Fire Safety Journal 45 (2010) 1–11

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Review

Building safety and human behaviour in fire: A literature review

Margrethe Kobes [a,b,*], Ira Helsloot [b], Bauke de Vries [c], Jos G. Post [a]

[a] *Netherlands Institute for Safety, Research Department, PO Box 7010, 6801 HA Arnhem, The Netherlands*
[b] *VU University Amsterdam, Faculty of Social Sciences, Boelelaan 1081, 1081 HV Amsterdam, The Netherlands*
[c] *Eindhoven University of Technology, Faculty of Architecture, Building and Planning, PO Box 513, 5600 MD Eindhoven, The Netherlands*

A R T I C L E I N F O

Article history:
Received 29 November 2008
Received in revised form
29 June 2009
Accepted 17 August 2009
Available online 4 October 2009

Keywords:
Fire response performance
Evacuation
Human behaviour in fire
Psychonomics
Building fire safety
Fire safety regulations
Conceptual framework

A B S T R A C T

The most crucial aspect of a building's safety in the face of fire is the possibility of safe escape. An important precondition is that its fire safety facilities enable independent and adequate fire response performances by the building's occupants. In practice, it appears that the measures currently required by law do not always provide the support that people in burning buildings need. Consequently, understanding how individuals behave in the case of fire and fire evacuation is essential if we are to bring fire safety measures into line with occupants' needs during an incident. This paper contains a review of the available literature on human behaviour in a fire so far as building safety is concerned. The findings are presented as an overview of the critical factors which determine occupants' fire response performances, namely the characteristics of fire, human beings and buildings. The study highlights that some of the assumptions about the existing paradigm of fire safety in buildings are not consistent with the knowledge set out in the literature. The key observation is that psychonomics appear to have significant influence on occupants' fire response performances. Accordingly, the traditional approach to fire safety will have to be supplemented by scientific knowledge from this field. Hence, there is a need for a new approach to fire safety design in buildings, which is set out herein.

Contents

* Corresponding author at: Netherlands Institute for Safety, Research Department, PO Box 7010, 6801 HA Arnhem, The Netherlands.
Tel.: +31 26 3552400; fax: +31 26 3515051.
E-mail address: margrethe.kobes@nifv.nl (M. Kobes).

0379-7112/$ - see front matter
doi:10.1016/j.firesaf.2009.08.005

1. Introduction

In the early stages of a fire, the people in a building typically have to either rely on themselves, or be rescued by others in their immediate vicinity [1]. The assistance of the professional emergency services, for example in the form of rescue operations by firefighters and emergency treatment by paramedics, can only be provided after the first and most important stage of a fire. Human behaviour during this initial phase is, therefore, an important factor in terms of survival [2,3]. It can be defined as the actions that people take based upon their perception of the situation, their intention to act, and the considerations involved before these actions are carried out. Accordingly, how people behave during an escape is referred to as evacuation behaviour.

The possibility of a safe escape is the most crucial aspect of a building's fire safety features. The term, fire safety, refers to fire prevention, limiting the spread of fire and smoke, extinguishing a fire and the chance of a quick and safe exit. Fire safety policies reflect the way in which people think about this issue in both society at large and the political arena. In some situations, occupants are incapable of evacuating a building. Therefore, in several countries, legislation provides for a 'defend-in-place strategy' for specific locations, such as hospitals, where patients are confined to their beds. With this approach, occupants are relocated to a safe location on the same floor instead of being evacuated. For buildings with assembly occupancy, an evacuation strategy is usually utilised. Nevertheless, major fires in a number of constructions have revealed that a safe escape from a burning building is not always possible for everyone, as the events at [4] the department store, L'Innovation (Belgium, 1967), the Beverly Hills Supper Club (Kentucky, 1977), the Stardust nightclub (Ireland, 1981), the Happy Land Social Club (New York, 1990) and the Station Nightclub (Rhode Island, 2003) have highlighted. Some of these fatal incidents were due to serious code violations, and classically led to amendments to fire safety regulations, since those in place had not adequately supported the evacuation of people from these buildings.

At present, our knowledge of occupants' performances when confronted with fire is still very limited. Yet, in terms of optimising fire safety policy, it is important to understand why certain incidents have led to there being many victims, or why a seemingly disastrous event resulted in very few casualties. These questions were the starting point for a literature review, which aims to identify the critical factors that influence fire response performance. The results were published in the book '*Fire response performance. The critical factors for a safe escape from buildings*' (in Dutch) [4], and are summarised in this paper. The findings only apply to buildings which are subject to building regulations wherein life safety is a primary objective.

2. Overview of considerable research into human behaviour in a fire

The field of scientific research into human behaviour in a fire is relatively new, although numerous studies have been conducted into this issue from the start of the 20th century, and are continuing. This section contains a selection of the investigations which broke new ground in the field.

2.1. Analysis of building evacuation affected by the spirit of the times

The study of building evacuation began at the start of the 20th century [5–7], when the main focus was on the movement of people in corridors, on stairs and through doors. Several researchers, including Pauls, Fruin, Predtetschenski, Milinski, Habicht and Braaksma in particular [8–10], collected detailed information about occupant density and travel speed. What they learnt had a major influence on the current approach to fire safety building regulations worldwide. In particular, the findings have led to a minimum width of evacuation staircases, a maximum flow rate capacity for fire exits, the required number of fire exits, and other specific architectural solutions. As a result, the necessary measures with which to ensure fire safety in buildings are currently, and predominantly, technology based, and they rarely take into account the normal practice of how a building is used. More seriously, consideration of real evacuation behaviour in the case of fire seems to have been neglected.

At the end of the 20th century, the interpretation of the fire safety of buildings changed from a technological to a more behavioural perspective. For example, Sime (1999, 2001) introduced an occupant response shelter escape time (ORSET) model [11,12]. This theoretical approach unifies aspects of building fire safety (architecture, engineering) and human behaviour during building evacuation (psychology, facilities management). The ORSET is expressed in terms of occupancy risk criteria, which are [12]: occupancy population and activity profiles, a pre-movement index, visual access/way finding design/index and means of escape. Sime considers occupancy to be the relationship between people and environments, and it is assumed that occupancy and behaviour depend upon an individual's surroundings. In accordance with the traditional psychological approach, people are viewed in terms of (stable) personality traits, capacities and individual characteristics. Sime, nevertheless, suggests that people do not respond in the same way in one particular physical (and social) location and circumstance, as they do in another. This suggests that human beings act according to how they adapt to both a situation, and the information and opportunity structures afforded to them by different locations [12]. Furthermore, this approach also implies that the possibility of a safe escape does not only depend on personal characteristics or the 'use and occupancy classification' of the building in which an individual happens to be; the layout, the floor plan and (interior) design of the building may also have an impact on the level of evacuation capability. For example, the availability of fire safety facilities, such as escape routes and emergency exits, is a decisive factor in determining the chance of surviving a fire. This availability depends, on the one hand, on the location of the fire and the extent of fire and smoke growth in the building, and on the other on how appropriate these fire safety facilities are and how well they have been maintained.

2.2. Movement velocity

The first investigations of movement velocity and movement time came at the beginning of the 20th century, and now several researchers from across the globe have conducted major research into this issue, including Fruin (USA), Pauls (USA), Predtetschenski and Milinski (Germany) [8–10], Habicht and Braaksma (Canada) [10] and Jin [13] in particular. The time needed for movement purposes is relatively well documented, meaning that it is possible to assess the required escape times for several types of buildings and building populations [8]. To do so, the results of investigations carried out by Pauls and Fruin have been converted into calculation tools, which are now included in legislation and codes of practice for fire engineering. Jin made an important addition thereto when he found that walking behaviour in smoky environments is different to that highlighted in earlier investigations in places without smoke contamination. Moreover, the behaviour of the elderly, young children, and those with some form of impairment, also deviates from what had been expected and included in the earlier calculation methods referred to [5,10].

2.3. Connection between fire and human behaviour

The first scientific research into human behaviour in the case of fire was conducted in the 1950s in the United States (US) [6]. Since researchers at that time assumed that buildings were engineered in such a way that they were safe enough in a fire, the focus was on the relationship between the (social) behaviour of people and fire development, and much less on the interaction between building design and a safe escape. The results revealed that the size of a fire is related to the behaviour of the personnel in the building either before or during the incident. Furthermore, interviews with those who survived the Arundel Park fire (1956) highlighted that the occupants who were in the building with relatives, re-entered it after their first escape in order to search for missing group members [6].

In the 1970s, the factor of human behaviour in a fire came to the attention of other researchers, and led to a revision of the interpretation of fire safety, and brought about several research and educational activities. Then, between 1969 and 1974, a major study into the evacuation of large office buildings was conducted in Canada. In 1972, Wood carried out large-scale research in Great Britain into human behaviour in residential fires. Using a standard questionnaire, firefighters interviewed 2139 individuals, who were involved in a total of 952 fires. Then, based upon Wood's research methodology, in 1977 Bryan conducted a comparable study in the US, interviewing 584 people who were involved in a total of 335 fires, half of which were residential and half of which were in other types of buildings, such as shops and offices. Both pieces of work showed (again) that family members tend to re-enter a burning building after initially escaping from it. Both studies also revealed that people tend to walk through smoke when making their escape, and that those in residential fires try to extinguish them. Although the two studies were conducted in two countries with dissimilar cultural contexts, the results were identical in their essence [6,7].

2.4. Evacuation of the functionally impaired

Serious research into the evacuation of the functionally impaired began in the 1970s, with a study into the evacuation of a high-rise building. Major investigations of this issue have also been conducted by Boyce, Shields and Silcock [9,14–17] among others [8,12,18–20]. In particular, studies of the safe use of elevators in fire evacuations and the defend-in-place strategy were conducted. The idea of making elevators suitable for evacuation in the case of fire dates from the beginning of the 1980s [21], but there is little empirical evidence available on the effect that their use has on the chances of survival. The studies of the WTC 9/11 disaster are the most important so far, with it being estimated that 3000 people were saved by self-evacuation and the use of elevators in the South Tower [22].

2.5. WTC evacuation studies

Crucial to our understanding of human behaviour in high-rise building evacuations are the studies from the WTC in 1993 and the WTC 9/11 disaster (2001) [9,22–29]. Researchers revealed data about matters such as escape and pre-movement times, pre-movement actions, the flow rates in staircases, and the use of elevators. An early study by Fahy and Proulx [23] was based on first-person accounts taken from newspapers, radio and television programmes, e-mail exchanges, and a variety of websites. In total, 475 stories were analysed, representing 435 survivors from the two WTC towers. In other research [24,28] by Galea and others, almost 300 survivors from the WTC were interviewed, generating almost 6000 pages of transcripts and a large amount of detailed data regarding the evacuation of the twin towers. In a third research project, by Averill and others, more than 1000 survivors were interviewed [22]. All of the evidence gathered from studies of the WTC 9/11 disaster has been incorporated into a High-rise Evacuation Evaluation Database (HEED), which is accessible to researchers internationally [24,28].

2.6. Pre-movement time

The findings of research by Sime, Proulx and Fahy [6,9,30] have revealed that pre-movement time is a more important element of required escape time than that which is needed to move to a safe place. Furthermore, incident analyses have shown that there is a connection between a delayed evacuation and a high number of fire deaths or injuries, particularly in residential buildings and hotels [2]. Consequently, pre-movement time and pre-movement behaviour are currently regarded as key aspects of the evacuation process. Several studies of the former have been conducted in the last two decennia [9]. Earlier evaluations, in particular those of the Beverly Hills Supper Club fire (Southgate, Kentucky, 1977) and the Cocoanut Grove Dance Hall fire (Boston, 1942), had already revealed that a delayed evacuation had resulted in a large number of fatalities. However, researchers at that time attributed the deaths to the specific characteristics of these two fires. However, it is now known that there is a delayed evacuation in nearly every fire [9], although pre-movement times are much less well documented and quantified [2].

2.7. Evacuation modelling

Most of the evacuation (simulation) models that exist are based upon calculations in which the distance to exits, walking velocity and the flow rate capacity of corridors, doors and stairs are decisive [31]. This is the result of prior research, which predominantly focused on these aspects of evacuation [12]. Few simulation models are based on human behaviour in evacuation scenarios, such as the preference for specific routes or exits, or the time needed to gather and interpret information. This is because there is insufficient, quantitative research data available on these factors [12]. Moreover, some of the behaviour that is exhibited during evacuations is insufficiently understood [31] and further research is required. Sime, for example, suggests that occupancy risks need to be operationalised further in case study work, and appraisals should be allied to floor plans. Further studies are also required into the following (among others) [12]:

- Fire and occupant response scenarios.
- Occupant and activity patterns: the setting in use, occupant response time and evacuation strategy.
- Patterns of movement which are not escapes.
- Visual access, visual access configurations and starting time distributions.
- Visual and sensory access/exposure.
- Way finding design criteria.
- Shelter and/or escape as alternative life safety strategies.
- Occupant location starting, exit arrival and flow rates at exits.

2.8. Way finding during fire evacuation

In the past 15–20 years, comprehensive research has been conducted into way finding, with car parks, shopping malls, underground facilities, hospitals and airport terminals being the subjects thereof. These studies have highlighted that specific architectonical constructions, spatial connections and layouts can be confusing, which adds unnecessary stress to the people who are using the buildings. Nevertheless, little of the research into way finding seems to be focused on fire evacuation and fire safety engineering [12].

3. Critical factors determining fire response performance

In this paragraph, the findings in the literature are presented as an overview of the critical factors which determine the fire response performance of the occupants of a building.

3.1. Fire response performance

3.1.1. Survival strategies in case of fire

There are three distinct strategies [7] for surviving a fire, the first of which is to (try to) extinguish it. The second strategy is to take shelter and wait to be rescued, and the third is evacuation. There is very little information in the literature about the extinguishment of a fire by a building's occupants, even though in 78% of the domestic fires in Great-Britain and 75.2% of those in Australia, the fire service was not called out [32]. This suggests that about three quarters of the fires in these countries had either extinguished themselves, or this had been achieved through the actions of occupants. With regard to the strategy of 'shelter and wait', it has been found that in several fires people tended to walk through smoke, or even chose to jump out of a building, instead of taking shelter and waiting to be rescued [10,30,33,34]. Yet, the strategy of instructing the occupants of hotels or apartment buildings to stay in their rooms is likely to be an effective way of ensuring their survival during a fire [35,36].

3.1.2. Human capability for survival in the case of fire

The assessment of how easy it is to evacuate a construction has usually been based on mobility, which is the capacity to move out of the building in question [37,38]. However, the literature on fires and human behaviour in response thereto has shown that other factors also play a decisive role. Accordingly, a new interpretation of 'evacuation capability in the case of fire' is required, with 'fire response performance' now being considered.

Fire response performance is an individual's ability to perceive and interpret signs of danger, and make and carry out decisions aimed at surviving a fire [4]. This definition is process related, and is based upon an understanding of evacuation. This process is divided into three activities and stages [3,5,8,39,40, among others]:

- Awareness of danger by external stimuli (cue validation period).
- Validation of, and response to, danger indicators (decision-making period).
- Movement to/refuge in a safe place (movement period).

3.1.3. Critical factors for survival in the case of fire

Generally speaking, three factors determine the degree of fire response performance in the event of fire in a building. These are as follows [4]:

- Fire characteristics.
- Human characteristics.
- Building characteristics.

In research published in 2001, Sime discussed the relationship between fire, occupant and setting [12], but greater detail of these concepts, and their influence on people's fire response performances, has not been found in the relevant literature. Accordingly, an overview and elaboration of the critical factors which determine the fire response performances of occupants is set out herein. These critical factors are presented, per characteristic, in Fig. 1.

The first factor to have a direct influence on the degree of fire response performance is the nature of the fire itself. A fire is a process of the ignition and combustion of materials, which generates heat and smoke. Building characteristics also have a direct impact, since a building is a physically enclosed environment in which people are present and activities are carried out. Finally, human nature also has a direct and major influence on the degree of fire response performance, and to analyse this, behaviour is examined both in terms of individuals (personal characteristics) and groups of people (social and situational characteristics).

3.2. The danger factor: fire

Fire and its effects on escape constitute the type of danger involved in response thereto. The critical factors are the perceptible characteristics of the fire, namely its growth rate, smoke yield, toxicity, and heat generated.

3.2.1. Perceptual features

Perceptible characteristics can be sub-divided into elements which can be seen, smelt or heard, and these influence the time it takes to discover a fire. The aspects of a fire which can be heard, apparently, have little influence on when it is discovered.

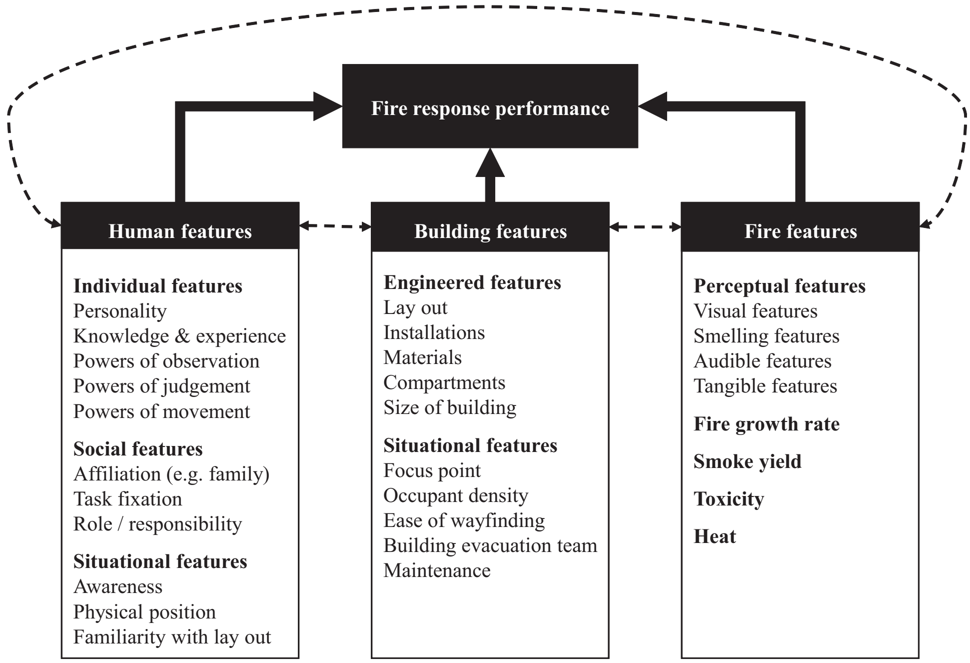

Fig. 1. Fire response performance model.

Furthermore, various experiments have shown that even an evacuation signal is often not regarded as being a clear indication of danger [30]. Smelling smoke, or seeing flames and smoke, are stronger indicators of a fire and the need to escape [8,30], although even then people have been found to continue their normal activities and wait for others to respond first, before they take action themselves [9,41]. In many cases, the degree of uncertainty about the danger of the situation delays the start of an evacuation. Therefore, eliminating this would be an important way of improving human behaviour in fires [7].

3.2.2. *Fire growth rate and heat*

The rate of fire growth can be determined by a formula based on exponential growth, which varies according to the fire growth coefficient of the material which is burning [42,43]. Chang and Huang [43] distinguish nine standard fire curves with different rates of fire growth. The curve of ultra-fast fire growth would, for example, apply when synthetic materials such as polyurethane (PU) are involved. The fire growth rate is an important factor in determining fire fatality, since many fatal incidents are characterised by rapid fire development after its initial discovery [4,12]. Some examples are [4] the Cocoanut Grove Dance Hall Fire (Boston, 1942) in which 490 people died, the DuPont Plaza Fire (Puerto Rico, 1986) in which 83 lost their lives, the Gothenburg Dance Hall Fire (Sweden, 1998) with 63 deaths, and the Volendam Dance Hall Fire (The Netherlands, 2001) in which 14 people died. Another noteworthy example is the Station Nightclub fire (Rhode Island, 2003), where there were 100 fatalities. A video of that incident revealed that within 90 s of ignition, the fire turned into an enormous conflagration, and the environment in the nightclub became untenable very rapidly [44,45]. According to Purser [46], a room becomes unsound when any of the following occurs: the temperature exceeds 120 °C (250 °F), the heat flux exceeds 2.5 kW/m^2, or the oxygen volume fraction drops below 12%. The results of real-scale experiments in a mock-up of the Station Nightclub demonstrated that the heat flux exceeded 2.5 kW/m^2 within 61 s, the temperature exceeded 120 °C within 76 s, and the oxygen volume fraction dropped below 12% within 87 s [44].

3.2.3. *Smoke yield and toxicity*

Incident evaluations have shown that people are often confronted with smoke during evacuations [8,33]. A number of individuals who had tried to leave a building by passing through a smoky environment reported that they had to change direction, or even retrace their steps, because of breathing problems, reduced vision, fear, or other reasons [33]. The reduction of sight as a result of smoke yield [8,13,33,47,48], and respiratory irritation because of toxicity [49], both have a negative impact on occupants' way finding performances. Experiments show that in the case of limited visibility, people tend to walk alongside walls for guidance [33,47,48]. Moreover, other results have demonstrated that the walking speed of those exposed to the impact of fire and smoke is slower than in normal conditions [8,13,47,48]. On the other hand, experiments have also highlighted that sound signals near exits will speed up escape times [47,48,50]. Jin [8,13] suggests that there is a required minimum visibility of 3–5 m through smoke for people who are familiar with a building's escape routes and a required minimum of 15–20 m for those who are not. Rasbash [8], on the other hand, proposed a 10 m minimum visibility distance through smoke, irrespective of familiarity with the surroundings.

Most fire fatalities [51] are due to the inhalation of smoke and toxic combustion gases [52]. Other effects of the exposure thereto are as follows [52]:

- Loss of the ability to react; unconsciousness.
- Slower walking speed, or modified behaviour, such as opting for a longer escape route.
- Psychological limitations with respect to escape as a result of changes to an individual's perception of danger.
- Long-term physical effects [52], such as cancer, lung damage and impairment of the immune system [53].

3.3. *The human factor*

Apart from the danger element of the fire, the human factor also influences fire response performance, which does, after all, relate to how people behave in a fire. In terms of human characteristics, the critical elements are individual, social, and situational features.

3.3.1. Individual features

Crucial personal characteristics are the personality traits of the people in a building, their knowledge and experience, their powers of observation and judgment, and their mobility.

Three personality traits, in particular, are significant. The most important distinction is between leaders and followers. In the event of fire, most people adopt the role of a follower [26,54], who initially does not respond to danger signals, but waits for others before taking action. The second key personality trait is the level of stress resistance. During a fire, someone's psychological stress levels may rise because their capacity for processing information is exceeded [55], or they are confronted with an unfamiliar situation [56]. Too much psychic stress can impair cognitive processes and how an individual responds to a given situation [55]. An increased stress level is not the same as panic, which can be defined as irrational, illogical and uncontrolled behaviour [57]. In 1954, Quarantelli was the first social scientist to find that there is no proof of the presence of panic in cases of major disasters [57], and other researchers followed suit, such as Sime [57], Proulx [58] and Auf der Heide [59]. The third significant trait is the belief in self-efficacy [60], which influences the choices that people make, the effort that they put in, how long an action is persisted with if obstacles are encountered (and people fail) and feelings. This is related to Bandura's Social Cognitive Theory. Bandura states that the level of motivation, emotions and activities is based more on what people believe than on objective facts. Belief is considered to be an individual representation of reality, which is so persuasive that it determines a person's behaviour and thoughts. In Social Cognitive Theory, it is assumed that most people have an internal system which enables them to control their thoughts, feelings, motivations and actions to some extent. This internal control is based on personal knowledge, feelings and biological characteristics, but actions and the influence of our surroundings also play a role [60].

An individual's observational powers, namely the ability to see, hear, smell, and feel, are his or her ability to perceive danger signals. Then, judgment enables someone to estimate the threat of danger by going through a cue validation process. Since decision-making during an evacuation depends upon the cues that the occupants perceive, and their interpretation thereof, cue validation is an important process. The perception of danger determines the reaction to signs of it [34]. If a fire is seen as being extremely dangerous, those present are more likely to try to escape [7]. However, most people have trouble estimating the danger that a fire poses. Our beliefs and assumptions about the speed of fire and smoke growth are often incorrect [2,61,62], meaning that we frequently put ourselves in danger when there is no need to do so. The perception of our surroundings also plays a decisive role in fire response performance. It has been found that it is not the actual length of an escape route, but how it is perceived, which determines which way out of a building is chosen [33,34,41]. For example, corridors with a number of corners and unfamiliar routes are experienced as being longer than straight and familiar ways out [63].

The next factor is mobility, which is related to an individual's powers of movement. Four levels can be distinguished, namely high, temporarily reduced, permanently reduced, and dependent mobility [38]. People who are in poor shape can be categorised as having temporarily reduced mobility. The WTC 9/11 studies revealed that individuals in high-rise buildings struggled more with temporarily reduced mobility than had been previously assumed [22,25,64]. Those who are bedridden or confined require assistance, and come into the category of dependent mobility.

3.3.2. Social features

Crucial social characteristics are the interactions between people present, the degree of task commitment, and the roles or responsibilities of those in the building. Incident evaluation has shown that in an emergency, people are more inclined to collaborate instead of acting on an individual basis [2,10,24,25,39,54]. Moreover, if there are strong social bonds between those involved in a fire, such as between family members, people will try to respond as a group for as long as possible [39,41,65]. Task commitment means that people cling to role patterns or expectations. Again, incident evaluations have revealed that when unexpected events occur, in the first instance people adhere to the role expectations appropriate to the function of the building where they are located [3,27,66]. This inhibits the recognition of danger and increases the processing time of information about the risks that a fire poses [3]. For example, people are often inclined to first finish the job they are doing before making their escape [34]. Moreover, those who have organisational responsibilities for a building, by virtue of their roles or positions, such as waitresses and department managers, are also inclined to assume these duties during an emergency situation [24,25,41].

3.3.3. Situational features

The key situational characteristics are awareness, physical position (passive or in motion) and familiarity with the layout of a building. Awareness refers to the occupants' state of alertness, which is temporarily reduced by the consumption of alcohol, drugs and narcotics [67]. People who are asleep also have a low level of alertness [41]. Indeed, in many fatal fires, those present were asleep when it started. Our knowledge of the influence of physical position is limited. It is suggested that those who are standing or walking are more likely to leave the room than people who are present in a prone or sitting position [41]. Familiarity with the layout of the building is typically related to route choice behaviour. Occupants normally evacuate using familiar routes, usually the main exit, which is often the entrance to a building [34,41]. As well as the occupants' familiarity with their surroundings, the choice of route also depends upon the availability of exits, the accessibility of the way towards them and the complexity of the building's layout [5,10]. Furthermore, affiliative behaviour is also considered to have an effect on route choices during an evacuation [54].

3.4. The environmental factor: the building

The third factor which affects the level of fire response performance in buildings is the environment. The physical characteristics of a construction constitute the setting in which people can exhibit their fire response performance, and it provides the primary conditions for the possibility of surviving a fire. In terms of building characteristics, the critical factors determining response in the event of a fire are the situational and the engineered features.

3.4.1. Situational features

Situational features include occupation density, ease of way finding, the presence of a focal point, the presence of a Building Evacuation Team (BET) and the level of implementation and maintenance of fire safety measures.

Occupation density refers to the number of people in a building. In the literature, a direct relationship has been observed between high occupation density and a high probability of fatalities in the event of fire [41,68]. Way finding covers the ways in which people orientate themselves within a building [69], and relates to how individuals need to have spatial knowledge and a variety of cognitive abilities to succeed. Way finding performance is determined by an occupant's perception and prior knowledge of both the surroundings and the situation. There are five categories of environmental factors which affect the ease of way finding [69]:

- Visual access.
- The level of architectural differentiation, i.e. unique building characteristics which people can use for orientation purposes.
- Layout.
- Familiarity with the building.
- The presence of signage and location marking.

Referring to the final category, incident evaluations have shown that evacuees are rarely aware of the presence of escape route signs at ceiling level, or, at least, their choice of route is not based upon them [26,70]. Experiments have shown that photo-luminescent low-level exit path markings are likely to be more effective during a fire evacuation than conventional escape route signs [71,72]. Although the concept of way finding has been studied comprehensively, very little of the research is focussed on fire safety regulations and fire safety engineering [12].

It can be said that there is a focal point when the attention of those present in a building is focused on a central feature, as in a theatre or classroom. If there is a fire, but the actors continue with the show or the teacher goes on with the class, then the audience or students will be inclined to remain seated [41]. Another essential element of safe fire escape requires that the fire safety facilities which have been put in place are in good order. However, in practice, it appears that their maintenance, for example the accessibility of fire exits, tends to be rather poor [73–77].

A BET, or emergency response team, is a group of people in a building who spring into action in emergencies. BET members are personnel who are regularly present at the location, and who are trained in fire extinguishment and the coordination of fire evacuation. Evidently, the presence of a well-educated and well-trained emergency response team exerts a positive influence on the speed of escape [9,40,41,78] and the use of emergency exits [28,34,41,71,79].

3.4.2. Engineered features

The engineered features of a building, which determine fire response performance, mainly relate to its layout, installations, materials, fire compartments and size. Relevant components of the layout are the escape route signage, the design of the escape routes and the design and location of the (emergency) exits and the (emergency) staircases. Several researchers have concluded that the maximum flow rate capacity of exits is 60 individuals per metre per minute [8], since this depends on effective exit rather than actual exit width [80]. Incident evaluations have revealed that emergency exits which are not used in normal situations will not be used in an emergency either [71]. This is especially true for locked exits with facilities which prevent 'inappropriate use' in normal situations, such as those that are connected to an alarm. Based upon the results of evacuation experiments in a department store [71], it is presumed that the fire exits will only be used if the doors are open, and the walking distance to the main entrance is twice as long as the walking distance to the fire exits. For example, during a fire in a care home for the elderly, 95% of patients were evacuated through the main staircase, and the other three available emergency staircases were not used at all. As a result, the total evacuation time was longer than that calculated by the architect [71].

Physical barriers, like fire and smoke compartments, the maximum walking distance to (fire) exits, and fire safety installations are the main components of egress and life safety systems. The installations can be divided between escalators and lifts, fire and evacuation alarms, emergency lighting, and sprinkler systems. These are tools which can be used in most types of buildings. Other fire safety installations, such as smoke and heat exhaust ventilation and stairway overpressure systems, are solutions to specific fire safety problems and are, therefore, not considered in the fire response performance model. So far as fire alarms are concerned, it has been found that a bell or a 'slow whooping' signal is rarely recognised as a sign of danger, and these are, thus, usually ignored by the occupants of a building [81,82]. A fire alarm which uses a spoken message, or a communication system broadcasting directives to personnel are taken most seriously by those present [79,81,82]. With regard to elevators, although their use is not currently allowed in the case of fire, they have been revealed to accelerate evacuations and save lives in high-rise buildings [9,21,22]. If the use of elevators in a case of fire is to be permitted, it will be necessary to warrant the fire safety thereof. For the details of what these requirements are, see the publications by Proulx [21] and Black [83].

Factors relating to materials include the issue of the flammability of those used for the construction, finishing and furnishing of a building. Compartmentation, on the other hand, relates to the physical barriers to the spread of fire and smoke. No information was found in the literature about the influence of the size of a building on fire response performance. However, data has been found on the correlation between the possibility of a safe escape and the height of a building. Experience of fatal fires in buildings with more storeys has shown that there is a high probability of fire or smoke in their staircases [4]. This finding suggests that the measures in place for fire safety in staircases require further attention. Recent studies of the evacuation of high-rise office buildings, including those of the WTC, revealed that movement velocity is generally slow if a building is fully occupied [25]. People who are already on the staircases commonly feel that they have priority, and tend to let only a few other individuals join the downward flow of evacuees. The following aspects have a major impact on (downward) evacuation velocity in staircases [25]:

- Size of the staircase.
- Population density in the staircase.
- Simultaneous evacuation from several floors.
- Evacuees trying to join the downward flow of people in the staircase.
- Small talk between evacuees.
- The use of cell phones and blackberries (or other smart phones).
- Evacuees who are overweight; extremely tall and short evacuees.
- Unsuitable footwear (tight shoes, high heels, etc.)
- Counter flow of firefighters.

Studies of the evacuation of the WTC towers (1993 and 2001) also show that greater numbers of people face difficulties when walking down stairs than was previously estimated [22,25,64], particularly when long distances down them are involved [22,64]. Furthermore, occupants are often not familiar with the staircases in high-rise buildings [22]. In response to the evacuation studies after the WTC 9/11 attack, the requirements for staircases in high-rise buildings have been changed. For these changes, see the International Building Code (published by the International Code Council), the Life Safety Code (published by the National Fire Protection Association) and the publication by the American Society of Safety Engineers [84].

4. Towards a psychonomic approach to fire safety

On reviewing the literature on the critical factors which determine fire response performance, it is clear that occupants' behaviour interacts with the conditions of the surrounding environment and the fire safety measures in place in the building. Consequently, it is recommended that a psychonomic approach to fire safety should be adopted.

4.1. Existing paradigm of fire safety

In the existing paradigm of fire safety in buildings, the issue is mainly viewed from the perspective of building construction and management, since this is what is laid down in building and fire codes in most western countries. As a result, fire safety policy includes both technical and social measures. It is assumed that government policy and its implementation and enforcement is one of the factors determining the level of fire safety, which is frequently defined by the number of fire fatalities. Fatal fires occur worldwide, primarily at night in buildings where people are sleeping [4,49,68], such as residential buildings and hotels. Additionally, fatal fires occur in buildings occupied by those who are unable to escape on their own, such as from nursing homes and places used for detention purposes [4], and in assembly buildings with high-density occupancy, such as cafés and nightclubs [4,68]. In the case of fatal fires in assembly buildings, the following factors–or a combination of them – are decisive in determining fatality [34,45,68]:

- High occupancy.
- The presence of combustible decorations.
- Unavailable emergency exits.

Fires with numerous casualties generally raise questions about the safety requirements in buildings with the type of occupancy levels that there were in the property wherein the fatal fire occurred. There are also serious indications that the findings of fatal fire investigations and scientific experiments have rarely led to a thorough evaluation of the basic principles of fire safety policy, or the role of inspections and the enforcement of existing regulations. On the contrary, after a major incident it is not uncommon for symbolic, improved, measures to be introduced [85] on the assumption that there is very little chance that the effectiveness thereof will be discussed in the near future. Moreover, absolute safety can be promised by means of such a symbolic policy, since the chance of similar major incidents occurring is generally very slight.

Green escape route signs are an expressive example of symbolic fire safety [4]. Policy makers and enforcers place a lot of emphasis on the colour, the pictogram and the location of these signs (the green emergency exit signs), but incident evaluations show that people usually either fail to notice, [70] or ignore them [26,70,86]. Moreover, these green signs are located in such a way that if fire breaks out, smoke will render them invisible.

Another example of the existing paradigm of fire safety in buildings, at least so far as the Netherlands is concerned, is the assumption that when people become aware of a fire, for instance when they hear an evacuation signal, they begin to leave the building immediately. However, incident evaluations [10,79] have proved that this is not the case. In fact, the time that people in a property need to become aware of a fire and to realise the danger it poses is longer than actual walking time [6,30]. Other examples of principles and assumptions in current (Dutch) policy which are not consistent with the knowledge in the literature are presented in Table 1.

Table 1
Difference between policy and actual fire safety.

Point of departure or assumption in (Dutch) policy	Knowledge from incident evaluations and experiments
Fire growth in a building is consistent with the standard fire curve, regardless of the use of a building and the materials present in it	Fire growth depends on the kind of material present in a building; for example, the combustion of synthetic materials leads to ultra-fast fire growth [43]
People who are mobile can escape without assistance	All people in a fire situation may be confronted with some degree of limitation [7,22,25,64] and are, therefore, potentially less or not at all self-reliant
People use escape route signage to find the closest exit	Incident evaluations show that in 400 cases of escape from fire, 92% of the survivors were not aware of the presence of escape route signage [70]
People escape via the nearest (emergency) exit	People usually escape via familiar exit routes and rarely via emergency exits [34,41,65,71]. The objective walking distance does not determine the choice of route [33,63]. Familiar routes are experienced as being shorter than unfamiliar routes [63]
People escape immediately after hearing a fire alarm bell	People (in groups) customarily ignore ambiguous cues like a fire alarm bell [86]. People are more likely to respond to verbal cues [65,79,81,82]. Social rules have a strong influence on people's (non-) reaction to cues of danger [39,65]
People's walking speed is constant, regardless of whether or not they are walking through smoke	People who are exposed to the effects of fire walk more slowly than the pace concluded from walking experiments in normal environmental conditions [8,47,48]

4.2. Psychonomics and fire safety

To bring fire safety policy into line with people's actual behaviour during a fire, it is recommended that the scientific knowledge available from the field of psychonomics should be utilised. The Dutch Psychonomic Society describes the concept as follows:

> Psychonomics deals with processes, such as observing, locomotion, learning, deciding, thinking, getting emotional, speaking, writing, which occur in numerous situations, at child and adult, individually and socially. It deals not only with the logos (doctrine) of behaviour, but also and in particular with the nomos, the laws that describes and predicts the behaviour. Psychonomic research is generally done in laboratories, in the form of experiments with the benefit of sophisticated equipment. The psychonomic approach is characterised by a preference for conducting tests under controlled circumstances, by a striving towards objectivity, accuracy and quantifying by formulating verifiable theories.

Psychonomics is concerned with discovering the laws which govern human behaviour [56]. These lead to an understanding of how people process information.

In the field of fire safety, the focus of psychonomics is on human behaviour in buildings, both before as well as during a fire. On the one hand it is about social aspects, such as affiliative behaviour, whereas on the other it concerns personal and situational factors, such as mobility and awareness. Both types of features are mainly concerned with the capacity to express a particular kind of behaviour, and the intentions and motivation behind it. The motivation for how we behave reveals itself in intuitive or learned behaviour on the one hand, and in behaviour that has been influenced by our situational surroundings on the other. These surroundings consist of a social and/or technical dimension. Examples of the former are affiliative behaviour and the training and presence of an in-house emergency and first-aid organisation. An example of the latter is the accessibility of fire exits, and building management clearly plays a role, for example in the implementation of good housekeeping, with thought being paid to the functioning of both the technical and social measures in a building.

Psychonomics addresses the reciprocal influence between fire and human characteristics, and between building and human characteristics. Consequently, the primary concern is with the occupants' perception of the fire and the build environment. Groner [87] has already found that people base their actions on their perceptions in particular circumstances. Thus, for building designers it is important to understand why people hesitate to evacuate when hearing a fire alarm, and why they take one route and not another [87]. The most important obstacle to predicting evacuation behaviour [88] is not our knowledge of movement behaviour itself, but our inability to predict how human beings act when it comes to when, where, and how they exit buildings. Without detailed data about the information that occupants use in evacuation circumstances, it is impossible to stipulate the necessary fire safety measures in a building design [88].

4.3. The implementation of the psychonomic approach

Referring to the most important presumption in (Dutch) fire safety regulations [89], namely that a building must be designed in such a way that people can reach (or stay in) a safe place before a fire has developed to the point that survival is no longer possible, the psychonomic approach to fire safety is essential. The necessity of the approach can be explained by the global fire safety engineering models of Available Safe Egress Time (ASET) and Required Safe Egress Time (RSET) [10,90]. The ASET is the period between the outbreak of the fire and the point at which fatal environmental conditions have arisen [10,90]. For the threshold values of these conditions, see O'Connor [5], Purser [46], Irvine et al. [49], BSI [90], Delichatsios [91] and Trijssenaar-Buhre et al. [92]. The RSET is the period between the outbreak of the fire and the point at which a safe place is reached [10,90]. It is determined by the time needed to carry out the basic actions required during the period of the fire and the period of escape. The evacuation has to be completed before fatal environmental conditions have arisen.

The disparity between the RSET and the ASET models plays a decisive role with regard to the prevention measures required to support the possibility of a safe escape in the case of fire. The latter depends on fire and fire suppression scenarios, both of which are based on knowledge of fire physics and construction engineering. A fire scenario describes the start or ignition, development and effects of a fire, whereas a fire repression scenario describes its suppression and extinguishment. The RSET, on the other hand, depends on evacuation scenarios based upon our knowledge of psychonomics. An evacuation scenario describes human behaviour when faced with a fire. The required fire safety measures for a building's design can be engineered with all three of these scenarios in mind, although this can be difficult because the principles and assumptions of fire safety policies are not consistent with current scientific knowledge in the fields of fire physics and psychonomics. Moreover, and probably most importantly, very little is known about psychonomics as it applies to fire safety.

5. Conclusions

Clear and extensive knowledge of human behaviour when faced with a fire is essential for the provision of the appropriate policy measures for a safe escape from it. However, our current understanding of how people act during an incident is still very limited, especially when it comes to the psychonomics related to fire safety. For example, we know how people behave, but we understand very little about what their motivations are for doing what they do. To determine which measures would hasten the time taken to make decisions, and which steps would lead to people choosing the right escape routes, we need information about the perceptions, intentions and motives of those who are trying to escape from a fire. Since fire response performance is dependent upon the environment in which an individual is present, the starting point for fire prevention measures should be the interaction between human behaviour and the characteristics of a building. To realise adequate fire response performance, the definition of the fire safety of a building design should be based on psychonomics. Accordingly, further research is needed on building psychonomics in these circumstances.

Acknowledgements

The authors would like to thank the Dutch ministry of the Interior and Kingdom Relations for their sponsorship of the research, and we are grateful to Nancy Oberijé BSc, Karin Groenewegen – Ter Morsche MSc, Eric Didderen BBA and Marco van Wijngaarden MEM for all of their help with the project. We would also like to thank Prof.Dr. B.J.M. Ale, Prof.ir. P.G. Luscuere, Dr. L.C. Boer, Dr. J.P. van de Sande, Dr. J.M. Gutteling, E. Oomes MSc, R.R. Hagen MPA, H. Veltkamp and J.M. Weges BSc, who have reviewed the manuscript of the Dutch version [4] of the literature review upon which this paper is based.

References

[1] L. Rubadiri, D.T. Ndumu, J.P. Roberts, Predicting the evacuation capability of mobility-impaired occupants, Fire Technology 33 (1997) 32–53.
[2] D.A. Purser, M. Bensilum, Quantification of behaviour for engineering design standards and escape time calculations, Safety Science 38 (2001) 157–182.
[3] T.T. Pires, An approach for modeling human cognitive behavior in evacuation models, Fire Safety Journal 40 (2005) 177–189.
[4] M. Kobes, Zelfredzaamheid bij brand; Kritische factoren voor het veilig vluchten uit gebouwen, Boom Juridische uitgevers, Den Haag, The Netherlands, 2008 [Fire response performance; the critical factors for a safe escape out of buildings].
[5] D.J. O'Connor, Integrating human behaviour factors into design, Journal of Fire Protection Engineering 28 (2005) 8–20.
[6] J.L. Bryan, A selected historical review of human behavior in fire, Journal of Fire Protection Engineering 16 (2002) 4–10.
[7] D. Tong, D. Canter, The decision to evacuate: a study of the motivations which contribute to evacuation in the event of fire, Fire Safety Journal 9 (1985) 257–265.
[8] H. Frantzich, A Model for Performance-based Design of Escape Routes, Department of Fire Safety Engineering, Lund Institute of Technology, Lund University, Sweden, 1994.
[9] R.F. Fahy, G. Proulxm, Toward creating a database on delay times to start evacuation and walking speeds for use in evacuation modelling, in: Second International Symposium on Human Behaviour in Fire, Boston, 2001, pp. 175–183.
[10] SFPE, Engineering Guide to Human Behaviour in Fire, SFPE, 2002.
[11] J.D. Sime, An occupant response shelter escape time (ORSET), model: research and practice, in: Fire and Explosions: Recent Advances in Modelling and Analysis, Professional Engineering Publishing Ltd., London, Bury St. Edmunds, 1999, pp. 23–33.
[12] J.D. Sime, An occupant response shelter escape time (ORSET) model, Safety Science 38 (2001) 109–125.
[13] T. Jin, Visibility and human behavior in fire smoke, in: SFPE Handbook of Fire Protection Engineering, third ed., National Fire Protection Association, Quincy, MA, 2002.

[14] K.E. Boyce, T.J. Shields, G.W.H. Silcock, Toward the characterization of building occupancies for fire safety engineering: prevalence, type and mobility of disabled people, Fire Technology 35 (1999) 35–50.
[15] K.E. Boyce, T.J. Shields, G.W.H. Silcock, Toward the characterization of building occupancies for fire safety engineering: capabilities of disabled people moving horizontally and on an incline, Fire Technology 35 (1999) 51–67.
[16] K.E. Boyce, T.J. Shields, G.W.H. Silcock, Toward the characterization of building occupancies for fire safety engineering: capability of disabled people to negotiate doors, Fire Technology 35 (1999) 68–78.
[17] K.E. Boyce, T.J. Shields, G.W.H. Silcock, Toward the characterization of building occupancies for fire safety engineering: capability of people with disabilities to read and locate exit signs, Fire Technology 35 (1999) 79–86.
[18] B.S. Robertson, C.H. Dunne, Way finding for visually impaired users of public buildings, Journal of Visual Impairment and Blindness 92 (1998) 349–355.
[19] B.S. Robertson, British antidiscrimination legislation and way finding in buildings in Scotland, Journal of Visual Impairment and Blindness (2001) 69–79.
[20] G. Proulx, Evacuation planning for occupants with disability, Internal Report No. 843, IRC-NRCC, Ottawa, Canada, 2002.
[21] G. Proulx, High rise evacuation: a questionable concept, in: Proceedings of the Second International Symposium on Human Behaviour in Fire 2001, Interscience Communications, London, 2001, pp. 221–230.
[22] J.D. Averill, D. Mileti, R. Peacock, E. Kuligowski, N. Groner, G. Proulx, P. Reneke, H. Nelson, Federal investigation of the evacuation of the world trade center on September 11, 2001, in: Proceedings of the Third International Conference on Pedestrian and Evacuation Dynamics 2005, Springer, Berlin, Heidelberg, 2007.
[23] R.F. Fahy, G. Proulx, Analysis of Published Accounts of the World Trade Center Evacuation, NIST NCSTAR 1-7A, Federal Building and Fire Safety Investigation of the World Trade Center Disaster, NIST, USA, 2005.
[24] E.R. Galea, G. Sharp, P.J. Lawrence, A. Dixon, Investigating the impact of occupant response time on computer simulations of the WTC North tower evacuation, in: Interflam 2007, Conference Proceedings, vol. 2, 11th International Fire Science and Engineering Conference, Interscience, London, 2007, pp. 1435–1442.
[25] G. Proulx, High-rise office egress: the human factors, in: Proceedings of the Symposium on High-Rise Building Egress Stairs, New York, 2007.
[26] C.W. Johnson, Lessons from the evacuation of the world trade centre, 9/11 2001 for the development of computer-based simulations, Cognition, Technology and Work 7 (2005) 214–240.
[27] J.D. Averill, D.S. Mileti, R.D. Peacock, E.D. Kuligowski, N. Groner, G. Proulx, P.A. Reneke, H.E. Nelson, Occupant Behavior, Egress, and Emergency Communications, NIST NCSTAR 1-7, Federal Building and Fire Safety Investigation of the World Trade Center Disaster, NIST, USA, 2005.
[28] E.R. Galea, An analysis of human behavior during evacuation, Journal of Fire Protection Engineering 28 (2005) 22–29.
[29] E.R. Galea, J. Shields, D. Canter, K. Boyce, R. Day, L. Hulse, A. Siddiqui, L. Summerfield, M. Marselle, P.V. Greenall, The UK WTC 9/11 evacuation study: methodologies used in the elicitation and storage of human factors data; in: Interflam 2007, Conference Proceedings, vol. 1, 11th International Fire Science and Engineering Conference, Interscience, London, 2007, pp. 169–181.
[30] G. Proulx, Playing with fire: understanding human behavior in burning buildings, ASHRAE Journal 45 (2003) 33–35.
[31] S. Gwynne, E.R. Galea, M. Owen, P.J. Lawrence, L. Filippidis, A review of the methodologies used in the computer simulation of evacuation from the built environment, Building and Environment 34 (1999) 741–749.
[32] M. Barnett, D. Bruck, A. Jago, Mean annual probability of having a residential fire experience throughout a lifetime: development and application of a methodology, in: Seventh Asia-Oceania Symposium on Fire Science and Technology, Hong Kong, 2007.
[33] S. Gwynne, E.R. Galea, P.J. Lawrence, L. Filippidis, Modelling occupant interaction with fire conditions using the building EXODUS evacuation model, Fire Safety Journal 36 (2001) 327–357.
[34] T.L. Graham, D.J. Roberts, Qualitative overview of some important factors affecting the egress of people in hotel fires, Hospitality Management 19 (2000) 79–87.
[35] P. Demers, Hotel fire. Las Vegas, NV, February 10, 1981. NFPA, Quincy, MA, 1981.
[36] J.L. Bryan, Human behavior and fire, in: NFPA Handbook, Section 7, NFPA, Quincy, MA, 1992 (Chapter 1).
[37] M. Kobes, Een bouwkundig perspectief op evacuatie uit gebouwen, in: R. van derBrand (Ed.), Zelfredzaamheid en fysieke veiligheid van burgers: Verkenningen. Nibra Publicatiereeks nr. 18. Nibra, Arnhem, 2005 [An architectural perspective on building evacuation, in: Resillience and physical safety of citizens: explorations].
[38] E. Oomes, Mobiliteit. Article in: 'Ome Ed', December 2006 [Mobility].
[39] J.D. Sime, Crowd psychology and engineering, Safety Science 21 (1995) 1–14.
[40] D.A. Purser, Data benefits: fire prevention, Fire Engineers Journal 21 (2003) 21–24.
[41] A. Sandberg, Unannounced Evacuation of Large Retail-Stores. An Evaluation of Human Behaviour and the Computer Model Simulex, Lund University, Sweden, 1997.
[42] D. Tang, K. Beattie, Integrated Prediction of Fire, Smoke and Occupants' Evacuation of Buildings, Dublin Institute of Technology/IES Limited, 1997.
[43] C.-H. Chang, H.-C. Huang, A water requirements estimation model for fire suppression: a study based on integrated uncertainty analysis, Fire Technology 41 (2005) 5–24.
[44] W. Grosshandler, N. Bryner, D. Madrzykowski, K. Kuntz, Report of the Technical Investigation of The Station Nightclub Fire. NIST NCSTAR 2, vol. I. US Government Printing Office, Washington, DC, 2005 (Chapter 4.6).
[45] N. Bryner, D. Madrzykowski, W. Grosshandler, Reconstruction. The Station Nightclub Fire. Computer modeling of the fire growth and spread, in: Interflam 2007, Conference Proceedings, vol. 2, 11th International Fire Science and Engineering Conference, Interscience, London, 2007, pp. 1181–1192.
[46] D. Purser, Toxicity assessment of combustion products, in: SFPE Handbook of Fire Protection Engineering, third ed., National Fire Protection Association, Quincy, MA, 2002.
[47] M. Isobe, D. Helbing, T. Nagatani, Many-particle simulation of the evacuation process from a room without visibility, Physical Review E (2004) 69.
[48] R. Nagai, T. Nagatani, M. Isobe, T. Adachi, Effect of exit configuration on evacuation of a room without visibility, Physica A 343 (2004) 712–724.
[49] D.J. Irvine, J.A. McCluskey, I.M. Robinson, Fire hazards and some common polymers: review paper, Polymer Degradation and Stability 67 (2000) 383–396.
[50] L.C. Boer, Praktijkproef geluidsbakens bij ontruiming tunnel in dichte rook, TNO, Soesterberg, The Netherlands, 2003 [Practical assessment of sound beacons in tunnel evacuation in thick smoke].
[51] R.G. Gann, Estimating data for incapacitation of people by fire smoke, Fire Technology 40 (2) (2004) 201–207.
[52] ISO, Guidelines for assessing the fire threat to people, ISO/TS 19706, 2004.
[53] P. Blomqvist, Emissions from fire, Consequences for human safety and the environment, Doctoral Thesis, Lund University, Lund, Sweden, 2005.
[54] B. Cornwell, Bonded fatalities: relational and ecological dimensions of a fire evacuation, Sociological Quarterly 44 (2003) 617–638.
[55] G. Proulx, A stress model for people facing a fire, Journal of Environmental Psychology 13 (1993) 137–147.
[56] W.B. Verwey, Psychologische functieleer en cognitieve ergonomie: een siamese tweeling?, Tijdschrift voor Ergonomie 29 (2) (2004) 4–9.
[57] J.D. Sime, The concept of 'Panic', in: D. Canter (Ed.), Fires and Human Behaviour, second ed., David Fulton Publishers Ltd., London, 1990, pp. 63–81.
[58] G. Proulx, Cool under fire, Fire Protection Engineering 16 (2002) 33–35.
[59] E. Auf der Heide, Common misconceptions about disasters: panic, the "disaster syndrome," and looting, in: M. O'Leary (Ed.), The First 72 h: A Community Approach to Disaster Preparedness, Nebraska, London, 2004.
[60] S. Sillem, Een psychologisch perspectief op evacuatie uit gebouwen, in: R. van der Brand (Ed.), Zelfredzaamheid en fysieke veiligheid van burgers: Verkenningen. Nibra Publicatiereeks nr. 18. Nibra, Arnhem, 2005 [A psychological perspective on building evacuation, in: Resillience and physical safety of citizens: explorations].
[61] G. Proulx, Misconceptions about human behaviour in fire emergencies, Canadian Consulting Engineer (1997) 36–38.
[62] G. Proulx, Occupant behaviour and evacuation, in: Proceedings of the Ninth International Fire Protection Symposium, Munich, 2001, pp. 219–232.
[63] G.G. Løvås, Models of way finding in emergency evacuations. Theory and methodology, European Journal of Operational Research 105 (1998) 371–389.
[64] R.W. Bukowski, Protected elevators and the disabled, Journal of Fire Protection Engineering 28 (2005) 42–49.
[65] J.D. Sime, Affiliative behaviour during escape to building exits, Journal of Environmental Psychology 3 (1983) 21–41.
[66] I. Donald, D. Canter, Behavioural aspects of the King's Cross Disaster, in: D. Canter (Ed.), Fires and Human Behaviour, second ed., David Fulton Publishers Ltd., London, 1990, pp. 15–30.
[67] D. Bruck, The who, what, where and why of waking to fire alarms: a review, Fire Safety Journal 36 (2001) 623–639.
[68] J.S. Tubbs, Developing Trends from Deadly Fire Incidents: A Preliminary Assessment, ARUP, Westborough, MA, 2004.
[69] M. Raubal, M.J. Egenhofer, Comparing the complexity of way finding tasks in built environments, Environment and Planning B 25 (1998) 895–913.
[70] M.J. Ouellette, Visibility of exit signs, Progressive Architecture 74 (7) (1993) 39–42.
[71] L. Benthorn, H. Frantzich, Fire Alarm in a Public Building: How Do People Evaluate Information and Choose Evacuation Exit? Department of Fire Safety Engineering, Lund Institute of Technology, Lund University, Sweden, 1996.
[72] G. Proulx, B. Kyle, J. Creak, Effectiveness of a photoluminescent wayguidance system, Fire Technology 36 (2000) 236–248.
[73] VROM, Brandveiligheid bij zorginstellingen. Beoordeling van brandveiligheidsvoorzieningen in dertig zorginstellingen. VROM-Inspectie, regio Noord-West, Haarlem, The Netherlands, 2004 [Fire safety in health care facilities. Assessment of fire safety measures in thirty health care facilities].
[74] VROM, Onderzoek veiligheid bij overdekte speeltuinen. Beoordeling van de naleving van de VROM-regelgeving bij 30 overdekte speeltuinen. VROM-Inspectie, regio Noord-West, Haarlem, The Netherlands, 2006 [Safety investigation of indoor playgrounds. Assessment of the compliance with the VROM regulations at thirty indoor playgrounds].
[75] VROM, Onderzoek veiligheid hotels. Brandveiligheid en legionella-preventie van 12 hotels in Zuid-Holland en Zeeland. VROM-Inspectie, regio Zuid-West, Rotterdam, The Netherlands, 2007 [Hotel safety investigation. Fire safety and legionella prevention in twelve hotels in the provinces Zuid-Holland and Zeeland].
[76] J.M. Weges, Brandveiligheidsscan aanmeldcentra voor asielzoekers. Netherlands Institute for Safety, NIFV/Nibra, Arnhem, The Netherlands, 2006 [Fire safety scan of refugee registration centers].

[77] J.M. Weges, Uitvoering brandveiligheid dakconstructies van stalen damwandprofiel. Netherlands Institute for Safety, NIFV/Nibra, Arnhem, The Netherlands, 2006 [Fire safety implementation in roof constructions of profiled steel plates].
[78] J.D. Sime, Accidents and disasters: vulnerability in the built environment, Safety Science 14 (1991) 109–124.
[79] G. Proulx, J.K. Richardson, The human factor: building designers often forget how important the reactions of the human occupants are when they specify fire and life safety systems, Canadian Consulting Engineer 43 (2002) 35–36.
[80] J. Pauls, The movement of people in buildings and design solutions for means of egress, Fire Technology 20 (1984) 27–47.
[81] G. Proulx, Why Building Occupants Ignore Fire Alarms, Construction Technology Update 42, IRC-NRCC, Ottawa, 2000.
[82] G. Proulx, D. Laroche, Study shows low public recognition of the temporal-three evacuation signal, Construction Innovation 6 (4) (2001) 1–6.
[83] B.D. Black, Life safety, fire protection, and mobility-impaired persons, Journal of Fire Protection Engineering 16 (2002) 26–29.
[84] ASSE, New York City Building Code Reference Standard RS 6-1 Photoluminescent Low-Level Exit Path Markings, Article on the American Society of Safety Engineers website, 2007.
[85] I. Helsloot, Voorbij de symboliek. Over de noodzaak van een rationeel perspectief op fysiek veiligheidsbeleid. Oratie. Boom Juridische uitgevers, Den Haag, 2007 [Beyond symbolism. Concerning the need of a rational perspective on physical safety policy. Inaugural speech].
[86] L.C. Boer, Gedrag van automobilisten bij evacuatie van een tunnel. TNO, Soesterberg, The Netherlands, 2002 [Behaviour of motorists in tunnel evacuation].
[87] N.E. Groner, Intentional systems representations are useful alternatives to physical systems representations of fire-related human behaviour, Safety Science 38 (2001) 85–94.
[88] N.E. Groner, On putting the cart before the horse: design enables the prediction of decisions about movement in buildings, in: Proceeding for the NIST Workshop on Building Occupant Movement During Fire Emergencies, NIST, USA, 2004.
[89] BZK, Brandbeveiligingsconcept: Gebouwen met een publieksfunctie. The Ministry of the Interior and Kingdom Relations, Den Haag, The Netherlands, 1995 [Fire safety design concept; buildings with a public occupancy].
[90] BSI, PD 7974-6. The application of fire safety engineering principles to [the] fire safety design of buildings, Human factors: life safety strategies, Occupant evacuation, behaviour and condition, British Standards Institute, London, 2004.
[91] M.A. Delichatsios, Should smoke yield be regulated for wall, ceiling and floor linings?, Fire Technology 40 (2004) 263–276.
[92] I.J.M. Trijssenaar-Buhre, I.M.E. Raben, T. Wiersma, S.I. Wijnant, Self-Rescue in Quantitative Risk Analysis, TNO, Apeldoorn, The Netherlands, 2007.