, a severe fire fuelled by a large number of polyurethane foam chairs broke out at 2:32pm on Level 3 of a 14 storey office building (Brennan 1997). The fire was confined to Level 3, but smoke migrated throughout the building to be a major hazard. Six occupants on Level 3 and three on Level 13 became trapped by smoke. Those on Level 3 were overcome by the smoke and rescued by the fire brigade. All other occupants evacuated safely via the fire stairs. The alarms did not sound and most occupants became aware of the fire from the smoke and/or notification from others. The public address system was used, but only after the fire brigade had arrived, by which time most occupants had left. Most occupants had participated in fire evacuation drills, except those trapped on level 13 who were relatively new to the building. The estimated pre-movement times for interviewees ranged from one minute to six. In this case the six minute delay resulted in the occupants being trapped on Level 13. Those trapped on Level 3 had responded very quickly but were prevented from reaching the exit by the fire.

The terrorist attacks on the two towers of the WTC on 11 September 2001 and the enormous media attention it attracted provided yet another valuable source of pre-movement data (in this case first-hand accounts of a full scale evacuation from a real incident published in the print and electronic media). This is not always the preferred route for information gathering as the interviewees are often self-selecting and journalists tend to report the more sensational parts of people's stories. Nevertheless, with journalists concentrating on only current events, their interviews most often occur very close to the event and as a result contain fresh recollections uncontaminated by time. In contrast, the formally structured human behaviour research interview is more likely to be conducted some time after the event and may be tainted by other accounts, memory lapses or selective amnesia. The Office of The Deputy Prime Minister in the United Kingdom commissioned a collection of mass media accounts of human behaviour relating to the 2001 evacuation of the WTC (Galea and Blake 2004). In this study, the accounts of 260 occupants were collected, and each of their experiences logged into a database for analysis. Consistent with journalists presenting the more dramatic stories, more than 60% of the occupants began their evacuation from above the 78th floor sky lobby.

A parallel study was carried out using the same information sources and resulted in the collation of first person accounts from 435 occupants (Proulx and Fahy 2004). The same issues raised in relation to the journalistic requirements for the reported accounts were equally valid. In this second study, analysis of the content of these accounts was carried out using a questionnaire to "interview" each account.

The findings of these studies indicate that during the pre-movement phase the majority did not know the cause of the incident and went to some lengths to seek information and therefore guidance. These actions included turning to radio and television, telephone and email, and moving to the windows. A significant 75% of those making telephone calls had not called emergency services but friends and relatives, mostly to assure them they were okay rather than for information gathering. Another feature of the pre-movement phase was the formation of groups, often led by a line manager.

Interestingly, after WTC Tower 1 had been struck by the first plane, a number of occupants of WTC Tower 2 had made the decision to evacuate. Approximately 15 minutes after WTC Tower 1 had been hit and less than five minutes before WTC Tower 2 was hit, an announcement was made over the public address system of Tower 2 stating that "the building is secure; no one need evacuate". Significantly, more than 70% of those already evacuating at the time of the announcement chose to ignore it and continue with their evacuation.

In another incident, a fire broke out in a storeroom located on the 12th floor of the 36 floor Cook County Administration building in Chicago (Proulx 2003). While the alarm was raised fairly promptly, due to the timing of the incident, 5:00pm on a Friday afternoon, many occupants continued with packing up for the day prior to evacuating. Those occupants who were already prepared for leaving the building simply continued to leave as if nothing was wrong. Their actions included using the elevators, despite instructions received during regular training drills and the placement of notices advising not to use elevators in the event of an evacuation. Building evacuations were to be staged with the use of the public address system. Initially the call was made to evacuate the floors in the immediate vicinity of the fire, but almost immediately a second call was made to evacuate the whole building. This occurred prior to fire brigade arrival. Many of the remaining occupants did commence evacuation as instructed, via the stairwells. The fire brigade chose to fight the fire from one of the stairwells, and in doing so considerable quantities of smoke from the fire floor began to fill the stairs. For security purposes, the doors from each floor onto to the stairs were locked to prevent re-entry to a floor from the stairs. This feature ended up trapping many of those who chose to evacuate using the very same stairs, ultimately leading to six fatalities. Many lessons were learned from this fire: the importance of reducing the pre-movement time; training, including understanding of how the building is set up; and not least, that there should be nominated refuge floors permitting evacuees to re-enter a floor from the stairs.

Experimental studies have also been carried out to record the human behaviour of office building occupants during evacuations to supplement that learned from real fire incidents. The data collected from recording occupant response to unannounced trial evacuations is considered valid for occupants of high-rise buildings that are remote from the fire.

Occupants in high-rise buildings remote from a real fire in the same building have been observed to be quite relaxed from the perception that they are exposed to a very limited risk. This response is then comparable to that witnessed in unannounced trial evacuations and therefore makes the data collected from these exercises valid (Pauls and Jones 1980). In one exercise, the public address system used to stage the evacuation did not function correctly, leaving building occupants without instructions for a couple of minutes. This was enough for many to consider it a false alarm or drill and to return to their floor. When the announcement was made (in both English and French as required in Canada), the English portion was ambiguous and the French indicated total evacuation. Some respondents even reported an extra announcement they could only have thought they heard. This evacuation provided as much confusion as has been recorded in real events. Fortunately, it was only a trial and could be used to improve the system.

The unannounced trial evacuation of a university facility found that pre-movement times ranged from around 10 to 200 seconds (Gwynne *et al* 2003). The greatest proportion (54%) of individuals undertook two actions prior to commencing to evacuate. Of the remainder, 28% completed one or no actions, and 18 % completed three or more. The range of prior actions analysed comprised of:

- evacuate immediately
- perform a computer shutdown
- disengage socially
- collect items, including bags, coats, paperwork etc.
- investigate the incident.

One concerning finding was that of the student population; 38.2% required staff prompting before they evacuated. The pre-movement time for these students was then dependent on the time taken for staff to reach the students in the course of completing their sweep of the building.

A different experimental technique was used in Australia (Saunders 1997). Here a film and accompanying questionnaire was used to collect data on decision-making during the early stages of an office building fire scenario. The film, set in a modern high-rise office building, presented the participants with an ambiguous situation of developing fire cues which they had to interpret. As the film progressed, it would be halted at stages and participants asked to record their decisions to the developing cues. As the film progressed, participants answers became more polarised, probably as a result of familiarity with the questionnaire. Nevertheless, the findings highlighted the same requirements for early, succinct and accurate information to be provided in order to achieve a reduction in the pre-movement phase.

4.4 Crowd activities purpose group

This purpose group can be expected to display a distinctly different set of occupant responses given an emerging fire incident. In crowd occupancies, by definition a significant proportion of the population are casual visitors be it for shopping, in a cinema or auditorium, church or stadium. There is limited affinity between the staff of the building and the "crowd". While occupants may respond well to instructions given by fire wardens, there is not the same hierarchical system assigning authority and respect that would be found, for example, in an office building.

4.4.1 NZBC Acceptable Solution definition

In the NZBC C/AS1, there are several sub-classifications used to provide distinction between different types of crowd occupancies. These are identified in NZBC C/AS1 Table 2.1, and the relevant section has been copied as Figure 3.

CROWD ACTIVITIES		
CS or CL	For *occupied spaces*. CS applies to *occupant loads* up to 100 and CL to *occupant loads* exceeding 100.	Cinemas when classed as CS, art galleries, auditoria, bowling alleys, churches, clubs (non-residential), community halls, court rooms, dance halls, day care centres, gymnasia, lecture halls, museums, eating places (excluding kitchens), taverns, enclosed grandstands, indoor swimming pools. Cinemas when classed as CL, schools, colleges and tertiary institutions, libraries (up to 2.4 m high book storage), nightclubs, restaurants and eating places with cooking facilities, *early childhood centres theatre* stages, opera houses, television studios (with audience). Libraries (over 2.4 m high book storage).
CO	Spaces for viewing open air activities (does not include spaces below a grandstand).	Open grandstands, roofed but unenclosed grandstand, uncovered fixed seating.
CM	Spaces for displaying, or selling retail goods, wares or merchandise.	Exhibition halls, retail shops. Supermarkets or other stores with bulk storage/display over 3.0 m high.

Figure 3. NZBC C/AS1 Table 2.1 abridged – Crowd activities purpose groups

In general, we tend to modify our behaviour in public spaces, and that includes our response to events such as fire alarms. In large public buildings such as museums, department stores and airport terminals, people are very unlikely to take any action, at least initially, when the alarm signal is activated. People will observe what others are doing, and if no one is paying attention to the alarm, they are reluctant to take any action that would make them appear to be over-reacting (Proulx 2000). In some instances, occupants can become so engrossed in what they are taking part in or witnessing they may not pay an alarm any attention as happened in the following example.

4.4.2 Examples of evacuation studies

In Dublin, a portion of an existing factory had been converted into an "amenity centre" consisting of a cabaret room, a restaurant and a public bar. Named the Stardust, it is now most famous for a fire that occurred there in 1981 (Fire Prevention No. 158, 1983). The fire was started deliberately in a partially shut-off area adjacent to the main cabaret room. The first reaction of patrons was that the heating had been turned on. The next indication occurred eight minutes later when people smelt smoke and on closer observation noticed a small fire. Staff raised the alarm to other staff, but did not activate the fire alarm system. One staff member rang for the fire brigade while others attempted to put the fire out using extinguishers. This occupied another one to two minutes during which time more of the patrons became aware of the fire. The ceiling began to collapse and black smoke entered the main room. The disc-jockey made an announcement urging people to remain calm and walk to the exits. This announcement coincided with a dramatic escalation in the fire, and patrons rushed the exits in response. The emergency lighting was at best ineffective, or not functioning, and in the darkness there was acute congestion at exits. Other factors exacerbated the situation: loose furniture and the portable stage were obstacles, lighting remained visible in the toilets making them appear to be the escape route, one exit was locked and had to be kicked down, and two exits were partially blocked by a parked van and rubbish containers. There were no fire procedures and neither had there been any fire drills. In the final tally, 48 people died from the effects of the fire.

The staff were as confused as the patrons during the fire, and their actions were uncoordinated and inadequate. At no time was the fire alarm activated, leaving the patrons with no prior warning other than the black smoke and reactions of others around them.

In 1998 a fire was deliberately lit at dance party held on the first floor of a hired venue in Sweden (Bengtson 2001). The fire began in a stack of furniture stored in the rear escape stairs. After perhaps 10 minutes of development, witnesses recorded white smoke becoming thicker and darker and a few people noticed flames. Some occupants interpreted the first cues as smoke from the smoke machine, although many remarked on the strange smell. The disc-jockey shouted a warning that “there is a fire, don’t panic, take it easy, but everybody should get out”. This motivated many to head for the exit, but other people took to the stage and started a well-known rap song. This action caused a lot of those to stop making their exit and head back towards the stage.

These ambiguous and confusing cues resulted in an extended pre-movement time. With only one exit remaining usable and overcrowding of the venue, there was not enough time for 63 of the occupants to evacuate.

In the 1987 King’s Cross Underground Station Fire, staff and British Transport Police had responded very promptly to the initial reports of a fire on one of the escalators (Roberts 1992 and Crossland 1992). Within the first four minutes, the escalators had been stopped and taped off. While staff had attempted to take control of the situation and prevent access to the fire zone, some passengers continued to the escalators despite exhortations by staff not to do so. This illustrates yet another behavioural trait that some people will always know best and ignore the good advice of others.

The disaster that unfolded caught a great number of people out including trained fire fighters. While the fire developed over the first 14 minutes, security staff had been directing the evacuation in relatively clear conditions. These conditions changed suddenly and catastrophically, catching all unprepared. The fire that had been drawing in clear air had “flashed over”, effectively changing direction, and began venting through the ticket office area at the top of the escalators. Smoke and hot gases rapidly filled the ticket hall and swept along the passageways linking the ticket office to street level.

The reports from witnesses gave further insight into response actions of people facing an emergency. Some people had stopped and watched the fire shortly before flashover; one witness saw the initial entry of flame into the ticket hall, but dismissing it as a sign of immediate danger, proceeded on his way. Others had run from the station at a much earlier stage because of the presence of relatively light smoke, but felt obliged to apologise for doing so. The failure to perceive the fire as a genuine threat to life, and the absence of an escape route free from exposure to the smoke and fumes from the fire, combined to create the conditions for a major loss of life.

An airport fire in Düsseldorf, Germany in 1996 killed 17 people when fire safety systems and procedures had not been thoroughly considered. As in most disasters, it is not caused by the failure of a single component, rather it is the unique combination of many (in this case welding sparks fell into a ceiling space igniting PVC covered cables and combustible insulation). The fire went largely undetected for almost 30 minutes. In summary, there was no fire watch during the welding, no fire walls or barriers within the suspended ceiling space, and no smoke detectors or sprinklers installed in the ceiling. When first detected, the airport fire safety team identified the “smell” as an electrical fault and called for an electrician. Eventually 25 minutes later, it was correctly identified when fire broke out catastrophically some 100 m from the point of origin.

Next, the wrong message was broadcast over the public address system directing evacuees towards the seat of the fire, not away from it, and the lifts were not stopped allowing one to take passengers directly to the fire. To make matters worse, the ventilation system was not automatically shut down (Fire and Flammability Bulletin, July 1996, and Fire Prevention No.312, September 1998).

Strictly speaking, pre-movement time begins when occupants are first alerted to a fire and ends when they start evacuation. In this incident, a considerable period of time passed before the fire was correctly identified, the alarm raised and evacuation begun. Here, the time taken in sending occupants in the wrong direction should be included in the pre-movement phase as it cannot be counted as productive evacuation activity.

In 2003, a fire at the crowded Station Nightclub in Rhode Island was accidentally started by a pyrotechnics display (Grosshandler *et al* 2005). To commence a band's performance, the venue lights were dimmed and pyrotechnics set off. The pyrotechnics ignited polyurethane foam lining the walls and ceiling of the stage area, the ensuing fire quickly developed spreading along the walls and ceiling area over the dance floor. Within 30 seconds of the foam igniting, the band had stopped playing, and a general evacuation had commenced. The reaction of occupants was very prompt with cell phone calls to the fire service timed at 36 seconds after ignition, and the fire alarm system activating after 41 seconds. The fire developed very rapidly with smoke recorded to be at floor level inside after only 90 seconds. Egress from the venue was hampered by crowding at the main entrance to the building, with up to two-thirds of all occupants attempting to exit via this route rather than using the alternative exits available. One hundred people lost their lives in the fire. The large loss of life was attributed to the inadequate exit provisions and the rapid fire growth fuelled by the polyurethane foam wall and ceiling linings. In this case, the pre-movement time of the occupants was not a contributing factor; rather it was the behavioural trait that people tend to attempt to exit via the same route they used to enter the building.

An altogether different scenario was witnessed in an unannounced trial evacuation of a Marks and Spencer store in Northern Ireland. The purpose of the evacuation was to obtain behavioural data relating to a large compartment single storey retail store (Shields 1998b). The alarm was activated at 3:00pm, at which time almost 70% of the respondents reported having no commitment to the activities they were engaged in. It follows then that it would be easy for staff to influence this large proportion of occupants to evacuate. Where occupants were highly committed was generally during changing and in the purchase process. These are activities most effectively and efficiently influenced by staff. Staff and management were able to switch from regular business to evacuation mode, including shutting down tills, within approximately 30 seconds and began floor sweeps and directing customers towards the nearest exits. This resulted in a very creditable two minutes and 45 seconds to evacuate 500 customers, illustrating the effectiveness of good planning and training.

In another experiment (Frantzich 2001), a series of unannounced trial evacuations were carried out at three different IKEA stores in Sweden; two were single storey and one multi-storey. The alarm activated a tone for five seconds, and then was followed with a public announcement telling occupants to evacuate using the nearest exit and follow the instructions of the staff. The message also told parents who had left children in the play area that they had already been evacuated – to prevent parents re-entering the building. This was repeated during the evacuation, and in some experiments the announcement was also given in English.

The pre-movement times were generally less than one minute, with most customers responding within 30 seconds. The longest pre-movement times were recorded at the cash desk and in the restaurant, with customers reluctant to leave either their place in the queue or their food respectively. Again, it is a credit to evacuation planning and staff training.

5. PRE-MOVEMENT DATA BY COUNTRY

A matrix has been used to provide a cross-reference of published pre-movement data by source country. It is entirely probable that people from different countries and cultural backgrounds will respond differently to any one incident. The matrix then clearly identifies where most of the pre-movement research and data gathering has occurred.

Response	Countries						
	New Zealand	Australia	UK	USA	Canada	Japan	Europe
Awareness of the fire	1, 2, 3, 4	5, 6, 7, 8, 9, 10, 11, 12, 25	13, 14, 15, 16, 17, 18, 19, 20, 21, 25	22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32	24, 25, 33, 34, 35, 36	25, 37	38, 39
Decision processes of the individual	3	5, 6, 8, 9, 10, 11, 12, 25	13, 14, 15, 16, 17, 18, 19, 20, 21, 25, 40, 41	22, 23, 24, 25, 27, 28, 29, 30, 31, 32, 42	24, 25, 33, 34, 35, 42, 43	25, 37	38, 39
Recognition	1, 2, 3, 4	5, 6, 8, 9, 10, 11, 12	13, 14, 15, 16, 17, 18, 19, 20, 21	22, 23, 27, 28, 29, 30, 31, 32, 42	33, 34, 35, 43, 42	37	38, 39
Validation	1, 2, 3, 4	5, 6, 8, 9, 10, 11, 12	13, 14, 15, 16, 17, 18, 19, 20, 21	22, 23, 27, 28, 29, 30, 31, 32	33, 34, 35, 43	37	38, 39
Definition	1, 2, 3	5, 6, 8, 9, 10, 11, 12	13, 14, 15, 16, 17, 18, 19,	22, 23, 27, 28, 29, 30, 31, 32	33, 34, 35, 43	37	39
Evaluation	3, 4	5, 6, 8, 9, 10, 11, 12	13, 14, 15, 16, 17, 18, 19, 20, 21, 40	22, 23, 27, 28, 29, 30, 31, 32, 42	33, 34, 35, 43, 42	37	39
Commitment	1, 2	5, 6, 8, 9, 10, 11, 12	13, 14, 15, 16, 17, 18, 19, 20, 40	22, 23, 27, 28, 29, 30, 31, 32, 42	33, 34, 35, 43, 42	37	38, 39
Reassessment		10, 11, 12	14, 15, 18, 19	22, 23, 27, 28, 29, 30, 31, 42	33, 34, 35, 42		39

Response	Countries						
	New Zealand	Australia	UK	USA	Canada	Japan	Europe
Behaviour Actions of Occupants							
First actions	3	5, 6, 8, 10, 11, 12, 25	13, 14, 15, 16, 17, 18, 19, 20, 21, 40	22, 23, 24, 25, 27, 28, 29, 30, 31, 32	24, 25, 33, 34, 35, 43	37	38, 39
Convergence clusters				30, 31, 42	33, 34, 42		39
Panic behaviour			18, 40	28, 29			
Re-entry behaviour	3	8, 11,	18, 40	23, 29, 31,	33		
Occupant fire fighting behaviour	3	6, 8, 11, 12	18, 19, 40	23, 29	34	37	
Occupants' movement through smoke	3	8, 10, 11,	18, 20, 40	27, 28, 29, 30, 31, 32	33, 34, 35,	37	
Pre-movement time data		8, 11, 25,	13, 14, 21, 26	24, 25, 27, 29, 31, 32	24, 25, 43	25,	

Figure 4. Matrix of publications on pre-movement research

(Refer to Section 10 References for complete references to these publications)

1 Grace T. 1997. *Improving the Waking Effectiveness of Fire Alarms in Residential Areas.*
Highlights different responses related to sleep types and age, sound attenuation and signal meaningfulness.

2 Duncan C. 1999. *The Effectiveness of the Domestic Alarm Signal.*
Experimental study on response to domestic smoke alarms.

3 Miller I. 2005. *Human Behaviour Contributing to Unintentional Residential Fire Deaths 1997–2003.*
Reviews 131 fatalities from 108 residential fires, occupant characterisation and the factors that influenced the occupant awareness and response actions.

4 Olsson P. and Regan M. 1998. *A Comparison Between Actual and Predicted Evacuation Times.*
Occupant response to an unannounced evacuation of university buildings, comparison with predicted evacuation performance.

5 Brennan P. 1998a. *Victims and Survivors in Fatal Residential Building Fires.*
Reviews 150 fatalities from 109 residential fires, occupant characterisation and the factors that influenced the occupant awareness and response actions.

6 Saunders W. 2001. *Gender Differences in Response to Fires.*
Hypothetical questionnaires used to generate probable response data to fire scenarios.

7 Bruck D. and Brennan P. 2001. *Recognition of Fire Cues During Sleep*.
Experimental-based study of the responsiveness of sleeping occupants to low level fire cues, including sounds mimicking early fire development, flickering light and smoke odour.

8 Brennan P. 1997. *Timing Human Response in Real Fires*.
Occupant response actions and timings in two real fire incidents; a 14 storey office building and an 18 storey apartment building.

9 Saunders W. 1997. *Occupant Decision-making in Office Building Fire Emergencies: Experimental Results.*
Study of participant decisions made in response to a film of ambiguous, but developing, fire cues.

10 Brennan P. and Doughty B. 1997. *Response in Fires*.
Occupant response actions to real fire incidents in residential dwellings, apartments and hotel/hostel accommodation complexes.

11 Brennan P. 1998b. *Response of Occupants Close to Fire*.
Case-by-case occupant response actions to discovering a fire and estimated timeframes. All incident reports gathered to construct database.

12 Metropolitan Fire and Emergency Services Board. 2003. *Human Behaviour in Fires Research Project.*
Interview survey of victims of residential fires, occupant response actions.

13 Shields T.J. *et al*. 1998b. *Towards the Characterisation of Large Retail Stores*.
Occupant response actions to an unannounced evacuation, actions of staff fire team, performance analysis expressed in percentages and times.

14 Shields T.J. *et al*. 1998a. *Evacuation Behaviours of Occupants with Learning Difficulties in Residential Homes.*
Occupant response actions to unannounced evacuations of two residential care homes, performance analysis expressed in actual time.

15 Purser D.A. 1998. *Quantification of Behaviour for Engineering Design Standards and Escape Time Calculations.*
Occupant response actions, including times to complete each action recorded during unannounced evacuations of various building types including offices, teaching laboratory, theatres, retail shops and complexes, hospital, leisure centre, library and underground station.

16 Boyce K. 1998. *Survey Analysis and Modeling of Office Evacuation Using the CRISP Model*.
Brief review of some occupant behaviour in real fire evacuations, summary of six office buildings surveyed to provide input for characterisation of the occupants, trial evacuation data from one office building and subsequent modeling using CRISP.

17 Davis D.T. 1998. *Study into Evacuation of Residents Following a Serious Fire, Lightfoot Street, Chester, Cheshire, 25 October 1996.*
Characterisation of occupants from low-rise residential terrace housing, a survey of the occupant responses and actions to a real fire in an adjacent warehouse that had spread to involve the nearby residences.

18 Canter D. *et al*. 1980. *Domestic, Multiple Occupancy and Hospital Fires.*
Occupant response actions to real fires, including analysis and decomposition diagrams of actions.

19 Purser D. and Kuipers M.E. 2004. *Interactions Between Buildings, Fires and Occupant Behaviour Using a Relational Database Created from Incident Investigations and Interviews.*
Occupant response actions to real fires expressed in percentages.

20 Sime J. *et al*. 1992. *Human Behaviour in Fires – Summary Report*.
Analysis of occupant response actions in relation to evacuation decisions taken during both real fire incidents and trial evacuations.

21 Gwynne S., Galea E.R., Parke J. and Hickson, J. 2003. *The Collection and Analysis of Pre-movement Times Derived from Evacuation Trials and their Application to Evacuation Modeling.*
Analysis of occupant pre-movement response times to unannounced trial evacuations conducted in a private hospital and a university facility building.

22 Edelman P. *et al*. 1980. *A Model of Behaviour in Fires Applied to a Nursing Home*.
Survey of 22 occupants of a nursing home fire, characterisation of occupants, their actions and coping behaviour.

23 Haber G.M. 1980. *Human Behaviour in Fire in Total Institutions: A Case Study*.
Three fires, in a nursing home, a penal institution, and a retirement home – the response and actions of staff in each are recorded with the implications of each discussed.

24 Proulx G. and Fahy R. 1997. *The Time Delay to Start Evacuation: Review of Five Case Studies*.
Summary delay time data from both real fire events and unannounced trial evacuations of high-rise residential and high-rise office buildings.

25 Fahy R. and Proulx G. 2001. *Toward Creating a Database on Delay Times to Start Evacuation and Walking Speeds for Use in Evacuation.*
Summary of data collected from both real fire events and unannounced trial evacuations in a broad range of buildings and occupancy types.

26 Charters D. 2001. *Analysis of the Number of Occupants, Detection Times and Pre-movement Times.*
Data sourced from a real fires database is presented in terms of probability of actions versus time for a range of building types and occupancies.

27 Blake S.J. *et al*. *An Analysis of Human Behaviour During the WTC Disaster of 11 September 2001 Based on Published Survivor Accounts.*
Occupant response actions to a real fire expressed in percentages, times and individual reported comments.

28 Proulx G. and Fahy R.F. *Account Analysis of WTC Survivors*.
Occupant response actions to a real fire expressed in percentages, times and individual reported comments.

29 Galea E. and Blake S. *Collection and Analysis of Human Behaviour Data Appearing in the Mass Media Relating to the Evacuation of the WTC Towers of 11 September 2001*.
Occupant response actions to a real fire expressed in numbers, percentages and, where possible, timings.

30 Fahy R. and Proulx G. 1997. *Human Behaviour in the World Trade Center Evacuation.*
Occupant response actions to a single real fire event that impacted slightly differently on each of the two towers, analysis expressed in numbers, percentage and limited timings and some analysis of response by gender.

31 Proulx G. *et al*. 2003. *Human Behaviour Study, Cook County Administration Building Fire, October 17, 2003, Chicago.*
Occupant response actions to a real fire, analysis of pre-movement decisions and timings.

32 Grosshandler W. *et al*. 2005. *Report of the Technical Investigation of The Station Nightclub Fire*.
Occupant response actions to a real fire, analysis of evacuation and fire development timeline.

33 Proulx G. 1998. *The Impact of Voice Communication Messages During a Residential High-rise Fire.*
Occupant response actions to a real fire expressed in percentages; suggestion that in future many occupants would not follow evacuation instructions over the voice communication system.

34 Proulx G. *et al*. 1995. *Study of the Occupants' Behaviour During the Two Forest Laneway Fires in North York, Ontario, January 6, 1995.*
Occupant response actions to a real fire in a 29 storey apartment building.

35 Proulx G. *et al*. 1998. *Study of the Occupants' Behaviour During the Ambleside Fire in Ottawa on January 31, 1997.*
Occupant response actions to a real fire in a 25 storey apartment building.

36 Yung D., Proulx G. and Benichou N. *Comparison of Model Predictions and Actual Experience of Occupant Response and Evacuation in Two High-rise Apartment Building Fires.*
Summary of occupant response actions in two high-rise apartment fires for the purposes of model validation. More complete occupant response analysis in these two fires is provided in references 34 and 35.

37 Sekizawa A. *et al*. 1998. *Occupants' Behaviour in Response to the High-rise Apartment Fire in Hiroshima City.*
Contains data on occupant response actions to a real fire expressed in percentages. The occupant behaviour may not be described as typical, as there had been 69 previous fires in the complex between 1972 and 1995.

38 Frantzich H. 2001. *Occupant Behaviour and Response Time – Results from Evacuation Experiments.*
Occupant response actions from three unannounced trial evacuations conducted in retail warehouses.

39 Bengtson S. *et al*. 2001. *The Behaviour of Young People in a Fire at a Dance Party in Gothenburg in 1998.*
Occupant response actions to a real fire expressed in percentages.

40 Wood P.G. 1980. *A Survey of Behaviour in Fires*.
Occupant response actions to real fires in 952 fire incidents, only frequency of occurrence of actions without reference to timelines. The fires studied were in property types including domestic dwellings, factories, multiple occupancy dwellings (e.g. flats), shops, schools and hospitals.

41 Fahy R.F. 2001. *Verifying the Predictive Capability of EXIT89.*
Compares predicted occupant response with actual occupant responses recorded in trial evacuations of a hotel with disabled occupants, an office building with upward travel and contra flows, and a department store. The buildings were all located in the United Kingdom. Evacuation times and exits used are recorded.

42 Proulx G. 2001. *High-rise Evacuation: A Questionable Concept*.
Report includes occupant response actions to two real fire case studies expressed in percentages.

43 Pauls J.L. and Jones B.K. 1980. *Building Evacuation: Research Methods and Case Studies*.
Occupant response actions in two unannounced trial evacuations of office building; the first a total building evacuation, the second a staged sequential evacuation. Study includes time and exit route analysis against predictions.

6. SUMMARY – EMERGENCY MANAGEMENT PLANNING

One of the key determinants in the success of an evacuation is the time to respond, and in many examples the occupants used up valuable time in the pre-movement phase. The most common causes of delay are: ignoring the alarm as another false alarm or nuisance car alarm; not recognising it as a fire alarm; or being delayed by information seeking and confirmation about any required action prior to commencing evacuation.

A large proportion of the research into and containing pre-movement evaluation concentrates on significant events, and more often these occur in the very large and high-rise buildings. Also, it is these buildings that are more likely to be the subject of alternative fire engineered design.

This study has highlighted a number of areas that, while not specifically pre-movement, do influence this component and impact on the overall emergency response plan.

There are some major issues relating specifically to high-rise buildings that remain to be resolved. In one paper written just before the collapse of the WTC towers (Proulx 2001), the question is asked: "Should we really be even attempting to evacuate all occupants from high-rise buildings, when only a fraction may be endangered by the fire"? There are many examples of real fire incidents in which people have been overcome by smoke while trying to evacuate from essentially a safe place within the building. If these occupants had chosen to defend in place they would have survived.

Defending in place certainly has merit. It avoids people attempting very long vertical travel distances and not all occupants can evacuate without assistance. It prevents overcrowding on stairs, which often do not have sufficient capacity for all occupants to use at the same time, and can provide easier passage for fire brigade personnel to access the building. Escape routes tend to become contaminated by smoke no matter how well designed. A longer term benefit of such a policy change is that it should reduce the incidence of prank alarms since it would take away the "fun" of causing a total building evacuation.

It is suggested that this approach may only be suited to residential or hotel high-rise buildings of non-combustible construction where a central fire alarm and voice communication system has been installed.

The standard procedure for the evacuation of buildings over 25 storeys is to implement a phased-evacuation. The instructions are given via an integrated public address communication system. Following the widely publicised collapse of the WTC on 11 September 11 2001, occupants are more likely to ignore the instructions to wait until floors closer to the fire have evacuated, and evacuate when they see fit. What then is the probability that occupants will follow instructions to defend in place?

The complete evacuation of such high-rise buildings is both stressful on the occupants and very time-consuming. One potential compromise is then to utilise the elevators in such evacuations. Evacuation by elevators is an option, and neatly addresses the issue of providing for the evacuation of mobility impaired occupants.

The potential for using elevators in building evacuations has been considered by many in the fire safety industry, and some view it as inevitable (Proulx 2003). Amongst the general public it is a commonly understood instruction that in the event of an evacuation: "Do not use the elevators". But, as illustrated in some of the examples, many occupants have been prepared to ignore this. While these issues can be addressed by design, there have been good reasons for not using the elevators, including:

- it can result in critical time for evacuation wasted waiting for an elevator that may not arrive

- elevators do not prioritise car and corridor calls, and may open on the fire floor (for example the Dusseldorf Airport fire)

- elevator cars cannot start until the doors are closed and overcrowding may prevent the doors from closing

- power failure may lead to entrapment.

To take control of emergency situations in larger buildings, a system of fire wardens has been used effectively. In general, for working and crowd occupancies (be they offices, manufacturing or shopping complexes) it is relatively straightforward to appoint and train a select number of 'permanent' occupants to be fire wardens who will take charge during any emergency requiring building evacuation. In the many instances where this system has been called upon, it has resulted in an orderly evacuation of the building. There is a clear link between efficient response and people taking command of a situation. This system has been demonstrated to work very well and the Marks and Spencer (Shields 1998b) and IKEA (Frantzich 2001) are good examples. It is fine so long as all the supporting systems are in place and are functioning.

In the military, difficult situations are managed effectively and efficiently by a combination of a highly disciplined system of rank (hierarchy) and training. When under threat, soldiers are trained to obey commanding officers and to follow orders without question.

Out in the civilian world such a system would not be tolerated, no matter how effective it may be. The appointment of fire wardens, regular training (fire drills) for familiarisation, and a commitment to providing fast accurate information is the next best alternative. It is a concern then that, over time, people have become more ready to question authority and less inclined to follow it blindly. Will future fire wardens have sufficient authority to ensure the evacuation system will function as planned?

They have to be given enough support and supplied with sound information relating to the incident to answer questions in a satisfactory manner for fellow occupants to buy-in to the system. With modern communication systems there is an expectation of a fast and efficient flow of information. When this is not available, pre-movement times have been demonstrated to significantly increase through people's attempts to gather apparently necessary information from alternative sources when in fact they should simply evacuate, or shore up the defences to remain in place.

In a vast number of the examples given, the fires have been detected by occupants prior to any automated system, and the alarm raised by fellow occupants has been considerably more effective in encouraging others to evacuate. Whatever the operational scheme employed for the management of building occupants during fire incidents, it all comes back to lack of ambiguity, clarity of message, believability and effective communication of the right information at the right time.

7. CONTINUING INTERNATIONAL RESEARCH INTO PRE-MOVEMENT BEHAVIOUR IN FIRE

There continues to be a considerable amount of research being carried out into the pre-movement component of human behaviour in fire scenarios.

The terrorist attacks on the WTC continues to provide a valuable resource for studying human behaviour. One major study being carried out in North America is led by NIST and NRC. Its aim is to look at the behaviour and fate of occupants and responders, both those who survived and those who did not, by collecting and analysing information on occupant behaviour, human factors, egress, emergency communication and the performance of the evacuation system on 11 September 11 2001. Another study into the same event is the HEED Project (High-rise Evacuation Evaluation Database), a collaborative effort by the UK Universities of Greenwich, Liverpool and Ulster. Their aim is to interview more than 2,000 survivors of the WTC disaster to study their responses such as: whether they started to evacuate immediately or continue to work, the urgency of evacuation, the realisation they were in danger, the formation of groups, and other evacuation shaping factors.

A selection of other work is summarised to provide a brief picture of the scope of research into the field of pre-movement:

The NRC is conducting research into Fire Risk and Human Behaviour. It is concentrating on generating data on human behaviour in different occupancies, characterising the response to alarms, fire and smoke as well as evacuation movement, with the aim of improving the existing computer models. In another project, NRC in collaboration with Arup and the National Fire Protection Association (NFPA) in the USA is closely aligned to the first. It is to take data from five evacuation drills and test a couple of existing egress models to provide a better understanding of the uncertainty and limitations, and to improve the predictive capabilities of these models.

The NFPA has a project in collaboration with Victoria University of Technology in Australia (VUT) to “optimise the smoke alarm signal”. It will study the audibility and waking effectiveness of smoke alarm signals in the elderly population.

The Center for Disease Control (CDC) in the USA, in collaboration with the Battelle Center for Public Health Research and Evaluation and the University of Maryland, is directing development of the Human Behaviour in Fire Study. The aim is to identify behavioural factors in residential fires that are associated with injuries and fatalities.

8. WHERE TO FROM HERE?

The reports and incidents reviewed in this paper illustrate that the pre-movement component of an evacuation can vary enormously. In many of the real fire incidents, the outcome would have been very difficult to predict. It highlights that considerable caution has to be exercised when modelling evacuation performance when based simply on estimating the pre-movement response time. Predictions made on the basis of statistical analysis are fine; however the quantity of data has to be sufficiently large for the analysis to be reliable. At present, considerably more data is required before we can achieve an acceptable level of confidence in our ability to predict the pre-movement component.

This review of human behaviour in real and simulated fire incidents raises a few questions.

- Is the data contained in our present stock of studies sourced from a broad cross-section of all fire incidents, or simply the most dramatic or catastrophic? It is the exception that in many instances makes these accounts interesting and worth telling/researching.

- Many of the incidents that are the source for pre-movement estimation occur in very much larger buildings than we have here in New Zealand. The high-rise apartment buildings and large residential complexes are relatively new to New Zealanders. Is it appropriate to simply take overseas findings from similar buildings and apply them directly in New Zealand, or would we be inclined to respond slightly differently because these lifestyles are new?

- In the New Zealand context, because we have a considerably smaller population, is there a greater likelihood of working with family members. If so, will a greater degree of affiliation between employees exist, and how may it affect the pre-movement component of an evacuation?

- Typically in New Zealand we have been a nation of "do-it-yourselfer's" especially when it comes to housing, and in particular when looking after our own patch. Does this mentality lead to any differences in how we may approach living in apartment complexes when it comes to fire safety, compared to overseas experience in which apartment living has long been a part of the culture?

- How should the data collected in trial evacuations be applied to modelling real fire incidents?

A significant proportion of pre-movement data has been collected from trial evacuations and should be used with some caution. These are dry-runs which achieve little more than a test of the system logic: that the alarm functions adequately, it can be heard by all occupants, the escape routes function without impediment, and occupants know the procedure. It is unlikely to present the occupants with the ambiguous cues that are so often a feature of the major fire incidents. Consequently the occupants have a very simplified decision process. While evacuation planning and regular drills without doubt do train occupants to recognise the alarm signal and the exit route and systems, the accounts contained in many of the research papers highlight that this theory is not always able to be put into practice.

The trial evacuation is not appropriate for all pre-movement data relating to apartment complexes where for "ethical" reasons occupants receive prior notice that a trial evacuation will occur in the near future. With occupants expecting to hear the alarm system operate, the pre-movement decision-making process has been activated long before the event. This was illustrated in a similar trial evacuation of a Wellington City Council owned block of flats. It was reported to the author that many tenants "knew" it was a trial, and chose either to ignore it or send their kids down to "respond" with instruction to inform the building manager: "Yes we know to evacuate, but mum has stayed back to finish cooking dinner" or "Coronation Street is on, so Mum will be down at the end of the programme".

On the other hand, evidence gathered in some of the unannounced trial evacuations demonstrates that predictions could be made for similar occupancies with a reasonable degree of accuracy. In particular, it would be fair to make predictions of the pre-movement component of an evacuation where the occupants are remote from the fire and their performance can be relied upon. It would suggest that occupancy performance is reliable where:

- a hierarchy of authority exists to install a thoroughly planned emergency response

- adequate training is provided to those appointed to take control (fire wardens)

- all occupants are familiar with the whole plan, not just their part in it, and the familiarity is reinforced through regular trials
- effective and accurate information is readily able to be communicated to those who require it, when they require it.

This is not applicable to all occupancy types. There are a lot of input variables contributing to the responses of an occupant. One substantial driver is the degree of association between the occupants. The situation in most workplaces provides a significantly lesser degree of association than that found within a family household. In the office, while people will look out for their fellow employees, essentially they only have themselves to consider. At home, a parent also has to consider the dependent child and other family members. This higher degree of association between family members is likely to have a strong influence on the pre-movement activities of evacuees from crowd purpose group occupancies.

In a working purpose group occupancy, where the building has a reliable means of raising the alarm, effective fire wardens and regular practices, then the pre-movement component is likely to be predictable within a small range. The prediction of the pre-movement component is considerably more difficult in the sleeping and crowd purpose group occupancies where greater affiliation between occupants is likely to over-ride external instruction. Another factor, prevalent in crowd, and to a lesser extent in working occupancies, is the negative influence of peer group pressure preventing any response action for fear of standing out, or being seen to over-react. In New Zealand the latter is possibly one of our greatest weaknesses. We are a nation prepared to cut down any tall poppy or non-conformist, and this does not bode well when it comes to doing the "right thing". Are New Zealanders any different in this regard?

In New Zealand, there are plenty of residential fires, and too many of these result in fatalities. There are very few controls placed on single dwellings in regard to fire safety, the most significant one of late being the requirement for stand-alone smoke detectors to be installed. As has been illustrated by the effectiveness of evacuations from commercial buildings versus those from apartment buildings, the key components to success are pre-planning of actions, prompt action, and the benefit of familiarity through regular evacuation drills.

If we could rely on all occupants of all buildings to be familiar with an evacuation plan, to respond promptly and to have practiced that response, then there would be no question as to a suitable estimate of the pre-movement component. But there are many situations where this will never be able to be relied upon.

9. CONCLUSIONS

In fire engineering, we can never predict all of the pre-movement actions for all of the occupants all of the time. At best, pre-movement components for specific occupancies could be estimated from statistical analysis and presented in the form of a probability distribution. At present the global database is small and the reliability of predictions based on it likely to be low. The collation of data from many more fire incidents is required.

In New Zealand, the small number of qualifying incidents means that to improve our ability to predict pre-movement times, international data will have to be incorporated. There is nothing wrong with this approach so long as the suitability of applying such data to New Zealand conditions is addressed. When considering international fire incidents they have to be from a representative sample of all fire incidents, not just the most interesting or dramatic, the building stock from where the data has been collected has to be comparable to that found in New Zealand, and the influence of any cultural differences has to be considered.

A study dedicated to recording the pre-movement response actions and times from real fire incidents in New Zealand is therefore required. The data from this study is essential to qualify the application of international data. In comparing the locally sourced data with that from international studies, it will assist in determining if any local factors will require modification of the international data set prior to its application here.

A detailed statistical analysis of pre-movement activities recorded on such a database could then be used to:

- tailor the estimation of pre-movement response times to specific occupancies
- estimate what proportion of incidents go according to plan versus those that do not
- estimate the proportion of pre-movement actions that lead to disaster, and
- improve the survivability of future fires in the present and future building stock.

New Zealand, was a leader in adopting and developing performance-based building codes, but central to these functioning at a practical level is acceptance that the demonstration of compliance is based on reliable and accepted performance predictions. A critical component of fire safety has been shown to be estimation of the pre-movement component. Internationally there is considerable ongoing research into pre-movement response actions and timings. If New Zealand is to continue to move forward in the use of alternative design solutions, it has to be able to take advantage of the international work by qualifying it with its own.

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