PD 7974-6:2004

The application of fire safety engineering principles to fire safety design of buildings —

Part 6: Human factors: Life safety strategies — Occupant evacuation, behaviour and condition (Sub-system 6)

Confirmed
December 2011

ICS 13.220.01

BSi
British Standards

Committees responsible for this Published Document

The preparation of this Published Document was entrusted by Technical Committee FSH/24, Fire safety engineering, to Subcommittee FSH/24/5, Fire service intervention, upon which the following bodies were represented:

Association of Building Engineers
BRE/LPC Laboratories
Chief and Assistant Chief Fire Officers' Association
District Surveyors Association
Fire Brigades Union
Fire Safety Development Group
Home Office
Home Office — Fire Service College
London Fire and Emergency Planning Authority
ODPM — Building Division

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 1 July 2004

Amendments issued since publication

Amd. No.	Date	Comments

The following BSI references relate to the work on this Published Document:
Committee reference FSH/24/5

ISBN 0 580 43812 0

Contents

Foreword

This Published Document (PD) was prepared by Subcommittee FSH/24/6. Other parts published are as follows:

— *Part 0: Guide to design framework and fire safety engineering procedures*;

— *Part 1: Initiation and development of fire within the enclosure of origin (Sub-system 1);*

— *Part 2: Spread of smoke and toxic gases within and beyond the enclosure of origin (Sub-system 2);*

— *Part 3: Structural response and fire spread beyond the enclosure of origin (Sub-system 3);*

— *Part 4: Detection of fire and activation of fire protection systems (Sub-system 4);*

— *Part 5: Fire service intervention (Sub-system 5);*

— *Part 7: Probabilistic risk assessment.*

These Published Documents are intended to be used in support of BS 7974:2001, *Application of fire safety engineering principles to the design of buildings — Code of practice*, but do not represent the only means of satisfying the recommendations of the code of practice.

This Published Document can be used to set specific acceptance criteria and undertake detailed analysis for evacuation. It can be used to identify and define one or more fire safety design issues to be addressed using fire safety engineering.

Drafting of this publication was completed in February 2004.

Acknowledgement is made to the contribution of Mr D. Berry of HM Fire Inspectorate — DTLR and Prof D. Purser of FRS/BRE in the preparation of this publication.

It has been assumed in the drafting of this Published Document that the execution of its provisions is entrusted to appropriately qualified and competent people.

Attention is drawn to the Building Regulations [1] and BS 7974:2001.

This Published Document takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a Published Document does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 49 and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

Introduction

This Published Document provides information on engineering methods currently available for the evaluation and management of occupant behaviour, particularly escape behaviour, during a fire emergency and for the evaluation of occupant condition, especially in relation to exposure to fire effluent and heat.

In most cases of fire, this involves evacuation of the occupants. A basic principle of a performance-based (fire safety engineering) building design is that the available safe escape time (ASET) is greater than the required safe escape time (RSET) by an appropriate margin of safety. An appropriate margin of safety takes account of the risks associated with different potential fire scenarios and the uncertainties in the prediction of ASET and RSET for particular design scenarios [2].

An ideal fire safety design should ensure that building occupants are able to reach a place of safety without ever coming into contact with or even being aware of fire effluent and/or heat. This should be the main design criterion for the safety of the majority of occupants in multi-compartment buildings (BS 7974 and BS ISO/TR 13387-8). A major design criterion is therefore the estimation of the time required for escape in situations where occupants are not directly affected by fire effluent or heat.

There will inevitably be some potential scenarios when some occupants will become aware of or be exposed to fire effluent, particularly when the occupants are in the enclosure of fire origin. This can vary between seeing fire or smoke or exposure to slight smoke contamination, common in many accidental fires, to life threatening exposures such as in major fire disasters. For all of these types of scenarios, it is important to be able to assess the likely effects of such exposures, either as part of the main design or as part of a risk assessment.

In order to achieve these evaluations, detailed input information is required in four main areas:

a) the building design and emergency life safety management strategy;

b) the occupant characteristics;

c) the fire simulation dynamics;

d) intervention effects.

The response of occupants to a fire condition is influenced by a whole range of variables in these four categories, related to the characterization of the occupants in terms of their number, distribution within the building at different times, their familiarity with the building, their abilities, behaviours and other attributes; the characterization of the building including its use, layout and services; the provision for warnings, means of escape and emergency management strategy; the interaction of all these features with the developing fire scenario and provisions for emergency intervention (fire brigade and rescue facilities).

Guidance is provided on the evaluation of escape and evacuation times from buildings:

a) in the absence of fire;

b) when escape behaviour and therefore RSET is influenced by fire effluents and heat;

c) the evaluation of ASET in relation to tenability limits due to fire effluents and heat.

This Published Document is intended for use together with BS 7974 and the other parts of PD 7974. These provide some of the information necessary to perform a life safety evaluation and a means for the results of the life safety evaluation to be incorporated into the wider aspects of a fire safety engineering design.

The time required for escape depends upon a series of processes consisting of:

a) time from ignition to detection;

b) time from detection to the provision of a general evacuation warning to occupants;

c) evacuation time, which has two major phases:

1) pre-movement time (the time between that when occupants become aware of the emergency and that when they begin to move towards the exits). This consists of the time required to recognize the emergency and then carry out a range of activities before travelling to exits;

2) travel time (the time required for occupants to travel to a place of safety).

For detection, warning and pre-movement recognition and response times, most research on human behaviour has been essentially qualitative (BS ISO/TR 13387-8, [2] to [6]). This has revealed the complexity of occupant behaviour during fire emergencies and the importance of these behaviours with respect to escape time. In many situations, they comprise the greatest part of the time required for escape (BS ISO/TR 13387-8, [2] to [8]). Despite this, there has been little attempt to quantify the wide range of behavioural phenomena and the interactions between them, so that it is difficult to apply them to escape time calculations. Attempts have been made to develop scoring systems for the qualitative evaluation of different occupancies with regard to the ease with which efficient evacuation can be achieved [5], but have not provided data usable by engineers for escape time calculations. In recent draft design standards, attempts have been made to relate pre-movement time to the type of warning system used (sounder, recorded voice message or direct personal address message) [7]. In many situations the fire safety management system and occupant characteristics are more important (BS ISO/TR 13387-8, [2,6]).

Travel involves physically-based processes more amenable to design calculation methods [2,7,8,9,10,11]. However, travel times can be affected by behaviours such as wayfinding and exit choice [2,3,5,6,7]. Also, certain physical phenomena such as merging flows, have not been adequately solved [12].

There is a considerable interaction between the various aspects of pre-movement and travel times in the determination of total evacuation times for groups of building occupants. This has important implications for design performance evaluations [6,8].

A range of human behaviours can be involved to a greater or lesser extent in all these phases of escape time.

The fire safety engineering approach adopted in BS 7974 considers a performance-based approach to achieve a global objective of fire safe design. The global design – described in more detail in the framework document BS 7974 and the Published Documents – is subdivided into a series of sub-systems.

One principle is that inter-relationships and inter-dependencies of the various sub-systems are appreciated, and that the consequence of all the considerations taking place in any one sub-system are identified and realised. Another principle is that the evaluation is time based to reflect the fact that real fires vary in growth rate and spread with time. Despite this performance-based approach, it has to be recognized that some prescriptive parameters might need to be observed in any assessment of the life safety provisions within a building.

1 Scope

This Published Document (PD) is intended to provide guidance to designers, regulators and fire safety professionals on the engineering methods available for the evaluation of life safety aspects of a fire safety engineering design in relation to evacuation strategies.

Should a fire occur in which occupants might be exposed to fire effluent and/or heat, the objective of the fire safety engineering strategy is to ensure that such exposure does not significantly impede or prevent the safe escape (if required) of essentially all occupants, without their experiencing or developing serious health effects.

Advice is presented on the evaluation and management of occupant behaviour, particularly escape behaviour, during a fire emergency and for the evaluation of occupant condition, particularly in relation to exposure to fire effluent and heat.

This Published Document addresses the parameters that underlie the basic principles of designing for life safety and provides guidance on the processes, assessments and calculations necessary to determine the location and condition of the occupants of the building, with respect to time.

This Published Document also provides a framework for reviewing the suitability of an engineering method for assessing the life safety potential of a building for its occupants.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the reference cited applies. For undated references, the latest edition of the referenced document (including any amendments).

BS 5588-0, *Fire precautions in the design, construction and use of buildings — Part 0: Guide to fire safety codes of practice for particular premises/applications.*

BS 5588-12, *Fire precautions in the design, construction and use of buildings — Part 12: Managing fire safety.*

BS 7899-1, *Code of practice for the assessment of hazard to life and health from fire — Part 1: General guidance.*

BS 7899-2, *Code of practice for assessment of hazard to life and health from fire — Part 2: Guidance on methods for the quantification of hazards to life and health and estimation of time to incapacitation and death in fires.*

BS 7974, *Application of fire safety engineering principles to the design of buildings — Code of practice.*

BS ISO/TR 13387-8, *Fire safety engineering — Life safety — Part 8: Occupant behaviour, location and condition.*

PD 7974-0, *Application of fire safety engineering principles to the design of buildings — Part 0: Guide to the design framework and fire safety engineering procedures.*

PD 7974-1, *Application of fire safety engineering principles to the design of buildings — Part 1: Initiation and development of fire within the enclosure of origin (Sub-system 1).*

PD 7974-2, *Application of fire safety engineering principles to the design of buildings — Part 2: Spread of smoke and toxic gases within and beyond the enclosure of origin (Sub-system 2).*

PD 7974-3, *Application of fire safety engineering principles to the design of buildings — Part 3: Structural response and fire spread beyond the enclosure of origin (Sub-system 3).*

PD 7974-4, *Application of fire safety engineering principles to the design of buildings — Part 4: Detection of fire and activation of fire protection systems (Sub-system 4).*

PD 7974-5, *Application of fire safety engineering principles to the design of buildings — Part 5: Fire service intervention (Sub-system 5).*

PD 7974-6, *Application of fire safety engineering principles to the design of buildings — Part 6: Evacuation (Sub-system 6).*

PD 7974-7, *Application of fire safety engineering principles to the design of buildings — Part 7: Probabilistic fire risk assessment.*

3 Terms and definitions

For the purposes of this Published Document, the terms and definitions given in BS ISO/TR 13387-8 and the following apply.

3.1
alarm time
interval between detection of the fire and the time at which a general warning is provided to all occupants in a specified space in a building

3.2
Available Safe Escape Time
ASET
calculated time available between ignition of a fire and the time at which tenability criteria are exceeded in a specified space in a building

3.3
compartment
building or part of a building constructed to prevent the spread of fire to or from another part of the same building or an adjoining building

3.4
enclosure
space defined by boundary elements (on all sides)

3.5
escape time
interval between ignition and the time at which all occupants are able to reach place of safety

3.6
evacuation time
interval between the time at which a warning of a fire is transmitted to the occupants and the time at which all of the occupants are able to reach a place of safety

3.7
exit
doorway or other suitable opening giving access towards a place of safety

3.8
fire scenario
set of circumstances, chosen as an example, that defines the development of fire and the spread of combustion products throughout a building or part of a building

3.9
management
person or persons in overall control of the premises whilst people are present, exercising this responsibility either in their own right, e.g. as the owner, or by delegation (of statutory duty)

3.10
means of escape
means whereby safe routes are provided for persons to travel from any point in a building to a place of safety

3.11
phased evacuation
process by which a limited number of floors (usually the fire floor and the storey above) is evacuated initially and the remaining floors are evacuated when necessary

3.12
presentation time
interval between the time at which a warning of a fire is given and the time at which a person reaches a place of safety assuming walking speed is unrestricted

3.13
place of safety
predetermined place in which persons are in no immediate danger from the effects of fire

NOTE The place of safety may be inside or outside the building depending upon the evacuation strategy.

3.14
pre-movement time
interval between the time at which a warning of a fire is given and the time at which the first move is made towards an exit

NOTE This consists of two components:

— *Recognition*: the interval between the time at which a warning of a fire is given and the first response to the warning;

— *Response*: the interval between the time at which the first response occurs and the time at which the first move is made towards an exit.

For groups of occupants, two phases can be recognized:

— the pre-movement time of the first occupants to move;

— the pre-movement time distribution between the first and last occupants to move.

3.15
Required Safe Escape Time
RSET
calculated time available between ignition of a fire and the time at which occupants in a specified space in a building are able to reach a place of safety

NOTE A temporary place of safety may be represented by a protected escape route or other form of protected compartment. An ultimate place of safety would be outside the building at a safe distance from it.

3.16
tenability criteria
maximum exposure to hazards from a fire that can be tolerated without violating safety goals.

3.17
travel distance
actual distance that needs to be travelled by a person from any point within a building to the nearest exit, having regard to the layout of walls, partitions and fittings

3.18
travel time
time needed, once movement towards an exit has begun, for all occupants of a specified part of a building to reach a place of safety

3.19
walking speed
unrestricted speed of movement of a person

3.20
walking time
time taken for a person to walk from their starting position to the nearest exit, assuming walking speed is unrestricted

4 Principles

4.1 General

The main aim is to provide a safe environment for building occupants for as long as they need to remain in the building and to provide for safe means of escape with sufficient capacity of all occupants to be able to evacuate in safety.

The traditional basis of prescriptive life safety design is concentrated on physical provisions for means of escape. The advantage of the prescriptive method is that it can usually achieve acceptable levels of safety by the application of what is relatively simple guidance that has been found to work empirically. Whilst this prescriptive guidance is not primarily time-based, the elements related to exit and stair provision are based on time-related egress flow calculations.

Note that prescriptive rules on travel distance, floor space factors and exit requirements control considerably more than just these stated parameters.

4.2 The basis of performance-based design

Performance based (FSE) design also makes use of these basic physical provisions to ensure life safety, but the design evaluation depends upon a time based comparison of the time available for occupants to escape (if necessary) or to reach a place of safety (Available Safe Escape Time – ASET), and the escape time (Required Safe Escape Time – RSET).

Using this approach, it is possible to deviate from the restrictions imposed by the prescriptive rules (for example by increased travel distances or other relaxations) provided the fire safety performance of the design can be demonstrated to be acceptable. Performance-based design can also be used for complex or innovative building designs where the prescriptive guidance cannot readily be applied.

4.3 ASET calculations

The prediction of ASET times requires estimation of the time-concentration (or intensity) curves for the major toxic products, smoke and heat in a fire (which is covered by PD 7974-0 to PD 7974-3 in the series) and on the derivation and estimation of ASET endpoints for these hazards (which is covered in this PD and by BS 7899-2).

4.4 RSET calculations

Escape time depends upon detection, warnings and a range of parameters related to occupant evacuation behaviour and movement. The characterization and determination of evacuation behaviour can be simplified in terms of two broad categories of behaviour:

a) *Pre-movement behaviours*: those involved in the responses of occupants before they start to move through escape routes that fall into the category of "pre-movement" behaviours. Although pre-movement behaviours may involve periods when occupants are inactive, they also include a range of behaviours involving movement, but these behaviours do not generally include movement to the escape routes. An important finding of behavioural research is that the pre-movement phase can often comprise the longest part of the total escape time [2, 6, 12, 13];

b) *Travel behaviour*: those involved in physical movement of occupants into and through escape routes, which fall into the category of "travel" behaviours.

Where occupants are predicted to see fire or smoke during an evacuation, or to be exposed to heat or fire effluent, their pre-movement and travel behaviours may be affected, in which case the fire condition data (see **4.3**) need to be taken into account. Guidance on the effects of the fire condition on RSET are provided in this PD.

A simplified scheme of the processes related to escape is illustrated in Figure 1.

Assessment of these processes for any particular fire scenario is aimed at calculating the RSET.

Immediate evacuation on detection of a fire is often not the preferred (or possible) initial course of action for many buildings and occupancy types. For many large buildings, phased evacuation strategies are used, whereby occupants are evacuated progressively from parts of a building threatened by fire. For such buildings, the escape route capacity is insufficient for a rapid simultaneous evacuation of the entire building.

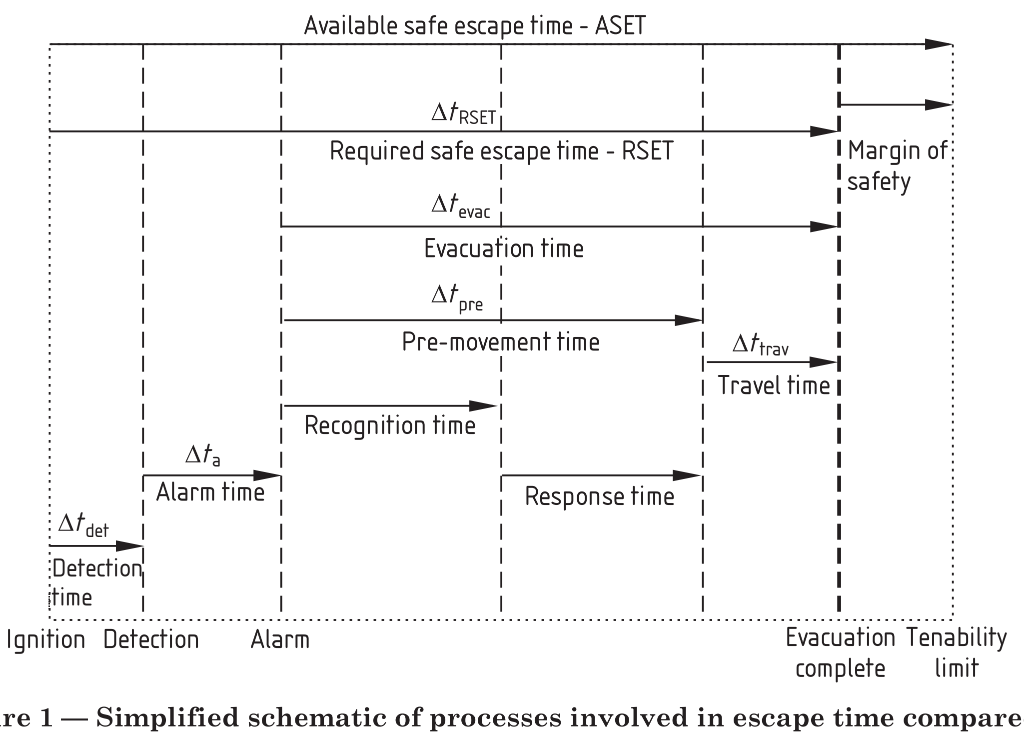


Figure 1 — Simplified schematic of processes involved in escape time compared to available safe escape time

The disruption resulting from total evacuation of a large building in response to a minor fire incident is also an issue. For flats and maisonettes, the design strategy is to evacuate only the compartment of fire origin and adjacent areas affected by the fire. For buildings such as hospitals, rapid evacuation can be impractical. A strategy of progressive horizontal evacuation is often used, whereby occupants are evacuated to an adjacent compartment as a place of temporary refuge [1]. Even when a strategy of immediate simultaneous evacuation is used, the time required for evacuation can be long (up to approximately an hour) for some occupancies, particularly those involving sleeping accommodation.

4.5 Margin of safety

For any specific set of ASET and RSET calculations, the margin of safety (t_{margin}) is represented by the difference between ASET (t_{ASET}) and RSET (t_{RSET}) as shown in equation (1).

$$t_{margin} = t_{ASET} - t_{RSET} \tag{1}$$

In order to allow for uncertainties in each step of the calculation, it might also be useful to apply a safety factor within the calculations. Guidance on probabilistic approaches is provided in PD 7974-7.

4.6 Elements used in quantification of RSET

The basic formula used for determining the escape time for a building is as shown in equation (2).

$$t_{RSET} = \Delta t_{det} + \Delta t_{a} + (\Delta t_{pre} + \Delta t_{trav}) \tag{2}$$

NOTE RSET (escape time) includes all four terms in equation (2). Evacuation time (t_{evac}) consists of the last two terms of the equation.

Δt_{det} is the time from ignition to *detection* by an automatic system or first occupant to detect fire cues. This depends upon the fire detection system in place and the fire scenario and is beyond the scope of this Published Document. Guidance on estimation of fire growth characteristics within the enclosure of origin is provided in PD 7974-1 and guidance on detection is provided in PD 7974-4.

Δt_{a} is the time from detection to a general *alarm*. This may vary between effectively zero (where the fire is detected by an automatic system triggering a general alarm on first detection) to several or many minutes (when for example, staged alarm systems are used or where there is no automatic detection. Guidance on default alarm times for different system configurations is provided in Annex A.

Δt_{pre} is the *pre-movement* time for the enclosure or building occupants. This has two behavioural elements for each individual occupant (recognition and response times) which may be addressed in some evacuation models. Further guidance is provided in Annex B. However, with regard to the main elements of escape and evacuation times of occupant groups it is important to recognize two phases:

— the period between the raising of a general alarm and the travel of the first few occupants: pre-movement time first occupants: [$\Delta t_{pre\ (first\ occupants)}$];

— the subsequent distribution of pre-movement times for the occupant group. This may be expressed as distribution of individual times or represented by a single time such as that of the population mode or the last occupant to move, depending upon the type of analysis: [$\Delta t_{pre\ (occupant\ distribution)}$].

Further guidance on default pre-movement times is provided in Annex C.

Δt_{trav} = *travel* time of the enclosure occupants or building occupants, each of which has sub-categories which need to be identified and assessed in a design review and incorporated into the performance assessment.

It has two major components:

— the time required for occupants to walk to an exit leading to a protected escape route: *walking* time [$\Delta t_{trav\ (walking)}$] [8, 13]. Walking time may be expressed as a distribution of individual times or represented by a single time such as the average time required to walk to the exits, or the time required for the last occupant to walk to an exit. This in turn depends upon the walking speed of each occupant and their distance from an exit. Walking time is determined by the physical dimensions of the building, the distribution of the occupants and their unimpeded walking speeds. It represents the minimum time required to walk to the exits since no allowance is made for the possibility of impeded walking due to high levels of occupant density within the enclosure;

— the time required for occupants to *flow* through exits and escape routes: flow time [$\Delta t_{trav\ (flow)}$]. Flow time is determined by the flow capacity of the exits. This can also be evaluated in terms of individual occupants or represented by the total time required for the occupant population to flow through the exits. Flow time represents the time required to evacuate an enclosure assuming all occupants are available at the exits and optimal use of exits is made.

Guidance on travel speeds and flow rates is provided in Annex D.

A concept found to be useful in the evaluation of evacuation times is that of "presentation time". Presentation time represents the time from a warning to that when an occupant presents themselves at an exit with the aim of leaving the enclosure, assuming that their progress across the space and through an exit is unimpeded (so that walking speed is unrestricted).

Another useful concept is that of time to queue (Δt_{queue}). This represents the time from the raising of a general alarm to that when queues form at the exits. Queue formation occurs when the occupant presentation rate at the exits exceeds the maximum occupant flow rate that can be sustained through the exits.

5 Design behavioural scenarios for quantification of pre-movement and travel times

5.1 General

The quantification of pre-movement and travel times is highly influenced by aspects of occupant behaviour. In order to deal with this aspect, a method has been developed whereby a set of key qualitative features of occupants behaviour is used to specify a small number of basic "design behavioural scenarios" analogous to design fire scenarios [2].

The occupant behaviours involved in escape depend upon a range of factors including:

— building characteristics (particularly occupancy type, method for detection and the provision of warnings, fire safety management systems and building layout);

— occupant characteristics (particularly occupant numbers, alertness (waking or sleeping) and familiarity with the building and its systems); and

— in situations where occupants are exposed to fire effluent, the fire dynamics (BS ISO/TR 13387-8, [7, 2, 3, 4, 8]).

All aspects of these variables should be considered for any specific building design as set out in Annex E.

Although some of these factors and their influence on evacuation are quantifiable in any specific building design, other factors, particularly those affecting occupant behaviour are essentially qualitative [2, 8]. The variables driving the responses of individual building occupants in emergency situations are extremely complex but, although each individual has a unique experience, when groups of building occupants are considered, a range of common situations and developing scenarios can be identified. These can be of sufficient simplicity that they can be useful in predicting generic evacuation times for design purposes [2, 6, 12].

Quantitative data for phases of behaviour, particularly warning and pre-movement times, have been obtained by observations of fire safety management and occupant behaviour during fire incidents and monitored evacuations for the main categories of design behavioural scenarios [8]. These are then combined with travel time calculations to provide a simple but robust method for the estimation of escape and evacuation times.

Each of these behavioural scenarios are summarized in Table 1. For each, the default time can be derived for alarm and pre-movement times, depending mainly upon the three safety management strategies and warning system in place.

Table 1 — Design behavioural scenarios and occupancy types

Category	Occupant alertness	Occupant familiarity	Occupant density	Enclosures/ complexity	Examples of Occupancy types
A	Awake	Familiar	Low	One or many	Office or industrial
B1 B2	Awake Awake	Unfamiliar Unfamiliar	High High	One or few One with focal point	Shop, restaurant, circulation space Cinema, theatre
 Ci Cii	Asleep Long term: individual occupancy. Managed occupancy:	Familiar	Low	Few	Dwelling Without 24 h on site management. Serviced flats, halls of residence, etc.
Ciii	Asleep	Unfamiliar	Low	Many	Hotel, hostel
D	Medical care	Unfamiliar	Low	Many	Residential (institutional)
E	Transportation	Unfamiliar	High	Many	Railway station/Airport

Certain building characteristics are also important, particularly spatial complexity, travel distances, occupancy factors, exits and escape routes. These mainly affect travel times and, in some situations, pre-movement times. The basic scenarios may be further subdivided into more closely defined scenarios in each class. Although all the occupant and building characteristics can affect escape times, the most important drivers are:

a) for occupants:

— number and distribution;

— alert/asleep;

— familiar and trained or unfamiliar;

— physical ability.

b) for buildings and building systems:

— warning system;

— fire safety management and staff/occupant training;

— single or multiple enclosures and spatial complexity.

c) for fire scenarios:

— fire alarms and cues available to occupants;

— features of the fire and fire effluent.

For each scenario category shown in Table 1, factors are described affecting occupant behaviour and the time required for various activities to be carried out during different phases of an evacuation. See Annex F for further details.

From the observations made, it is considered that each basic category has certain general requirements and ranges of likely alarm and pre-movement times. Each design behavioural scenario is defined primarily from the perspective of the occupants rather than the building, but a number of examples of occupancy types for each category are shown.

Any particular building may contain a number of enclosures in different design behavioural scenario categories. For example, a hotel is likely to include offices and working areas occupied by staff (Category A), assembly, circulation, restaurant and shopping enclosures occupied by guests (Categories B1 and B2) and guest bedrooms (Category Ciii). All of these scenarios therefore need to be considered.

5.2 Major behavioural modifiers in each scenario category

5.2.1 *Levels*

Within each category, occupant behavioural characteristics, particularly alarm time and pre-movement time distributions, are further dependent upon a range of variables of which three are considered important as follows:

— the quality of the alarm system (classified into levels A1 to A3: see **5.2.2**);

— the complexity of the building (classified into levels B1 to B3: see **5.2.3**);

— and in particular, on the quality of the fire safety management (classified into levels M1 to M3: see **5.2.4**).

5.2.2 *Effect of alarm system on pre-movement*

The effect of the alarm system on pre-movement is as follows:

— *Level A1 alarm system*: automatic detection throughout the building, activating an immediate general alarm to occupants of all affected parts of the building.

— *Level A2 (two stage) alarm system*: automatic detection throughout the building providing a pre-alarm to management or security, with a manually activated general warning system sounding throughout affected occupied areas and a general alarm after a fixed delay if the pre-alarm is not cancelled.

— *Level A3 alarm system*: local automatic detection and alarm only near the location of the fire or no automatic detection, with a manually activated general warning system sounding throughout all affected occupied areas.

See also Annex A.

5.2.3 *Effect of building complexity on evacuation time to a protected escape route*

Building complexity affects pre-movement time and time required for wayfinding (searching for a suitable escape route) as follows:

— *Building Level B1* (e.g. simple supermarket) represents a simple rectangular single storey building, with one or few enclosures and a simple layout with good visual access, prescriptively designed with short travel distances, and a good level of exit provision with exits leading directly to the outside of the building;

— *Building Level B2* (e.g. simple multi-storey office block) represents a simple multi-enclosure (usually multi-storey) building, with most features prescriptively designed and simple internal layouts;

— *Building Level B3* represents a large complex building. This includes large building complexes with integration of a number of existing buildings on the same site, common with old hotel or department stores, also large modern complexes such as leisure centres, shopping centres and airports. Important features are that internal layout and enclosures involve often large and complex spaces so that occupants may be presented with wayfinding difficulties during an evacuation and the management of an evacuation therefore presents particular challenges.

5.2.4 ***Classification of fire safety management characteristics and effects on evacuation time***

In many situations, the time taken to begin the travel phase of an evacuation (i.e. the pre-movement time), and the subsequent conduct of the travel phase, has been found to very dependent upon the implementation of the fire safety management strategy. This depends upon elements such as staff training and emergency management practice, but is also dependent upon the quality of the tools at the disposal of management to carry out an efficient and timely evacuation. The most important of these tools are the alarm system and certain building features such as those influencing building complexity. In order to assess the influence of fire safety management on evacuation time, a classification system of three levels of fire safety management has been developed. This can be linked with the classification of the alarm system and the classification of the building complexity:

— *Management Level M1*: the normal occupants (staff or residents) should be trained to a high level of fire safety management with good fire prevention and maintenance practice, floor wardens, a well-developed emergency plan and regular drills. For "awake and unfamiliar" there should be a high ratio of trained staff to visitors. The system and procedures are subject to independent certification, including a regular audit with monitored evacuations for which the performance must match the assumed design performance. Security videotapes from any incidents or unwanted alarms are made available for audit under the certification scheme. This level would usually also imply a well designed building with obvious and easy to use escape routes (to level B1 or at least B2), with automatic detection and alarm systems to a high level of provision (level A1). If used by the public, a voice alarm system should be provided.

— *Management Level M2*: similar to level 1, but have a lower staff ratio and floor wardens may not always be present. There may be no independent audit. Building features may be level B2 or B3 and alarm level A2. The design escape and evacuation times will be more conservative than for a Level M1 system.

— *Management Level M3*: representing standard facilities with basic minimum fire safety management. There is no independent audit. The building may be Level B3 and alarm system A3. This is not suitable for a fire-engineered design unless other measures are taken to ensure a safety, such as restrictions on fire performance of contents, high levels of passive protection and/or active systems.

Further guidance on fire safety management is provided in BS 5588-12.

5.3 Estimation of pre-movement times based on design behavioural scenario

While detection and alarm times may be represented by single numbers, a difficulty with respect to pre-movement and travel times is that each building occupant has their own individual times [2, 6, 8, 13]. It is therefore necessary to consider the pre-movement and travel time distributions of groups of occupants, firstly within individual occupied enclosures and then throughout the building and escape routes. A further complication is that within each occupied enclosure, there are interactions between the distributions of pre-movement and travel times for occupant groups, so that the terms cannot be considered directly additive.

Pre-movement time distributions depend primarily upon the design behavioural scenario category and the fire safety management level, with some effect of building complexity. Computer simulations of building evacuations may consider the evacuation time and travel time for each individual occupant. However, it is possible to make an adequate estimation of evacuation times for most situations by considering two main criteria, the pre-movement times of the first few occupants in an enclosure to move (pre-movement time of the 1st percentile of occupants) and the pre-movement times of the last few occupants to move (99th percentile of occupants). Data on pre-movement time distributions for different behavioural scenarios are currently extremely limited, but some measured distributions exist [8, 16 to 27]. Based upon the limited data available, suggested default values for pre-movement time 1st and 99th percentiles for different design behavioural scenarios are presented in Annex C. The overall findings from the data are that both pre-movement times for the first and last few occupants to move can be very short (a few minutes or less) and predictable when occupants are awake and fire safety management is of a high standard, and much longer and less predictable when fire safety management and warning system are a lower standard, and in any building containing occupants who may be sleeping.

5.4 Estimation of travel times based on design behavioural scenario

Travel time to a protected escape route for a single enclosure depends upon two main aspects:

a) the distance of an occupant from the exit of choice (or the average travel distance to the exits for a group of occupants) and their walking speed;

b) the maximum occupant flow capacity of the exits used by occupants.

The distance each occupant needs to travel to a protected exit (and the average distance for a group of occupants) depends upon the position of the occupant(s) within the enclosure, the size and shape of the enclosure, the distribution of available exits and the exit choice behaviour of the occupants.

When calculating travel distances it is usual to discount the largest exit (assume that this might be blocked by a fire) (BS 5588-0, [1, 7]), and to calculate evacuation times assuming the remainder of exits are available. Travel distances should reflect the effect of the internal layout of a building rather than direct distance for an empty building shell.

Guidance on horizontal and vertical travel speeds, the effects of occupant density is provided in Annex D. These can be influenced by smoke. Guidance on effects of smoke density on travel speed is also provided in Annex G.

In practice, when groups of occupants evacuate an enclosure, the occupant density increases rapidly near the exits, so that queues form and the subsequent evacuation time depends upon the maximum flow capacity of the exits. Guidance on queue formation and exit flow capacity is provided in Annex G and Annex H.

5.5 Interactions between pre-movement time, walking time and exit flow time for evacuation time calculations

Since pre-movement time for a group of occupants in an enclosure follows a distribution, there is a considerable degree of interaction between pre-movement times, walking times and exit flow times. For a detailed analysis of evacuation time it is necessary to consider the location of each individual occupant, their individual pre-movement and walking times, the effects of occupant density on walking times and the flow times through the chosen exits. It is possible to carry out such analyses using computer evacuation simulation methods such as GridFlow [8], Simulex [26], Crisp [27] or Exodus [28].

In practice, it is possible to reduce such complex interactions to simple calculations without incurring a significant error. This can be achieved for any building enclosure by considering two simple cases [12, 13]:

a) a case where the enclosure is sparsely populated with a population density of less than one third of the design population;

b) a case where the enclosure contains the maximum design population.

For both cases, the largest exit should be discounted.

For the first case the evacuation time depends upon the pre-movement time of the last few occupants to decide to leave and the time required for them to travel to the exits and walk through. Since the occupant density is low the walking speed to the exits is essentially unimpeded and there is no queuing at the exits. Evacuation time is then given by equation (3):

$$\Delta t_{\text{evac}} = \Delta t_{\text{pre(99th percentile)}} + \Delta t_{\text{trav (walking)}} \quad (3)$$

where:

$\Delta t_{\text{pre(99th percentile)}}$	is the time from alarm to movement of last few occupants (from Table C.1).
$\Delta t_{\text{trav (walking)}}$	is the walking time (the unimpeded walking speed multiplied by average travel distance to exits. (A conservative estimate could use the maximum direct travel distance for the enclosure).

For the second case the evacuation time depends upon the pre-movement and walking time of the first few occupants plus the flow time of the exits, which is given by equation (4):

$$\Delta t_{\text{evac}} = \Delta t_{\text{pre(1st percentile)}} + \Delta t_{\text{trav (walking)}} + \Delta t_{\text{trav (flow)}} \tag{4}$$

where:

$\Delta t_{\text{trav (flow)}}$ is the time of total occupant population to flow though available exits.

The longer case should be used for design purposes and, in most scenarios, the second case will represent the longest required escape times.

A worked example from a computer simulation of and evacuation case showing the interactions between pre-movement times, walking times and exit flow time and their influence on evacuation time is shown in Annex I.

5.6 Calculation of escape and evacuation times for single enclosures and for multi-storey or multi-enclosure buildings

A series of generic worked examples of the application of the method for calculating escape (RSET) and evacuation times for single enclosures involving different design behavioural scenario cases is presented in Annex H.

The escape and evacuation time calculation methods described apply to any individual occupied enclosure within a building, giving the time required to evacuate the occupants into a protected escape route. When an evacuation involves simultaneous evacuation of more than one enclosure into an escape route such as a corridor or stair, then the time to evacuate depends upon the flow capacity of the escape route and the ways in which the flows from different enclosures merge. Calculation of times to clear individual enclosures cannot be carried out simply using hand calculations and is best done using computer simulation models. The flow rate of occupants from individual enclosures depends upon the nature of the merging flows at the landings of the escape stairs with occupants from other enclosures and on the flow capacity of the stairs.

Consider, for example, a situation where two floors are evacuated simultaneously and the flow capacity of a stair is the same as the flow capacity of the enclosure exits leading to it. If the flow from the upper floor merges equally with the flow from the floor below, the flow rate from each floor will be half the maximum flow rate from each storey exit. In some crowded situations, the flow of occupants in a stairwell from the upper floor may dominate, so that to some extent occupants from the lower floor cannot evacuate until those from the upper floor have gone. This is the basis of the method used to calculate evacuation times for multi-storey buildings described in Nelson and Mowrer's chapter in the SFPE Handbook [10]. In other building configurations, various degrees of merging flows are likely to occur. In some cases, deference behaviour may occur, whereby occupants on descending the stairs will give preference to occupants entering the stair and the storey exits. In such situations the lower floors of the building may clear first, so that those on the upper floors may not be delayed [11].

Another consideration with regard to structural design requirements is the time required for total evacuation of a multi-storey building. Once occupants have begun to evacuate, this depends upon the flow capacity of the available stairs and the population using them. For the prescriptive guidance in ADB [1] it is recommended that, when stairs are protected by lobbies, it can be assumed that all stairs will always be available for escape in case of fire, although an exit from the fire floor should be considered unavailable. Where lobbies are absent, it should be assumed that one stair will be unavailable. Consideration should also be given to the extent that the building population will make use of different stairs to escape.

The time required for a given population to evacuate a building using a specific stair (and hence for total evacuation of a building using all available stairs) can be calculated using computer simulations. Simple calculations can also be used to provide an accurate estimate of the travel component for total evacuation of a multi-storey building.

Pauls in [11] developed equation (5) from 58 experimental high rise building evacuations by stairs. The predictive curve has a net error in predicting total simultaneous evacuation travel times in buildings of 8 to 15 stories of 0.2 %.

$$T = 0.68 + 0.081p^{0.73} \quad (5)$$

where:

T is the minimum time (minutes) to complete an uncontrolled total evacuation by stairs;

p is the actual evacuation population per metre of effective stair width (actual width minus 0.3 m).

6 Occupant condition

6.1 Effects fire effluent and heat on ASET and RSET

Exposure of building occupants to fire effluent or heat affects both ASET and RSET. These depend on:

a) the time-concentration (or intensity) curves for the major toxic products, optically dense smoke and heat in the fire at the breathing zone of the occupants, which in turn depend upon:

1) the fire growth curve in terms of the mass loss rate of the fuel (kg/s) and the volume into which it is dispersed (kg/m^3) with time;

2) the yield of toxic products, smoke and heat in the fire (for example kg CO per kg of material burned).

Guidance on calculation methods for these terms is given in PD 7974-0 to PD 7974-3.

b) The toxic or physiological potency of the heat and effluent (the exposure concentration (kg/m^3), or exposure dose ($kg \cdot m^{-3} \cdot min$ or $ppm \cdot min$) required to cause toxic effects (and the equivalent effects of heat and smoke obscuration).

This term requires consideration of three aspects:

1) exposure concentrations or doses likely to impair or reduce the efficiency of egress due to psychological and/or physiological effects;

2) exposure concentrations or doses likely to produce incapacitation or prevent egress due to psychological and/or physiological effects;

3) lethal exposure concentrations or doses.

Guidance on calculation methods for this term is presented here and in BS 7899-2.

The endpoint of an ASET calculation is the time when conditions in each building enclosure are considered untenable. Untenable conditions occur when it is predicted that an occupant inside or entering an enclosure is likely to be unable to save themselves (is effectively incapacitated) due to the effects of exposure to smoke, heat or toxic effluent.

The psychological and physiological effects of exposure to toxic smoke and heat in fires combine to cause varying effects on escape capability, which can lead to physical incapacitation and permanent injury or death.

Behaviour modifying or incapacitating effects include:

a) effects of seeing smoke or flames including:

1) fear of approaching smoke or heat-logged areas or escape routes;

2) fear of fire or smoke in an occupied compartment. This may act as a stimulus to escape or a barrier to escape, depending upon the location and intensity of the fire or smoke;

3) attraction towards fire in an occupied compartment (friendly fire syndrome) to observe or tackle fire;

b) impaired vision resulting from the optical opacity of smoke and from the painful effects of irritant smoke products and heat on the eyes;

c) respiratory tract pain and breathing difficulties or even respiratory tract injury resulting from the inhalation of irritant smoke which can be very hot. In extreme cases, this can lead to collapse within a few minutes from asphyxia due to laryngeal spasm and/or broncho-constriction (particularly in asthmatics and other sensitive subjects). Lung inflammation can also occur, usually after some hours, which can also lead to varying degrees of respiratory distress;

d) asphyxiation from the inhalation of toxic gases resulting in confusion and loss of consciousness (particularly in sensitive subjects such as the elderly and those with heart disease);

e) Pain to exposed skin and the upper respiratory tract followed by burns, or hyperthermia, due to the effects of heat, preventing escape and leading to collapse.

All of these effects can impair escape or lead to permanent injury, and all except a) and b) can be fatal if the degree of exposure is sufficient.

With regard to hazard assessment and tenability criteria, the major considerations with respect to means of escape and life safety are as follows:

a) the psychological effects of seeing fire effluents on escape behaviour in the absence of direct exposure;

b) the psychological and physiological effects of exposure to heat and toxic smoke on escape behaviour and ability;

c) the point where exposure results in incapacitation;

d) the point where exposure results in death.

In a design context, the important considerations with respect to psychological and physiological considerations are to set reasonable tenability limits for occupants to remain in a place of relative safety or to use a particular escape route, and to determine the likely effects of any exposure sustained on escape capability and subsequent health.

6.2 Simple criteria for tenability based upon zero exposure

Where a design fire calculation is based upon a descending upper layer of hot smoke filling an enclosure or escape route, engineering tenability criteria are often based upon a minimum clear layer height of 2.5 m above the floor and a maximum upper layer temperature of 200 °C. Occupants are considered to be willing and able to escape in clear air under such a layer and the downwards heat radiation is considered tolerable.

6.3 Tenability in relation to willingness to enter or ability to move through smoke

In situations where smoke is mixed down to near floor level, some building occupants might move through dense smoke in some situations, but in other situations people might be unwilling to enter smoke logged escape routes, turn back or be unable to find an exit. Where heat is not an issue, the immediate effects of smoke depends upon the visibility distance, and the sensory irritancy of the smoke if people are exposed directly.

In a number of studies of fires in buildings, a proportion of people (approximately 30 %) were found to turn back rather than continue through smoke-logged areas [29 to 31]. The average density at which people turned back was at a “visibility” distance of three metres. The optical density ($D \cdot m^{-1}$) is 0.33, extinction coefficient 0.76) and women were more likely to turn back than men. A difficulty with this kind of statistic is that, in many fires in buildings, there is a choice between passing through smoke to an exit or turning back to take refuge in a place of relative safety such as a closed room. In some situations, people have moved through very dense smoke when the fire was behind them, while in other cases people have failed to move at all.

Behaviour might also depend on whether layering permits occupants to crouch down to levels where the smoke density is lower and whether low level lighting is used to improve visibility.

Based upon considerations such as these in relation to parameters such as the size and complexity of the building, it is possible to set design limits for optical density of smoke. Guidance on suitable criteria are given in BS 7899-1 and BS 7899-2 (and in reference [32]).

As an approximate guide it might be assumed that occupants will not use an escape route if the visibility in that route is less than three metres ($D \cdot m^{-1} = 0.33$), extinction coefficient 0.76). However, if they enter an escape route contaminated to this optical density and become exposed to the smoke, then their ability to progress depends upon both the optical density and the irritancy of the smoke. Where visibility is less than 10 m, some people have been found not to use an escape route where the distance to the exit is greater than approximately 10 m.

6.4 Tenability criteria for smoke – ability to move through smoke

Ability to escape *through* smoke depends upon the effects of irritancy and visual obscuration on ability to move through building spaces and ability to locate escape routes and exits. More stringent criteria are required for large building enclosures than for domestic enclosures since occupants might need to see for greater distances to locate exits and are more likely to be unfamiliar with their surroundings.

Based upon the finding that people move as if in darkness at a visibility of five metres ($D \cdot m^{-1} = 0.2$) in irritant smoke, and that smoke from most fires contains a variety of irritant chemical species, it is proposed that a design tenability limit of five metres visibility should be used for small or domestic enclosures and 10 m visibility ($D \cdot m^{-1} = 0.08$) in large enclosures. In practice, the irritancy of smoke depends upon the composition of the burning fuel and the decomposition conditions in the fire. These issues are discussed in detail in BS 7899-2 and in Purser [32].

6.5 Effects of smoke on walking speed

Exposure to smoke also affects RSET calculations because walking speed has been found to be related to smoke density and irritancy [33, 34]. Simple expressions for the relationships between unrestricted walking speed and smoke density for irritant and non-irritant smoke are shown in Annex G.

6.6 Tenability criteria for exposure to fire and heat

With regard to flames, an important criterion is the visual appearance of fire to occupants (flame area and height) and position in relation to occupant location and potential escape routes. For example, it might be considered that occupants will be likely to move away from a location where the width or height of the flames is more than 30°, or that they will be unlikely to enter an escape route containing a flaming fire.

Exposure to radiant heat may occur when occupants must pass close to a fire or under a hot effluent layer. Combined exposure to radiant and convected heat occurs when occupants are exposed directly to hot air or effluent.

A tenability limit for exposure of skin to radiant heat has been proposed as an exposure resulting in severe pain to unprotected skin [32]. This occurs above a threshold heat flux of approximately 2.5 kW/m^2. Below this level, exposure can be tolerated for several minutes and, at higher fluxes tolerance, time rapidly decreases to a few seconds. Severe pain occurs when the “exposure dose” of radiant heat is approximately $(80 \text{ to } 100\ kW/m^2)^{1.33}$ s. It is considered that an occupant would be strongly inhibited from exposing themselves to these conditions.

If an occupant was exposed to such conditions in an enclosure or escape route, then an exposure dose of $(240 \text{ to } 730\ kW/m^2)^{1.33}$ s would be sufficient to cause second degree burns, and third degree burns at $(1\,000\ kW/m^2)^{1.33}$ s. Although some occupants might be able to demonstrate some escape capability at these higher exposure doses, they are likely to suffer burn injuries above around $(200\ kW/m^2)^{1.33}$ s. Exposure of 30 % of the skin surface to $(2\,000\ kW/m^2)^{1.33}$ s is sufficient to result in death of approximately 50 % of subjects [32, 35].

For convected heat, the main considerations are skin pain and burns at temperatures above approximately 121 °C and hyperthermia at lower temperatures [32]. The body of a fire victim may be regarded as acquiring a “dose” of heat over a period of time during an exposure, but a short period of exposure to a high radiant flux or temperature is more incapacitating than a longer exposure to a lower flux or temperature.

For exposure of up to two hours to convected heat from air containing less 10 % by volume or water vapour, it is possible to calculate a Fractional Effective Dose (FED) value for the summed effects of radiant and convected heat. Their accumulated sum is then compared with a predetermined total FED value judged to represent an acceptable probability of incapacitation.

— If the total accumulated FED value is less than the predetermined target FED, the probability of safe escape for those exposed is considered to be acceptable.

— Conversely, if the accumulated total FED value is greater than the predetermined target FED, the probability of safe escape for those exposed is considered to be unacceptable.

Thermal burns to the respiratory tract from air containing less than 10 % by volume water vapour do not occur in the absence of burns to facial skin. Therefore tenability limits with regard to skin pain and burns are normally lower than for thermal burns to the respiratory tract. Thermal burns to the respiratory tract can occur upon inhalation or air above only 60 °C when saturated with water vapour, as can occur when water is used for fire extinguishment. Thermal tolerance data for unprotected skin of humans suggest a limit of about 120 °C for convected heat, above which considerable pain is quickly incurred along with the production of burns within a few minutes [32]. Depending upon the length of exposure, convective heat below this temperature may still result in incapacitation due to hyperthermia.

Expression for the calculation of tenability times for the effects of convected and radiant heat are given in BS 7899-2 equations (9) to (11) and Table 6. These have been used to produce guidance on suitable tenability limits given in Annex G.

6.7 Tenability criteria for toxic gases

Toxic gases in fires consist of a mixture of irritants and asphyxiants. Irritants affect escape efficiency and movement speed at low concentrations due to the painful and debilitating effects on the eyes and the pain and breathing difficulties resulting from effects on the nose, mouth throat and lungs. At high concentrations they can cause incapacitation. The effects depend upon the concentrations of the mixed irritants present and the potency of each irritant species.

Irritants in fire effluent consist of a range of organic compounds, including acrolein and formaldehyde, which are likely to be present in any fire effluent atmosphere at concentrations depending upon the chemical composition of the fuel and the fire decomposition conditions. Other irritant species that can be present are acid gases such as hydrogen chloride or nitrogen oxides. The presence of these irritants depends upon the appropriate chemical elements being present in the fuel (Purser SFPE) [32].

Since the concentrations of different irritants depend upon the fuel composition and the combustion conditions, and are difficult to predict for engineering calculations, it is proposed that smoke from fires involving typical building fuel loads should be assumed to be moderately irritant. Tenability limits and effects on movement speed may therefore be based on the results obtained by Jin for irritant wood smoke (see Annex G). Where particular irritant species are considered likely to be present and a more detailed analysis is required, expression for calculating tenability limits for mixed irritant atmospheres of known composition are presented in BS 7899-2.

Asphyxiant gases important with respect to incapacitation and death in fires are carbon monoxide, hydrogen cyanide, carbon dioxide and low oxygen. Asphyxiant gases have little or no immediate effect on exposed subjects, but when a sufficient exposure dose has been inhaled during the course of a fire, then confusion, rapidly followed by incapacitation, occurs due to collapse and loss of consciousness. If the subject is not rescued immediately after incapacitation occurs, death is likely within a few minutes.

For these reasons, asphyxiant gases can be considered as having no significant effect on evacuation behaviour or movement speed (RSET), but are a major determinant of the ASET endpoint – the time when incapacitation is predicted.

The basic principle for assessing the asphyxiant component of toxic hazard involves the determination of the exposure dose of each asphyxiant gas, i.e. the integrated area under the concentration-time curve [32, BS 7899-2]. Fractional Effective Doses (FEDs) are determined for each asphyxiant at each discrete increment of time. Their accumulated sum is then compared with a predetermined total FED value judged to represent an acceptable incidence of incapacitation (e.g. 0.3 FED).

If the total accumulated FED value is less than the predetermined maximum FED value (e.g. 0.3), the incidence of safe escape for those exposed (i.e. the probability that all occupants will be able to escape safely) is considered to be acceptable. Conversely, if the accumulated total FED value is greater than the predetermined target FED, the incidence of safe escape for those exposed is considered to be unacceptable.

The initial effects of asphyxiant gases at relatively low FED values are on exercise capability. For most people this would mean that they would be capable of less exertion than normal, but be able to perform normally at low levels of exertion (such as walking). For occupants with heart conditions, there could be a serious problem, such as angina pain at low levels of activity. At higher FED values, intoxication and collapse may occur in any occupants.

Methods and associated guidance for the calculation of FEDs for asphyxiant gases are given in BS 7899-2, **5.5**.

There is a considerable range of sensitivities to asphyxiants within the population. It is considered that effects on approximately 90 % of the population will be minimal at up to and including 0.3 FED. In order to protect vulnerable sub-populations, particularly in situations where vulnerable subjects are likely to be present (such as health care or residential care premises) then a tenability limit of 0.1 FED should be sufficient to enable safe escape of essentially all occupants.

Simplified guidance in the form of suggested limiting values for major asphyxiant and irritant gases is given in Annex G.

7 Summary

The time required for escape (RSET) depends upon a series processes consisting of:

a) time from ignition to detection;

b) time from detection to the provision of a general evacuation warning to occupants;

c) evacuation time, which has two major phases:

1) pre-movement time (the time between that when occupants become aware of the emergency and that when they begin to move towards the exits), which consists of the time required to recognize the emergency and then carry out a range of activities before travelling to exits;

2) travel time (the time required for occupants to travel to a place of safety).

A range of human behaviours can be involved to a greater or lesser extent in all these phases of escape time. In terms of detection, warning and pre-movement recognition and response times, most research has been essentially qualitative. There is currently no basis for the quantification of the wide range of behavioural phenomena and the interactions between them, other than by simple observation of behaviour during real or simulated emergencies. However, the overall times required for these behaviours often comprise the greatest part of the time required for escape.

Travel to and through exits and escape routes involves more physically based processes, which have been relatively well quantified, and are amenable to relatively simple calculation methods for design purposes. However, travel times can be affected by behaviours such as wayfinding and exit choice. Also, certain physical phenomena such as merging flows, have not been adequately solved.

The occupant behaviours involved in escape depend upon a range of factors including:

— building characteristics (particularly occupancy type, method for detection and the provision of warnings, fire safety management systems and building layout);

— occupant characteristics (particularly occupant numbers, alertness (waking or sleeping); and familiarity with the building and its systems;

— fire simulation dynamics.

A method for the quantification of escape and evacuation times is proposed, whereby a set of key qualitative features of occupants behaviour are used to specify a small number of basic "design behavioural scenarios" analogous to the design fire scenarios used in fire safety engineering design. Quantitative data for phases of behaviour, particularly warning and pre-movement times, have been obtained by observations of behaviour during fire incidents and monitored evacuations for the main types of design behavioural scenarios. These are then combined with travel time calculations to provide a simple but robust method for the estimation of escape and evacuation times for design purposes.

The main design behavioural scenarios are defined in terms of occupant characteristics as follows:

— Scenario 1: Occupants awake and familiar with the building and its systems;

— Scenario 2: Occupants awake and unfamiliar with the building and its systems;

— Scenario 3. Occupants sleeping and familiar with the building and its systems;

— Scenario 4: Occupants sleeping and unfamiliar with the building and its systems.

The list of scenarios contains a number of subdivisions. It is also possible to extend the list to include special cases such as health care occupancies.

For all scenarios, a key feature identified as having a very significant effect on escape and evacuation times is the fire safety management strategy.

The most comprehensive method for calculating escape and evacuation times involves the use of computational models in which the physical characteristics of building spaces and escape routes are represented. The building is populated with occupants with a range of behavioural characteristics and the evacuation time is calculated for each individual occupant. Depending upon the sophistication of the model the behaviour of each occupant, their position and condition can be calculated as they move through the building spaces. From this can be obtained an escape and evacuation time profile for the building. By varying the parameters, a profile of evacuation times can be estimated for a range of scenarios.

A simple but robust method is proposed for estimating escape and evacuation times based upon a number of key phases. Each phase is represented by a single number which when summed for all phases provides an estimate of escape and/or evacuation time. The phases considered are as follows:

a) time to detection;

b) time to the provision of a general warning;

c) pre-movement time. For a group of occupants, this can be considered as having two phases:

1) the pre-movement time of the first few occupants to move;

2) the pre-movement time distribution for all occupants from when the first few begin to move to that when the last few occupants begin to move (pre-movement time of the 99th percentile);

d) travel time, which consists of three main components;

1) walking time: the average time required for occupants to move from their starting location to a protected escape route (or to the outside of the building);

2) time to queue formation at the exits;

3) exit flow times.

These phases are then used for calculation of two types of evacuation cases:

— the first type involves situations where occupant densities are high and evacuation time is dominated by exit flow limitations;

— the second type involves situations where occupant numbers and densities are low, with occupants often widely dispersed though a number of enclosures. In these case evacuation time is dominated by pre-movement time distributions and travel distances.

The method involves a simple calculation for each class for any design situation. Evacuation times are then taken as whichever calculation provides the longest time.

For both types it is necessary to obtain estimates of detection time, warning time and the pre-movement time of the first few occupants. The next stages depend upon the class.

a) Calculation or flow-limited evacuation:

For a flow-limited evacuation, the next step is to derive an estimate of time to queue formation, which depends upon the early stages of the pre-movement and walking time distributions. Default values are presented.

The next step is a simple calculation of the flow time for the total occupant population (time required to flow through available exits).

Evacuation time is then given by summing the pre-movement time of the first occupants, the time to queue and the flow time.

This method for flow-limited evacuation time calculation cannot be used for complex situations involving merging flows or multiple "pinch points" within a building containing a large number of enclosures and several escape routes. It can be used to estimate the total evacuation time for such complex buildings.

b) Calculation of pre-movement and travel limited evacuation:

For this case the next step is obtain an estimate of the width of the pre-movement time distribution (the time from the pre-movement of the first few occupants to move to that when the last few occupants move).

The next step is to obtain an estimate of average walking time. This depends upon the average travel distance and walking speeds of occupants. For a prescriptively designed building a default value can be assumed of 15 s (to a protected escape route).

Evacuation time is then given by summing the pre-movement time of the first occupant, the pre-movement distribution time (to obtain the total pre-movement time of the last few occupants to move) and the average walking time.

The psychological and physiological effects of seeing or being exposed to fire effluent and heat can affect evacuation times by altering occupant behaviour and travel speeds. Guidance is provided on how to evaluate these influences on RSET. Fire effluent and heat are also responsible for determining tenability limits and hence ASET. The prediction of ASET requires estimation of the time-concentration (or intensity) curves for the major toxic products, smoke and heat in a fire (which is covered by PD 7974-0 to PD 7974-3 in this series) and on the derivation and estimation of ASET endpoints for these hazards (which is covered in this PD and by BS 7899-2).

Annex A (normative) Default alarm times

A.1 Effect of alarm system on alarm time

A.1.1 *Level A1 alarm system*

Automatic detection throughout the building, activating an immediate general alarm to occupants of all affected parts of the building.

Δt_a is effectively zero.

A.1.2 *Level A2 (two stage) alarm system*

Automatic detection throughout the building providing a pre-alarm to management or security, with a manually activated general warning system sounding throughout affected occupied areas and a general alarm after a fixed delay if the pre-alarm is not cancelled.

Δt_a is taken as time out delay (usually two or five minutes).

If a voice alarm system is used for either an A1 or A2 system, the time taken for the message to be spoken twice should be added to the alarm time.

A.1.3 *Level A3 alarm system*

Local automatic detection and alarm only near the location of the fire or no automatic detection, with a manually activated general warning system sounding throughout all affected occupied areas.

Δt_a is likely to be long and unpredictable.

A.2 Effect of evacuation strategy on alarm time

A further important variable affecting alarm time, particularly for large buildings consisting of more than one fire compartment, is the warning management strategy.

For smaller or uncompartmented buildings, a simultaneous evacuation alarm should be provided to all occupants irrespective of their location within the building with respect to the point of fire origin.

For buildings consisting of a number of compartments (usually multi-storey buildings), a phased evacuation strategy may be used. In these cases it is usual to evacuate the fire floor and the floor above (or in some cases the two floors above and the floor below the fire) first in case of fire. Occupants on other floors are instructed to stand by for further instructions, and evacuated only if and when considered necessary as a result of further fire spread. In such situations, the time from ignition to evacuation alarm may be up to an hour or more. For domestic apartment buildings a defend-in-place strategy is used, so that only immediately affected parts of the building are evacuated. For such buildings, the time required for protection is long and indefinite, so that the fire compartment needs to withstand burnout of the fuel load.

Annex B (normative) Pre-movement behaviours and determinants

B.1 The two components of pre-movement time

The two components of pre-movement time (recognition and response) have the characteristics given in **B.2** and **B.3**.

B.2 Recognition

This consists of a period after an alarm of cue is evident but before occupants of a building begin to respond.

During the recognition period, occupants continue with the activities engaged in before the alarm of cue, such as working, shopping or sitting. The length of the recognition period can be extremely variable, depending upon factors such as the types of building, the nature of the occupants and the building alarm and management system [2, 6, 36, 37].

In single enclosure buildings that are well managed, the recognition period is likely to be short. In multi-enclosure buildings where occupants might be remote from the fire (especially those with a sleeping risk such as hotels, residential homes and hostels), the recognition times can vary considerably [2, 6, 36, 37]. The recognition time ends when the occupants have accepted that there is a need to respond.

During the recognition process, each occupant is engaged in their normal activities, but is receiving and processing cues about the developing emergency situation. For each individual, this process ends when they decide to take some action in response to the emergency cues received.

The evaluation of location therefore starts with the distribution of occupants throughout the building at the start of the recognition process. The first evaluation is to estimate the time that the recognition process ends for each occupant. The recognition time will vary between different individual occupants in any one enclosure within the building, and for groups of occupants in different enclosures. For simple evaluations, a single figure such as the average or slowest recognition time might be taken for each group of occupants. For more complex evaluations, recognition times may be assigned to each individual occupant.

B.3 Response

This consists of a period after occupants recognize the alarms or cues, and begin to respond to them, but before they begin the travel phase of evacuation (where necessary). As with the recognition period, this may range from a few seconds to many minutes, depending upon the circumstances [2,6,36,37].

During the response process, occupants cease their normal activities and engage in a variety of activities related to the developing emergency. At the end of the response process, each occupant will have decided either to remain in the same enclosure or to begin evacuation. For simple evaluations, a single figure such as the average or slowest response time might be taken for each group of occupants. For more complex evaluations, response times may be assigned to each individual occupant.

Examples of activities undertaken during the response time include:

— investigative behaviour, including action to determine the source, reality or importance of a fire alarm or cue;

— stopping machinery/production processes or securing money and other risks;

— seeking and gathering together children and other family members;

— fighting the fire;

— the time involved in determining the appropriate exit route (i.e. "wayfinding");

— the time involved in other activities not fully contributing to effective evacuation where necessary (e.g. acting on incorrect or misleading information); and

— alerting others.

Pre-movement times can vary considerably for different individuals or groups of individuals both within an enclosure and in different enclosures within the same building. The distribution of pre-movement times depends upon a range of factors including the occupants proximity to and knowledge of the fire as afforded by the architecture of the setting, the warning system and management systems.

For example, in an open plan setting such as a theatre auditorium, the distribution of pre-movement times is likely to be narrow (everyone starting to move at about the same time). In a multi-enclosure setting, such as a hotel, there is likely to be a wide distribution of pre-movement times. Those in the enclosure of fire origin might complete the pre-movement process before those in other enclosures even become aware of the fire.

The provision of reliable data on the pre-movement times to be expected in various situations, and their incorporation into egress behaviour models, is an important requirement for the assessment of escape time, and therefore for fire safety engineering design. Although databases of pre-movement times currently available are somewhat limited, they do provide a basis for design calculations appropriate to a range of occupancy types [8,36,37]. Guidance on default values is given in Annex C.

A range of factors can be taken into account in order to estimate pre-movement time. The principal ones are as follows:

a) building parameters:

1) occupancy use:

i) floor plans, layout and dimensions;

ii) contents;

iii) warning system;

iv) fire safety management emergency procedures;

2) occupant status:
i) occupant numbers and location;
ii) occupant characteristics – age and health status;
iii) occupant activities;
iv) occupant condition;
3) fire simulation dynamics:

b) building condition and fire location:
1) visibility of smoke or fire;
2) exposure to fire effluent or heat;
3) fire alarm status and type;

c) other warnings or cues (e.g. from management or other occupants).

Annex C (normative) Default pre-movement time distribution data and derivations

C.1 General

Pre-movement distributions consist of two phases:

— the time from alarm to the movement of the first few occupants to begin their travel phase; and

— the subsequent distribution of times for the population of occupants to begin their travel phase.

Once the first few occupants begin to move, pre-movement distributions tend to follow approximately log-normal distributions, with a rapid increase in the number of occupants starting to move soon after the beginning of the distribution and a long tail until the last few occupants move as illustrated in Figure C.1. The quality of warnings and management affects both the time the first occupants begin to move and the width of the distribution.

Figure C.2 illustrates pre-movement time distributions measured in a number of unannounced monitored evacuations. These include a restaurant in a shopping mall, two outpatient clinics in a hospital and three retail stores.

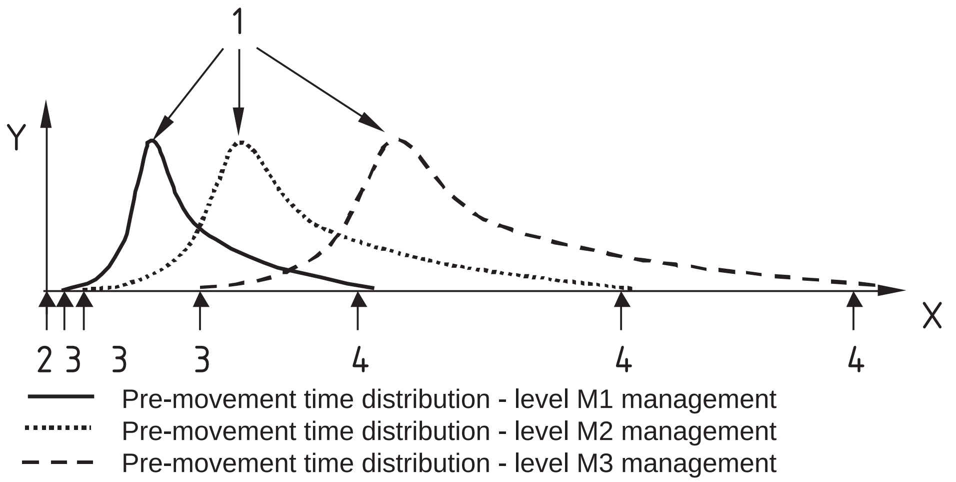
The curves all show a similar shape, with short periods before travel begins and narrow subsequent distributions, all representing well-managed cases. The printed data are from a security video of poorly managed fire incident [8]. After four minutes, conditions became severely smoke logged, forcing occupants to evacuate.

It is essential that realistic pre-movement time data are used in evacuation time calculations.

The most important considerations are the pre-movement times of the first few occupants in each affected enclosure (for example the 1st percentile) and the pre-movement time of the last few occupants (for example the 99th percentile). Pre-movement time data have been reported from video records of occupant behaviour in a small number of fire incidents and a significant number of unannounced evacuations in a range of occupancies [8, 14 to 25]. It is also possible to estimate maximum pre-movement times from total building evacuation time data [8].

The results of these studies have shown that pre-movement times are very dependent upon occupant and building factors, expressed in terms of the design behavioural scenario, and for any particular scenario upon the fire safety management. The type of warning system and the building complexity also have some influence [2, 8].

The main influences on pre-movement times for the main design behavioural scenarios are described in the following sections. Suggested default pre-movement times for the scenarios summarized in Table 1 are given in Table C.1 in terms of time for the first few occupants to move (1st percentile pre-movement time) and for the last few occupants to move at the tail of the pre-movement time distribution for an occupant population (99th percentile pre-movement time). For each scenario category, default pre-movement times are proposed for management levels M1 to M3. The levels of the other modifiers affecting pre-movement times (alarm level A1 to A3 and building complexity B1 to B3) associated with particular scenario types are also shown. Thus, for example, under Category A (awake and familiar), a level M1 management would require A1 or A2 alarm system and B1 or B2 building complexity. If the level of building complexity was B3, an extra 0.5 min should be added to the pre-movement time. If the alarm system was level A3, the management level could only be M3. Level classifications are described in **5.2**.



Key

X Time

Y Persons/s

1 $\Delta t_{\text{pre (occupant distribution)}}$

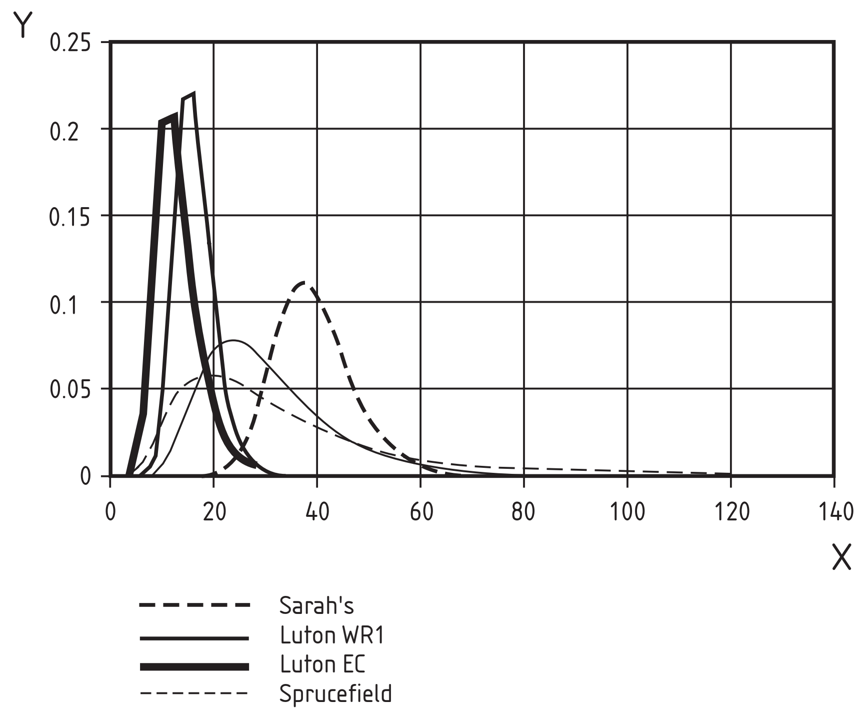
2 Alarm

3 $\Delta t_{\text{pre (first occupants)}}$

4 99th percentile

NOTE Pre-movement of first occupants to move and subsequent pre-movement time distribution is lengthened by progressively lower levels of fire safety management.

Figure C.1 — Representation of pre-movement time distributions and effects of different levels of fire safety management



Key

X Time/s

Y Frequency

Figure C.2 — Some examples of measured pre-movement time distributions

Table C.1 — Suggested pre-times for different design behavioural scenario categories

Scenario category and modifier	First occupants $\Delta t_{pre\ (1st\ percentile)}$	Occupant distribution $\Delta t_{pre\ (99th\ percentile)}$[a]
A: awake and familiar		
M1 B1 – B2 A1 – A2	0.5	1.0
M2 B1 – B2 A1 – A2	1	2
M3 B1 – B2 A1 – A3	*>15*	*>15*
For B3, add 0.5 for wayfinding		
M1 would normally require voice alarm/PA if unfamiliar visitors likely to be present		
B: awake and unfamiliar		
M1 B1 A1 – A2	0.5	2
M2 B1 A1 – A2	1.0	3
M3 B1 A1 – A3	*>15*	*>15*
For B2 add 0.5 for wayfinding		
For B3 add 1.0 for wayfinding		
M1 would normally require voice alarm/PA		
Ci: sleeping and familiar		
(e.g. dwellings – individual occupancy)		
M2 B1 A1	*5*	*5*
M3 B1 A3	*10*	*>20*
For other units in a block assume one hour		
Cii: managed occupancy		
(e.g. serviced apartments, hall of residence)		
M1 B2 A1 – A2	*10*	*20*
M2 B2 A1 – A2	*15*	*25*
M3 B2 A1 – A3	*>20*	*>20*
Ciii sleeping and unfamiliar		
(e.g. hotel, boarding house)		
M1 B2 A1 – A2	*15*	*15*
M2 B2 A1 – A2	*20*	*20*
M3 B2 A1 – A3	*>20*	*>20*
For B3, add 1.0 for wayfinding		
M1 would normally require voice alarm/PA		
D: medical care		
Awake and unfamiliar (e.g. day centre, clinic, surgery, dentist)		
M1 B1 A1 – A2	0.5	2
M2 B1 A1 – A2	1.0	3
M3 B1 A1 – A3	*>15*	*>15*
For B2 add 0.5 for wayfinding		
For B3 add 1.0 for wayfinding		
M1 would normally require voice alarm/PA		
Sleeping and unfamiliar (e.g. hospital ward, nursing home, old peoples' home)		
M1 B2 A1 – A2	5[b]	10[b]
M2 B2 A1 – A2	10[b]	20[b]
M3 B2 A1 – A3	*>10*[b]	*>20*[b]
For B3 add 1.0 for wayfinding		
M1 would normally require voice alarm/PA		
E: transportation (e.g. railway, bus station or airport)		
Awake and unfamiliar		
M1 B3 A1 – A2	1.5	4
M2 B3 A1 – A2	2.0	5
M3 B3 A1 – A3	*>15*	*>15*
M1 and M2 would normally require voice alarm/PA		

NOTE There is a lack of data on evacuation behaviour and the times required for key aspects of evacuation. Therefore the limitations of the database needs to be borne in mind when proposing or assessing designs incorporating engineered solutions in relation to human behaviour.

In particular the database needs to be improved by the provision of information such as evacuation time records, video records from real evacuation incidents (including fires) and data from monitored evacuations in a reasonably large set of each occupancy type, including sleeping accommodation. This could then provide a definitive database for design applications and the further development of predictive evacuation and behaviour models.

[a] Total pre-movement time = $\Delta t_{pre\ (1st\ percentile)} + \Delta t_{pre\ (99th\ percentile)}$. Figures with greater levels of uncertainty are italicized.
[b] These times depend upon the presence of sufficient staff to assist evacuation of handicapped occupants.

C.2 A: Awake and familiar

For situations where occupants are awake and familiar with the building, pre-movement times and pre-movement time distributions have been found to be very short when fire safety management is of a high standard and staff are well-trained [2, 8]. Pre-movement and total evacuation times have been measured in approximately 70 occasions in a range of office and laboratory buildings under different managements as part of BRE and related research programmes [2, 8, 13 to16, 21]. The data obtained from studies carried out are summarized in Table 4 of [8]. Since the pre-movement times obtained on any one occasion will vary, even within a specific building, it is not possible nor particularly useful to present detailed data here.

Based upon the overall data obtained, it has been found that for well-managed cases (Level M1), the first few occupants can be expected to move within a few seconds of a sounder or voice alarm. It is therefore proposed that a figure for the1st percentile pre-movement time of 0.5 min is realistic and relatively conservative. The additional period for the last few people to move has also been found to be very short and a default period of one minute is proposed.

For a level M2 management, occupants might not respond quite so quickly, but can be relied upon to cease operations and evacuate in response to warnings.

M3 management might apply if there is some doubt about the commitment of an organization to fire safety management and staff training.

On a small number of occasions it has been found that occupants have ignored alarms and continued their normal activities for at least several minutes until challenged.

C.3 B: Awake and unfamiliar

A number of video studies have been made of unannounced evacuations from stores and supermarkets as part of the BRE research programme [2, 8, 13 to 16] and studies carried out by the University of Ulster [17]. The BRE programme also included two theatres and several lecture theatre evacuations, as well as investigations of a number of fire incidents in stores [8, 13 to 16]. The results of these studies were that the pre-movement times of the first few occupants, and the subsequent distribution, were very short when the evacuation was well managed by trained staff. There was also some benefit from voice alarm systems over sounders [8, 17, 18].

A problem with this scenario category is that occupants are unlikely to evacuate unless encouraged by staff or instructed by a voice alarm system, and even this can be ignored in some cases.

While the short pre-movement times in Table C.1 for M1 and M2 management systems are considered to be reasonably good default values for well-managed and well-staffed situations, a number of studies have shown very long pre-movement times when occupants are unfamiliar with a building or its systems and are not managed by trained staff.

Examples include the Equinox office building study, where unfamiliar occupants took approximately 11 min to respond to a sounder [18], the clothing store fire, where shoppers and staff failed to evacuate for four to five minutes until fire and smoke made conditions untenable [8] and the Tyne and Wear Underground station studies in which occupants ignored a sounder for up to nine minutes [19]. In the Equinox and Tyne and Wear studies, better results were obtained when voice alarm messages were used, but with increasing use of such systems in recent years this has not always found to be the case.

On the basis of these studies, short 1st and 99th percentile default pre-movement times are proposed for M1 and M2 managed occupancies. It is suggested that some extra time is added for wayfinding in more complex buildings. Where efficient emergency management cannot be guaranteed, pre-movement times become much longer and more variable. An approximate default time of 15 min for the 1st percentile plus a further 15 min for the 99th percentile is suggested.

C.4 C: Sleeping

With all forms of sleeping scenarios, it is difficult to obtain short pre-movement times [8, 20, 23 to 25]. Occupants might or might not be roused by alarms and might require a considerable time to prepare themselves and decide to evacuate.

There are few detailed studies of pre-movement times in sleeping accommodation. Reports from a number of incidents in hotels or hostels have shown that occupants might require many minutes to evacuate. In at least one case where times have been reported, although the first quartile moved after three minutes, the third quartile required 131 min [20].

Due to the long periods reported and their extreme variability, very conservative default times should be used. For occupants close to the fire, within a private dwelling, it is considered that design pre-movement times could be as short as 5 min to 10 min for well-managed situations (where occupants have well-maintained smoke detectors and a family fire game plan) [22]. In practice, flaming fires can produce lethal conditions within this time period so individual response times must be shorter in many cases, but there is an annual rate of approximately 6 000 smoke exposure injuries in dwellings.

For sleeping and unfamiliar scenarios such as hotels, it is considered that occupants cannot be relied upon to evacuate efficiently without management intervention. Even for a well-managed occupancy with a well-designed warning system, it is suggested that default 1st percentile pre-movement time should be 15 min. For managed occupancies, somewhat shorter times may be appropriate if occupants are well trained.

C.5 D and E medical care, transportation

Medical day centres and clinics are considered as a form of awake and unfamiliar. Hospitals, nursing homes and old peoples' homes are considered as a form of sleeping and unfamiliar. Where occupants are disabled, pre-movement times can depend upon the availability of staff to assist evacuation. Buildings associated with transportation (railway or bus stations and airports) are considered a form of awake and unfamiliar. These are often very complex spaces so particular consideration should be given to staff training and wayfinding issues for other occupants.

Annex D (normative)
Guidance on travel speeds and flow rates

D.1 Horizontal travel speeds

Unimpeded walking speeds are typically quoted as being around 1.2 m/s. For example, Pauls in [11] quotes 1.25 m/s, based on empirical studies in office buildings. Nelson and Mowrer [10] quote 1.19 m/s – their method is derived from the work of Fruin [36], Pauls in [11], and Predtechenskii and Milinskii [37].

Ando *et al*. [38] studied travellers in railway stations, and found that unimpeded walking speed varied with age and sex. The speed/age distributions for males and females were unimodal and positively skewed, both peaking at around 20 years of age (males at about 1.6 m/s and females at about 1.3 m/s).

Thompson and Marchant [26] developed new techniques for analysing video footage of crowd movement, and derived a method for modelling the movement of individual people based on the inter-personal distance between them. (This became the basis of the SIMULEX model). From this work, Thompson and Marchant [26] suggested that the "interference threshold" is 1.6 m, such that when the separation between individuals is greater than this, their walking velocity is unaffected. They quote unimpeded walking speeds of around 1.7 m/s for males and 0.8 m/s for females (the median value being 1.4 m/s). According to this model, the velocity decreases as the interpersonal distance decreases (below 1.6 m), reaching zero when the individuals are tightly packed, such that the interpersonal distance is equal to their body-depth.

Guidance on the effects occupant density on walking speeds is presented in Nelson and Mowrer [10]. If the population density is less than 0.54 persons/m^2 of exit route, individuals move at their own pace, independent of the speed of others. Movement ceases when population density exceeds 3.8 persons/m^2. Between these limits, speed is given by equation (D.1):

$$S = k - akD \tag{D.1}$$

where:

S = speed along the line of travel;

D = density in persons/m^2;

k = 1.4 for horizontal travel;

a = 0.266.

D.2 Vertical travel speeds

Ando *et al*. [38] quoted unimpeded velocities on stairs of about 0.8 m/s for travel downwards and 0.7 m/s for travel upwards.

Fruin [36] (cited in Gwynne *et al*. [28]) presented a range of values for travel speed on stairs, according to age and sex. For travel downwards, these ranged from 1.01 m/s for males under 30 years, to 0.595 m/s for females aged over 50. For travel upwards, they ranged from 0.67 m/s for males under 30, to 0.485 m/s for females over 50. Fruin's figures are calculated from observations made on two staircases, one with 7 inch risers and 11.25 inch treads, and one with 6 inch risers and 12 inch treads. Travel speeds up and down were faster for the stairs with the smaller rise height.

Nelson and Mowrer [10] present travel speeds for four different stair designs (of rise height between Metrificate 6.5 and 7.5 inches, and tread between 10 and 13 inches). They give travel speeds ranging from 0.85 m/s to 1.05 m/s, with speed increasing as rise height decreases. There was no differentiation between upwards and downwards travel, nor were the data broken down by sex and age.

The effects of density on vertical travel speeds is given by equation (A.1) using different constants for k as shown in Table D.1.

Table D.1 — Constants for equation (A.1) (effects of density on travel speed), maximum unimpeded travel speeds (m/s) and flow rates (persons/s/m of effective width) for horizontal and stair travel

Exit route element mm		k	speed	flow
Corridor, aisle, ramp, doorway		1.40	1.19	1.3
Riser mm	**Tread** mm			
191	254	1.00	0.85	0.94
178	279	1.08	0.95	1.01
165	305	1.16	1.00	1.09
165	330	1.23	1.05	1.16

D.3 Maximum flow rates

Table D.2 shows a summary of maximum exit flow rates from the literature (reproduced from Thompson and Marchant [26]. Table D.3 shows the implicit flow rates in ADB.

Approved Document B (ADB) [1], provides guidance on meeting the requirements of the England and Wales Building Regulations with regard to fire safety, including means of escape. The third column of the table shows the implicit maximum flow rate capacity for the stated population to pass through the exits assuming the population passes through in 2.5 min.

The maximum design sustained flow capacity implicit in ADB (and in BS 5588-0) for an enclosure with a population in excess of 220 is 1.33 persons/m/s, where the width is the clear width. This contrasts with the more conservative value in Nelson and Mowrer of 1.3 persons/m/s, where 2 × 0.15 m boundary layers are subtracted from the actual width to provide the effective width. For example, a one metre wide doorway would provide a maximum design flow rate of 0.91 persons/m/s.

Pauls has suggested that the derivation of the higher flow rate limits shown in Table D.2 may not be truly representative of actual building evacuations. The more conservative Nelson and Mowrer data have therefore been used for the worked example shown here. Different flow rates are given for stair than for horizontal escape routes in Nelson and Mowrer, while no allowance for reduced flow rates on stairs is made in ADB (or in the Scotland and Ireland Guidance Documents).

Using the ADB design flow rates, the time required for occupants to flow out of a prescriptively designed enclosure containing a maximum design population is 150 s (2.5 min). For the worked example case which has a population of 900 and four available exits each 1.125 m in width, the Nelson and Mowrer [10] method gives a design flow time of 210 s (3.5 min).

Table D.2 — Summary of maximum flow rates (reproduced from Thompson and Marchant [26])

Source	Maximum design flow persons/m/s	Ultimate flow capacity persons/m/s	Comments
Check Scot and NI 5588-11 Approved Document B	1.33[a]		Standard British code for buildings
SCICON report	1.37		Data from football crowds
Guide to Safety at Sports Grounds	1.82[b]		Based on Japanese data and derived from 60 persons/0·55 m/min unit exit width calculation
Hankin and Wright	1.48	1.92	Commuters on the London Underground
Fruin	1.37	4.37	Max. flow is a peak regimented, “funnelled” flow under pressure
Daly	1.43		For underground stations
Ando *et al.*		1.7 – 1.8	Japanese commuters at railway stations
Fire and Buildings, The Aqua Group	1.5		General design text
Predtechenskii and Milinskii		1.83	“emergency conditions” for adults in mid-season dress
SFPE handbook (Nelson and Mowrer)	1.3[c]		2 × 0·15 m boundary layers deducted from width of exit
Polus *et al.*	1.25 – 1.58	1.58	Pedestrian movement on sidewalks in Israel

[a] Derived from exit capacities.
[b] Unit exit width method.
[c] Effective width method.

Table D.3 — Maximum flow capacities from ADB [17]

Maximum number of persons	Minimum width mm	Maximum flow capacity persons/s/m
50	750	0.44
110	850	0.86
220	1 050	1.40
More than 220	5 per person	1.33

Below the maximum flow capacity, flow rates depend upon occupant density and travel speeds. The formula for specific flow (number of persons evacuating past a point per metre of effective width per second) is shown in equation (D.2):

$$F_S = SD \qquad (D.2)$$

where:

F_S = specific flow;

D = density;

S = speed.

Combining equations (D.1) and (D.2) gives (D.3):

$$F_S = (1 - aD)kD \qquad (D.3)$$

where k is obtained from Table D.1.

As population density increases, specific flow increases up to a maximum density of 1.9 persons/m^2. At higher densities, the flow rate falls off to zero at 3.77 persons/m^2.

Maximum specific flow rates for stairs are shown in Table D.1.

As stated, flow rates are considered to be affected by boundary layers, which should be subtracted from the actual width of a corridor, doorway, or stair according to Table D.4.

Table D.4 — Boundary layer widths

Exit route element	Boundary layer mm
Theatre chairs, stadium benches	0
Railings, handrails[a]	89
Obstacles	100
Stairways, doors, archways	150
Corridor, ramp walls	200
Wide concourses, passageways	460

[a] Where handrails are present, use the value resulting in the lesser effective width.

Annex E (normative) Detailed information required for ASET and RSET calculations

E.1 General

In order to achieve these evaluations, detailed input information is required in four main areas (BS ISO/TR 13387-8, [7]):

— the building design and emergency life safety management strategy;

— the occupant characteristics;

— the fire simulation dynamics;

— intervention effects.

The response of occupants to a fire condition is influenced by a whole range of variables in these four categories, related to:

— the characterization of the occupants in terms of:

— their number;

— their distribution within the building at different times;

— their familiarity with the building;

— their abilities, behaviours and other attributes;

— the characterization of the building, including its use, layout and services; the provision for warnings, means of escape and emergency management strategy;

— the interaction of all these features with the developing fire scenario and provisions for emergency intervention (fire brigade and rescue facilities).

These aspects are described in more detail in the following sub-clauses. A simplified scheme is presented in Clause **5** [12], based upon those aspects having the most important effects on escape and evacuation times.

E.2 The building characteristics and fire safety management strategy

E.2.1 *Building characteristics, its management in relation to fire safety and the emergency life safety strategy*

The first major input to the life safety evaluation processes comprises details of the building characteristics, its management in relation to fire safety and the emergency life safety strategy. These comprise the basic building dimensions, internal arrangement and services relevant to fire safety, as follows:

— layout and geometry (including size, building height, ceiling height, layout, complexity, compartment, subdivision into internal spaces, interconnection of spaces; travel distances; door and stair corridor widths, normal circulation routes, opening/closing forces of fire doors; door furniture);

— escape routes (including visual access, complexity, protection (passive/active), lengths, horizontal, vertical (escape upwards or downwards), accessibility (e.g. by break-glass and key only, by crash bar), use during normal flows in building, final exits (number distribution related to characterisation data), etc.;

— building use [including general building/occupancy type (e.g. office, department store, theatre, etc.), layout and functions/uses in particular locations within the building which may impact on likely behavioural responses and escape route usage (some functions might tend to provide easy access and escape while others might not)];

— fire safety management system (including management of the building; management and maintenance of essential equipment; management of staff and occupants of the building; fire prevention management; management flexibility; training of staff and occupants, security and fire surveillance, emergency procedures);

— life safety strategy (including life safety design philosophy, evacuation strategies; passive/active fire control systems, fire detection, alarm and communication systems, facilities for fire brigade, emergency lighting, wayfinding system, fire safety management);

— application of active systems (including sprinkler/spray systems, sprinklers for life safety, gas suppression systems, smoke management or extraction and ventilation systems);

— signage and lighting (including emergency lighting);

— refuge areas (form, degrees of protection and tolerability, communication systems and connection to escape routes, staging areas, access for assisted escape or rescue);

— environmental considerations (e.g. wind and internal air pressurisation on door opening force, evacuations in wet, hot or cold conditions, dress requirements, effect of snow on exits).

E.2.2 *The occupant characteristics*

The second major input to the life safety evaluation process is the occupant characteristics. The main considerations are the likely nature and timing of occupant response to cues or alarms and likely subsequent pattern and timing of occupant movements, particularly in carrying out an evacuation if required. Also important is the likely susceptibility of the occupants to sight of or exposure to fire effluent or heat.

Occupant characteristics to be considered include:

— population numbers and density: expected numbers in each occupied space including seasonal variations;

— familiarity with the building: depends on factors such as occupancy type, frequency of visits and participation in emergency evacuations;

— distribution and activities;

— alertness: depends on factors such as activities, time of day, sleeping or awake;

— mobility: depends on factors such as age and any disabilities;

— physical and mental ability;

— social affiliation: extent to which occupants present as individuals or in groups such as family groups, groups of friends, etc.;

— role and responsibility: includes categories such as member of the public, manager, floor warden etc.;

— location: location in building relative to escape routes, etc.;

— commitment: extent of commitment to activities engaged in before the fire;

— focal point: point where occupant attention is directed, such as the stage in a theatre or a counter in a shop;

— responsiveness: extent to which occupant is likely to respond to alarms etc.;

— occupant condition: as determined by the analysis of occupant condition.

E.2.3 *The fire simulation dynamics*

E.2.3.1 *General*

The third major input to the life safety evaluation process are the fire simulation dynamics. The object of the life safety design is to protect occupants from exposure to fire effluents or heat (or physical trauma from structural failure). This is achieved by a combination of the provision of adequate means of escape and protection of occupied spaces. In order to evaluate life safety during a fire it is necessary to obtain continuous information on the extent of the fire and fire effluent and their effect on the building.

The specific factors given in **E.2.3.2** and **E.2.3.3** need to be considered.

E.2.3.2 *Fire alarms and cues available to occupants*

When the fire originates in an occupied enclosure, it is necessary to determine the visibility of the flames and smoke, so that an estimate can be made of the time when occupants would become aware of the situation, and how they would respond to it. For both occupied and unoccupied fire enclosures, it is necessary to know when an automatic alarm system would be triggered, and when information on fire spread would be available from analogue addressable systems. The main requirement is to be able to determine what information is available to building occupants throughout the fire incident.

E.2.3.3 *Fire size and extent, smoke density, toxic gas concentrations, temperature and heat flux in all building enclosures, activation of suppression and smoke control systems*

For all enclosures in the building, it is necessary to know the size of the fire, the extent to which it is contained or has spread through adjacent enclosures, any structural failures and the temperature and heat fluxes in affected enclosures. It is also necessary to know the optical density and concentrations of irritant gases in the smoke, and the concentrations of asphyxiant gases present.

For occupied enclosures this information, is required to assess the tenability of the enclosure to occupants, and the extent to which their escape out of each enclosure is affected. For unoccupied enclosures, the information is required particularly if they form part of potential escape routes or refuges. Where the fire effluent is in well-defined layers, the height of the hot layer and downward radiant flux needs to be reported.

E.3 Intervention effects

Circumstances can arise in a building where the intervention of the fire brigade is necessary to secure the safety of the occupants. To assist the fire brigade in the execution of intervention strategies, it is necessary to include appropriate facilities in the design of the building. This is considered beyond the scope of this guide.

Annex F (normative)
Features of design behavioural scenario categories

F.1 Category A: Occupants awake and familiar

Examples: working space: office or workshop, warehouse.

Scenario features are as follows.

— Occupants may be present in small groups in a single enclosure or dispersed in small numbers throughout a number of enclosures, usually with low occupant densities. Pre-movement time may be lengthened somewhat when occupants are dispersed.

— Occupants involved in a variety of individual or small group activities, they are awake and familiar with the building features including alarm systems and fire safety management procedures.

— Occupants have well defined roles and carry some responsibility for the building, its operation and emergency strategies and are trained in emergency procedures.

— Floor wardens and other staff have special responsibilities to ensure a rapid and efficient evacuation if alarms sound. Occupants are staff and may expect to be disciplined if they fail to follow emergency procedures and evacuate in an efficient manner.

In well-managed office buildings, with good management procedures and well-trained staff, pre-movement times should be very short, even with a sounder alarm system. Particularly in a multi-enclosure system, an important consideration is the pre-movement time of the slowest occupants to respond, especially isolated individuals. Travel times depend mainly on travel distance unless occupant densities are high, when queuing at exits can occur and flow times can dominate. Poor fire safety management can lead to long pre-movement times. Office buildings are most likely to fit into building levels B1 or B2, and since occupants are familiar with the building, spatial complexity should be less important unless outside visitors are commonly present. Reported pre-movement times from offices during well managed evacuations tend to be very short, between a few seconds and a few minutes [6] and times for occupants to reach a safe escape route are rarely more than a few minutes from general alarm [6].

F.2 Category B: Occupants awake and unfamiliar

Examples:

— *no focal point*: shopping enclosure, restaurant, bar, supermarket, department store floor, mall area, airport check in or lounge areas, circulation space, restaurant, day centre;

— *focal point*: assembly, cinema, theatre.

Scenario features are as follows.

— Occupants are largely unfamiliar with the building and systems, they are committed to various activities, family and friends and might not respond to alarms.

— Authority figures (sales staff, managers, stewards) are present who are trained in the building emergency management systems and procedures.

— A rapid sweep of the area by staff can be used to ensure a rapid customer evacuation, otherwise alarms may not trigger an evacuation, although voice alarms or personal address messages may be effective.

— Special provisions might be necessary for restaurant areas or bars.

— Sports stadia or very large arenas may be considered a special subset.

— Layout of assembly enclosure and exits should be simple but subsequent escape routes may be complex and hard to identify quickly.

Sales areas can be large with complex layouts and visibility limited by stock. Restaurant areas might also be present. There is also likely to be a wider range of physical and mental abilities (including children, the elderly and family groups who may be scattered at the time of the emergency). Customers can be reluctant to leave goods they have collected or paid for (e.g. in supermarkets). In theatres, occupants are attending to the stage or screen, but this provides a focal point, which can be used by management to control an evacuation. Staff training is therefore particularly important in interrupting the ongoing activity swiftly, but does provide an opportunity to impose rapid control.

During a number of monitored evacuations and incident investigations [6], pre-movement times have been short, with narrow distributions, when management was efficient and staff acted quickly to encourage occupants to evacuate. On at least one occasion when staff did not act quickly much longer pre-movement times occurred [6]. When design occupant densities are high, evacuation times are mainly dependent upon exit flow capacity, especially if exit choice is not optimal (as is often the case).

F.3 Category C: Sleeping

Examples:

— *familiar*: apartment block, house, residential home;

— *unfamiliar*: hotel, hostel.

Scenario features are as follows.

— Low occupant densities and mixed ability and age of residents, who might be sleeping.

— For residences, occupants should be familiar with warning and evacuation procedures. Fire safety management is often basic in residences but can be more developed in managed accommodation.

— Dwellings are small, with simple layouts and are familiar to occupants.

— When one member of a household detects a fire cue or alarm their first actions are usually to investigate, but warning others is often a high priority, so that once detection has occurred, warnings to other occupants may be delivered within a short time.

— Pre-movement times can be long, especially with sleeping occupants or when cues are ambiguous, or occupants inebriated.

— For hotels and hostels, occupants are largely unfamiliar with the building and systems and are dispersed among a large number of enclosures. Some authority figures may be present consisting of staff, security and managers who are trained in the building emergency systems and emergency management procedures.

— Non-staff occupants can lack a sense of responsibility for the building and systems, and might not respond to alarms. Their main commitment is activities such as sleeping.

— Layout is likely to be complex and escape routes hard to identify quickly.

For these reasons, a rapid and efficient evacuation is unlikely to be achieved. If there are sufficient well-trained staff present, and if they act quickly, then a rapid sweep might be used to secure a local evacuation of an affected area. In many situations, evacuation can be counterproductive, since occupants are likely to be relatively safe in their rooms. Pre-movement times for even the first few occupants to respond can be very long (up to an hour), and the distribution of pre-movement times is likely to be very wide. Evacuation times are likely to be dependent on maximum pre-movement times and walking times, flow restrictions at potential "pinch" points are unlikely to occur. Occupants might be reluctant to leave their belongings and the temporary refuge of their rooms. For these reasons, passive fire protection should be a major strategy.

F.4 Category D Medical care

Examples: hospitals and nursing homes.

Scenario features are as follows.

— As for Category C, with additional aspects.

— Occupants with low levels of physical and/or mental abilities to respond to emergencies.

— Each occupant expected to require assistance from one or more staff members to evacuate.

— A high level of management supervision and participation in emergency procedures is expected.

— Occupants might be bedridden and attached to medical appliances (e.g. drips, monitors).

— Evacuation involves moving beds and wheel chairs.

F.5 Category E Transportation

F.5.1 *Buildings* *(a special case of awake and unfamiliar)*

Examples: railway stations and airports.

Scenario features are as follows.

— Many complex enclosures and very large spaces; escape routes not easily identified.

— Security restrictions in some areas impose behavioural limitations on occupant responses.

— Occupants likely to be encumbered by luggage which they will be unwilling to abandon in case of an emergency.

— High occupant densities.

— Occupants might be largely unfamiliar with the building and systems but authority figures are present consisting of sales staff, security, managers and stewards who are trained in the building emergency systems and emergency management procedures.

— Special provisions might be necessary for restaurant areas or bars.

— Occupants with a variety of languages.

F.5.2 *Vehicles*

Examples: coaches, trains, ships.

Scenario features are as follows.

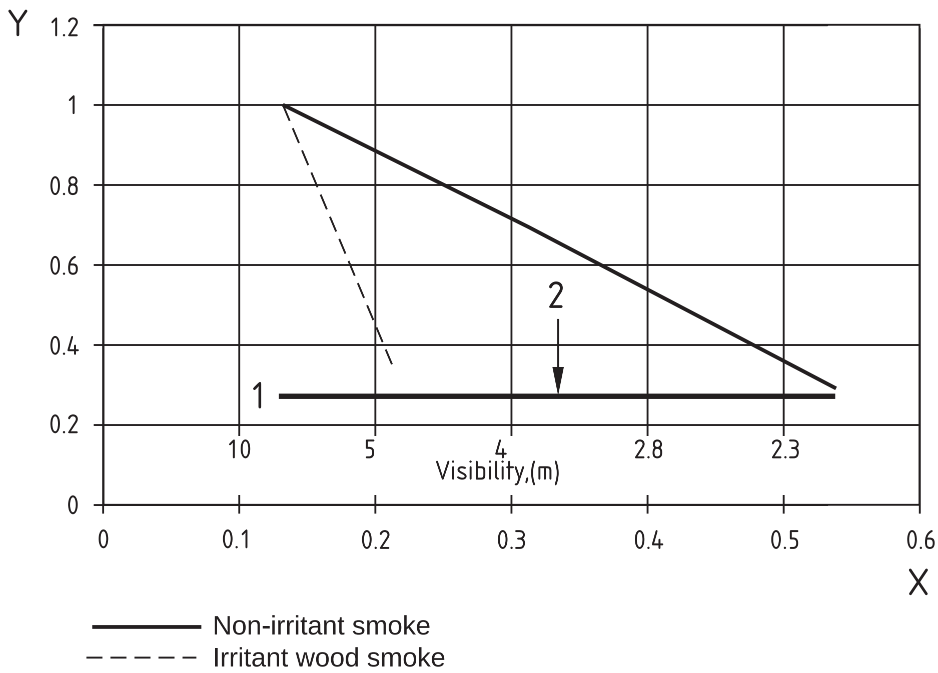
— Alarm times (time from detection to warning) are dependent upon the detection and warning systems in use and the behaviour of the first occupants alerted (security staff or occupants discovering fires). Depending upon the system in use, they might be calculable or, particularly where they rely on human response, research data might be needed.

Annex G (normative)
Effects of smoke on walking speed and proposed tenability endpoints for smoke, toxic gases and heat

Figure G.1 shows the effects exposure to non-irritant smoke and irritant wood smoke on walking speed and walking speed in darkness derived from the work of Jin [33]. Also shown illustrated is the smoke density at which 30 % of people will turn back rather than enter [30, 31].

An equation for the relationship between walking speed and smoke optical density ($D \cdot m^{-1}$) is given by:

Walking speed in non-irritant smoke (m/s)	= 1.36 – 1.9 × smoke optical density ($D \cdot m^{-1}$)
Walking speed in irritant smoke (m/s)	= 2.27 – 9 × smoke optical density ($D \cdot m^{-1}$)



Key

X Smoke/$D \cdot m^{-1}$

Y Walking speed/$m \cdot s^{-1}$

1 Walking speed in darkness

2 30 % of people turn back rather than enter

Figure G.1 — Walking speeds in non-irritant and irritant smoke

Table G.1 shows the main criteria used to derive tenability limits. Based upon the consideration that smoke from fires in buildings or vehicles has been found to be irritant, a design tenability limit of $D\cdot m^{-1} = 0.2$ is recommended for small enclosures such as dwellings. A proportion of people might not enter smoke at this density and if they do their movement speed is likely to be reduced to that in darkness. For larger enclosures, such as those in public buildings, a design tenability limit of $D\cdot m^{-1} = 0.08$ is proposed, so that occupants can orientate themselves and find exits.

Table G.1 — Smoke tenability limits

Smoke density and irritancy $D\cdot m^{-1}$ (extinction coefficient)	**Approximate visibility** diffuse illumination	**Reported effects**
None	Unaffected	Walking speed 1.2 m/s
0.5 (1.15) non-irritant	2 m	Walking speed 0.3 m/s
0.2 (0.5) irritant	reduced	Walking speed 0.3 m/s
0.33 (0.76) mixed	3 m approx.	30 % people turn back rather than enter
Suggested tenability limits for buildings with:		
— small enclosures and travel distances;		$D\cdot m^{-1} = 0.2$ (visibility 5 m)
— large enclosures and travel distances.		$D\cdot m^{-1} = 0.08$ (visibility 10 m)

These limits are intended to enable safe escape of the majority of building occupants. Some occupants might attempt to escape though even dense smoke in some situations. Also of importance is the tenability of smoke in terms of toxic gases and heat.

Above certain concentrations, it is considered that exposure to irritant gases in smoke will severely impair and even prevent escape. For the majority of flaming fires, it is considered that the concentrations of mixed smoke irritants will be below this level provided the smoke optical density does not exceed $D\cdot m^{-1} = 0.2$. Exceptions could be smouldering fires, for which the organic irritant yields tend to be high, and fires involving fuels giving off significant yields of inorganic acid gases (HCl, HBr, HF, SO_2, NO_x). Guidance on estimation of irritancy for such fires is given in BS 7899-2 and Purser [32].

Asphyxiant gases cause incapacitation (collapse) when a sufficient exposure dose has been inhaled. This depends upon the concentrations of mixed asphyxiant gases present and the time for which they are inhaled. Detailed guidance on estimation of the effects of individual asphyxiant gases and the interactions between them is given in BS 7899-2 and Purser SFPE [32]. A proposed tenability endpoint for design purposes is 0.3 multiplied by the predicted FED for incapacitation.

Since there is some relationship between smoke density and the concentrations of irritant and asphyxiant gases in fires, it is considered that, at the proposed smoke tenability limit of $D\cdot m^{-1} = 0.2$, the majority of fires will remain tenable with respect to asphyxiant gases for at least 30 min.

Another simple approach is to provide tenability limits for different estimated exposure durations based upon the concentrations of carbon monoxide, carbon dioxide, oxygen and hydrogen cyanide in the fire effluent. Table G.2 shows some proposed limiting exposure times for asphyxiants based upon a 0.3 FED tenability limit for conditions considered typical for fires in buildings using the FED calculation equations from BS 7899-2.

Two categories are proposed consisting of fires likely to involve fuels containing significant quantities of nitrogen-containing materials in furniture or clothing (>2 % nitrogen by mass of fuel, such as fires in residences or retail premises) and fires likely to involve mainly cellulosic or other materials low in nitrogen (<2 % by mass of fuel, such as office fires). For both cases, a moderately vitiated combustion condition typical of building fires is assumed with a CO_2:CO concentration ratio of 10:1. For one category a CO:HCN ratio of 12.5:1 is assumed and, for the other, the CO:HCN ratio is assumed to be >50:1. The results are expressed in terms of maximum CO concentrations, assuming the other gases are present at the ratios stated.

Proposed design tenability limits for heat are based upon time to pain for unprotected skin. Detailed guidance on estimation of tenability times for heat in fires is given BS 7899-2 and Purser SFPE [32]. Table G.3 provides a simple guide derived using these data and calculation expressions. Proposed tenability limits are $2.5\ kW\cdot m^{-2}$ for exposure to radiant heat, 115 °C for up to five minutes exposure to convected heat and 68 °C for up to 30 min (water content of atmosphere <10 % H_2O by mass). For atmospheres saturated with water vapour (such as in sprinklered fires), a tenability limit temperature of 60 °C is recommended for any exposure period up to 30 min.

Table G.2 — Proposed design tenability limit exposure concentrations for asphyxiant gases expressed as carbon monoxide for five minute and 30 min exposures

Category	Maximum asphyxiant concentration as CO ppm	
	Five minute exposure	**30 min exposure**
Fuel contains nitrogen (>2 % by mass)	800	125
Fuel with low nitrogen (<2 % by mass)	1 200	275

Table G.3 — Tenability limits for radiative and convective heat

Mode of heat transfer	Intensity	Tolerance time
Radiation	<2.5 $kW \cdot m^{-2}$	>5 min
	2.5 $kW \cdot m^{-2}$	30 s
	10 $kW \cdot m^{-2}$	4 s
Convection	<60 °C 100 % saturated	>30 min
	100 °C < 10 % H_2O[a]	8 min
	110 °C < 10 % H_2O	6 min
	120 °C < 10 % H_2O	4 min
	130 °C < 10 % H_2O	3 min
	150 °C < 10 % H_2O	2 min
	180 °C < 10 % H_2O	1 min

[a] v/v

Annex H (informative)
Generic worked examples for a number or design behavioural scenarios

H.1 Awake and familiar: Example — Escape and evacuation times for office accommodation

H.1.1 *General*

Office buildings tend to have the following attributes.

— Staff are likely to be widely dispersed, often in separate enclosures although some might be grouped in open plan offices.

— Occupants are familiar with the building, its warning systems and fire safety management procedures.

— In well-managed office buildings with good management procedures and well-trained staff, pre-movement times should be very short, even with a sounder alarm system.

— Particularly in a multi-enclosure system, an important consideration is the pre-movement time of the slowest occupants to respond. Some individual isolated occupants can be slower to respond, especially if they do not feel threatened.

— Travel times depend mainly on travel distance except where occupant densities are high, when queuing at exits can occur and flow times can dominate.

— Poor fire safety management can lead to long pre-movement times.

H.1.2 *Time to detection*

Time to detection depends upon the system in use and the design fire conditions. Automatic detection is considered essential for performance-based design.

H.1.3 ***Time to general warning***

Time to warning depends upon the system in place:

— Level 1: Where automatic detection triggers an immediate general alarm, the design warning time can be taken as 0 s.

— Level 2: Where automatic detection activates a pre-alarm to management or security with a default general alarm time, the warning time should be taken as the time-out default (usually two to five minutes depending upon the system). Otherwise, warning time is difficult to predict but a default 10 min might be considered.

— Level 3: Where there is no automatic warning or only local warning the general warning time is likely to be long and unpredictable depending upon the presence and actions of individual occupants discovering the fire. The time to general warning might be any time between a few minutes and several hours.

H.1.4 ***Pre-movement times for first few occupants and pre-movement time distributions***

From experimental evacuations, pre-movement times from offices tend to be very short [6]. Occupants are all or mostly employees, and so are familiar with the building and its systems. They are alert and either sitting or standing. Most importantly, they should be used to emergency evacuation procedures.

If the management and systems are good they will be assailed by a loud alarm sounder, such that remaining in occupation is uncomfortable. This should be reinforced by encouragement to leave by a floor warden within 30 s of the alarm being sounded.

In office evacuations monitored at a number of sites [6, 16], times for occupants to reach a safe escape route are rarely more than 2 to 2.5 min from general alarm. Individual total pre-movement times are usually distributed between a few seconds and two minutes.

Factors which lengthen pre-movement times in office accommodation might be commitment to activities common to any office such as computer work, telephone calls, meetings, photo copying, coffee breaks or being in the toilets. Another factor might be differences between a single open plan office space or a more rambling or complex space, or set of spaces containing cellular offices where individual staff members might be isolated.

The whole pre-movement time is still very dependent upon the management/staff culture. It is possible to imagine a situation where lax management does not implement an efficient emergency plan, so that when the alarm is given occupants ignore the situation until conditions become threatening in some parts of the building, or someone decides to start an evacuation. Depending upon the intrusiveness of the alarm and the fire cues, this might vary between a few minutes to many minutes.

If the management culture is Level 1 then total pre-movement times (time from alarm to movement of 99 % of occupants) should not exceed approximately 1.5 min.

H.1.5 ***Walking times***

In offices, it is to be expected that the occupant population would have a narrow walking speed distribution. For prescriptive travel distances, the walking times to protected escape routes should be short (depending upon the average distance to escape routes in individual buildings).

Walking times in escape routes depend upon the length (or height) of escape routes. Guidance on the selection of horizontal and vertical walking speeds is given in Annex D. If occupant densities are low, the average walking time may be added to 99 % pre-movement time.

If occupants densities are sufficiently high (separation distance between individual less than 1.6 m) then allowance for reduced travel speeds due to crowding and queuing at pinch points will be necessary.

H.1.6 ***Time to queue and flow time***

If high occupant population densities are present, it is possible that queuing might occur at some storey exits. A default figure for time to queue once the first few occupants have moved could be 30 s. This should be added to the time for the first few occupants to move (also 30 s).

To this should be added the flow time into the protected escape routes, which depends upon occupant density, assumed exit width used. This depends upon aggregate exit width remaining after discounting and assumed exit choice behaviour. This should be justified based upon the specific building and occupant characteristics.

H.1.7 *Summary for offices*

H.1.7.1 *Level 1*

Automatic detection with immediate activation of general alarm sounder (or voice).

High standard of training, floor warden provision and fire safety management, independent audit and certification.

Detection time:	depends upon design
Alarm time:	0 s
Pre-movement time of first few occupants:	30 s
Pre-movement time of last few occupants:	1.5 min
Walking time to protected escape route:	15 s (30 m maximum direct distance)
Evacuation time:	2.25 min
Total escape time:	Detection + Alarm + 2.25 min

H.1.7.2 *Level 2*

Good standard of warnings and fire safety management, staff training and floor warden provision.

Automatic detection with pre-alarm to security, general alarm default time two to five minutes.

Detection time:	depends upon design
Alarm time:	two to five minutes
Pre-movement time of first few occupants:	60 s
Pre-movement time of last few occupants:	3.5 min
Walking time to protected escape route:	15 s (30 m maximum direct distance)
Evacuation time:	2.75 min
Total escape time:	Detection + Alarm + 5.25 to 8.25 min

H.1.7.3 *Level 3*

Basic standard of warnings and fire safety management, minimal staff training and floor warden provision.

Automatic detection and alarm but basic fire safety management or no automatic detection and alarm.

Alarm time:	indeterminate: a few minutes to hours
Pre-movement time of first few occupants:	indeterminate: a few minutes to >30 min
Pre-movement time of last few occupants:	indeterminate: 30 min to an hour minimum
Walking time to protected escape route:	15 s (30 m maximum direct distance)
Evacuation time:	>20 min
Total escape time:	Detection + Alarm + >20 min

H.1.7.4 *Notes*

For all categories where high occupant densities occur evacuation time after first few occupants move should be taken as 30 s plus population flow time.

The following times might be added for other variables:

Open plan office:	+ 0 min	Cellular offices:	+ 0.25 min
Compact/small floor area:	+ 0 min	Large floor area:	+ 0.25 min

If more than 20 % of occupants are likely to be outside visitors unfamiliar with systems, add 0.5 min.

Recorded voice alarms or PA systems should not normally reduce pre-movement times for office areas significantly. However, if voice alarms or PA are used, there might be a greater probability of achieving an efficient evacuation, especially if a high percentage of visitors is common.

To the pre-movement times must be added the travel and flow times calculated according to standard methodology.

H.2 Awake and unfamiliar: Example 1 — Escape and evacuation times in a retail enclosure

H.2.1 *General*

In retail enclosures, customers are likely to be unfamiliar with the building and its systems. They also might lack a feeling of responsibility to respond to alarms, announcements, other cues or might even ignore quite large fires if they do not feel directly threatened. Their main commitments are likely to be to the shopping activity and to any accompanying family members or friends.

For these reasons, a rapid and efficient evacuation is likely to be achieved only if there is an efficient fire safety management plan and if the staff are well trained to implement it. If the staff do not act, it is likely that not only alarms but direct exposure to fires will not trigger an evacuation.

In this situation, a voice alarm or personal address message is more likely to initiate an evacuation. Alternatively, if there are sufficient well-trained staff present, and if they act quickly, then a rapid sweep of the area can be used to ensure a rapid evacuation of the customers.

Against this is the likelihood that there will be a pre-alarm system installed. The time between detection and general warning may constitute a significant part of the total escape time. Staff can spend some time investigating the incident or even fighting the fire before deciding to evacuate customers, so that in a large sales area there might be some delay between the first discovery of a fire and the general alarm being raised. There might be some reluctance to be responsible for stopping business and inconveniencing customers.

For retail enclosures such as supermarkets or stores, where occupants are unfamiliar with alarm and evacuation procedures, efficient management with staff "sweepers" and voice alarms provide short pre-movement times and narrow pre-movement time distributions. Sales areas might be expected to contain a number of staff and there is usually a relatively high staff/customer ratio, compared with other occupancies.

If the design occupancy density is considered in supermarkets or stores, evacuation times and if exit provision is at the level of the prescriptive requirements then evacuation times are mainly dependent upon flow capacity of exits.

Sales areas often have large areas and complex layouts, with visibility limited by stock. There might also be restaurant areas incorporated into the sales area.

Also in sales areas there is likely to be a greater range of physical and mental abilities than in an office environment (including children, the elderly and family groups who may be scattered at the time of the emergency). Customers might be reluctant to leave goods they have collected or paid for (e.g. in supermarkets). In supermarket evacuations, it is important that customers are instructed to leave trolleys behind. If trolleys are taken to the exits or abandoned near the exits then this might impose density and flow restrictions in crowded situations.

H.2.2 *Time to detection*

Time to detection depends upon the system in use and the design fire conditions. Automatic detection is considered essential for performance-based design.

H.2.3 *Time to general warning*

Time to warning depends upon the system in place.

— Level 1: Where automatic detection triggers an immediate general alarm, the design warning time can be taken as 0 s.

— Level 2: Where automatic detection activates a pre-alarm to management or security with a default general alarm time, the warning time should be taken as the time-out default (usually two to five minutes depending upon the system), otherwise warning time is difficult to predict but a default 10 min might be considered. Where voice or personal address warning systems are used, a period of 30 s might be required for the delivery of the emergency message.

— Level 3: Where there is no automatic warning or only local warning, the general warning time is likely to be long and unpredictable depending upon the presence and actions of individual occupants discovering the fire. The time to general warning might be between a few minutes and several hours.

H.2.4 ***Pre-movement times for first few occupants and pre-movement time distributions***

During a number of monitored evacuations and incident investigations [7,8], pre-movement times have been short with narrow distributions when management was efficient and staff acted quickly to encourage occupants to evacuate. On at least one occasion when staff did not act quickly much longer pre-movement times occurred. Also, in a number of serious incidents in retail premises, occupants were trapped by rapid fire growth, emphasising the need for a rapid response in such occupancies. Once a general alarm is sounded then staff must begin to sweep occupants out of the store. Some might be in toilets or changing rooms, or separated from family members. They might also be unsure of the availability or locations of escape routes or exits.

For prescriptively designed retail enclosures, evacuation times tend to be dominated by flow restrictions at the exits and escape routes when the design population is assumed. For lower occupancy levels, pre-movement times and walking times might be the limiting factor on evacuation time, but evacuation times will be less than that for the design population for well managed cases.

An important consideration with respect to situations with high occupant densities in certain parts of a store is the consequences of uneven exit choice on flow times. Stores often have a complex layout, emergency exits might be locked (with break-glass key provision) and frequently do not form part of the normal access routes for customers. Customers are likely to choose familiar exits routes (especially the route by which they entered).

For these reasons, it is likely that some exits will be favoured preferentially over others during an emergency evacuation. The design should be examined and the exit choice ratio for evacuating occupants should be justified. A number of cases should be run to examine the effect of exit choice on evacuation time.

H.2.5 ***Walking times***

In retail premises, it is to be expected that the occupant population would have a moderately wide walking speed distribution. For prescriptive travel distance, the walking times to protected escape routes should be short depending upon the dimensions of the building and the location of the available exits. For an enclosure with a 30 m direct travel distance the average walking time was approximately 15 s. Walking times should be calculated based upon the expected walking speed of occupants and the calculated average actual travel distance to chosen exits for the occupant population.

H.2.6 ***Time to queue***

High occupant populations densities are likely to be present so queuing is likely to occur at some exits. A default figure for time to queue once the first few occupants have moved could be 30 s.

H.2.7 ***Summary for retail***

H.2.7.1 *Level 1*

Automatic detection with immediate activation of general alarm. Voice alarm preferable but sounder sufficient if backed by immediate staff sweep.

High standard of staff training and fire safety management, independent audit and certification.

Detection time:	depends upon design
Warning time:	0 s
Pre-movement time of first few occupants:	30 s
Time to queue formation after first occupants:	30 s
Pre-movement time of last few occupants:	2.5 min
Walking time to protected escape route:	15 s (in the example examined)
Flow time ADB:	2.5 min
Flow time Nelson and Mowrer:	3.5 min
Evacuation time (flow controlled N and M [ADB]):	4.5 [3.5] min
Escape time (flow controlled N and M [ADB]):	Detection + Alarm time + 4.5 [3.5] min
Evacuation time (unrestricted):	2.75 min
Escape time (unrestricted):	Detection + Alarm time + 2.75 min

Therefore evacuation and escape time depends upon flow controlled evacuation.

H.2.7.2 *Level 2*

Automatic detection with pre-alarm to security, general alarm default time two to five minutes.

Voice alarm preferable but sounder sufficient if backed by immediate staff sweep.

Good standard of staff training and fire safety management provision.

Detection time:	depends upon design
Alarm time:	two to five minutes
Pre-movement time of first few occupants:	one minute
Time to queue formation after first occupants:	30 s
Pre-movement time of last few occupants:	four minutes
Average walking time to protected escape route:	15 s (in the example examined)
Flow time ADB:	2.5 min
Flow time Nelson and Mowrer:	3.5 min
Evacuation time (flow controlled N and M [ADB]):	5 [4] minutes
Escape time (flow controlled N and M [ADB]):	Detection + Alarm + (2 to 5) + 5 [4] minutes

H.2.7.3 *Level 3*

Basic standard of warnings and fire safety management, minimal staff training.

Automatic detection and alarm but basic fire safety management or no automatic detection and alarm.

Alarm time:	indeterminate: a few minutes to an hour
Pre-movement time of first few occupants:	indeterminate: a few minutes to 15 min
Pre-movement time of last few occupants:	indeterminate: a few minutes to 20 min
Walking time to protected escape route:	15 s
Evacuation time:	>20 min
Total escape time:	Detection + Alarm + >20 min

H.2.7.4 *Notes*

If the staff numbers are very small compared to the customer numbers and size of the store, add 0.5 min.

If the floor area is large or the layout complex, add 0.5 min.

If the alarm system is a voice alarm system, add 0.5 min. If the alarm system is a sounder, it is necessary to be more rigorous regarding the staff implementation of the fire safety management emergency plan.

If a fire occurs or breaks into a general occupied enclosure such that the fire or smoke occupy a sufficient area to be visible and appear threatening to the majority of the occupant population, this might curtail the pre-movement time distribution. For a Level 1 or Level 2 system, this is unlikely to reduce evacuation times significantly, since they are limited by exit flow capacity. For a Level 3 system evacuation is likely to begin when such conditions develop. The subsequent minimum evacuation time is then approximately a further four minutes (depending upon the layout of the building and available escape routes).

H.3 Awake and unfamiliar: Example 2 — Escape and evacuation times in an assembly enclosure

This differs from the shop case mainly in that occupant attention is concentrated on a focal point, which simplifies warnings and fire safety management. Occupants might be largely unfamiliar with the building and systems but authority figures are present consisting of managers and stewards who are trained in the building emergency systems and emergency management procedures. The enclosure will have a focal point (such as a stage or screen). Examples are theatres, cinemas, lecture theatres and large meeting rooms. Sports stadia or very large arenas may be considered a special subset.

— In assembly buildings with high occupant densities, queue formation is rapid and travel times depend upon exit flow capacity and exit choice.

— An important parameter is the pre-movement time of the *earliest* occupants to evacuate, since these determine time to queue formation.

— Pre-movement time distributions are narrow (people tend to leave all at once). Some occupants may delay leaving their seats when they see queues at the exits; this has no effect on evacuation times since they simply join the ends of queues when they are shorter (airport lounge effect). This will affect which individuals get out first.

— Good control and short pre-movement times can be obtained by staff announcements from a focal point, but this depends upon the time required for management to respond and respond *appropriately*.

As with the shop case the warning time depends upon the detection and warning system installed. Staged, pre-alarm systems are common, in which case warning times can be significant.

In an assembly area such as a theatre or cinema occupants are focussed on a central point and are "controlled" in regimented seating patrolled by ushers. Pre-movement times can therefore be short and uniform once the performance is interrupted with a message from the stage.

In general, escape and evacuation times from assembly enclosures should be similar to those from retail enclosures.

H.4 Sleeping and unfamiliar: Example — Escape and evacuation times in a hotel

In occupancies such as hotels, occupants are likely to be unfamiliar with the building and its systems. They also might lack a feeling of responsibility to respond to alarms, announcements, other cues or might even ignore quite large fires if they do not feel directly threatened. Their main commitment is to sleeping.

For these reasons a rapid and efficient evacuation is unlikely to be achieved, even if an efficient fire safety management plan is in place and the staff are well trained to implement it. Alarms cannot be relied upon to trigger an evacuation.

In this situation, a voice alarm or personal address message is more likely to initiate an evacuation. In many situations, evacuation can be counterproductive, since occupants are likely to be relatively safe in their rooms. Alternatively, if there are sufficient well-trained staff present, and if they act quickly, then a rapid sweep of the affected area might be used to secure a local evacuation.

Against this is the likelihood that there will be a staged pre-alarm system installed. The time between detection and general warning may constitute a significant part of the total escape time. Staff might spend some time investigating the incident or even fighting the fire before deciding to evacuate occupants. There might be some delay between the first discovery of a fire and the general alarm being raised. There might be some reluctance to be responsible for stopping business and inconveniencing residents.

Occupants are scattered in small numbers throughout many enclosures. Pre-movement times for even the first few occupants to respond may be very long (up to an hour). The distribution of pre-movement times is likely to be very wide.

Evacuation times are likely to be dependent on maximum pre-movement times and walking times, flow restrictions at potential pinch points are unlikely to occur.

Hotels have large areas and complex layouts. Fires and fire effluent are likely to be remote from occupants until such time as they might be threatened.

There is likely to be a greater range of physical and mental abilities than in an office environment (including children, the elderly and family groups who might be scattered at the time of the emergency). Occupants might be reluctant to leave their belongings and the temporary refuge of their rooms.

For these reasons passive fire protection should be a major strategy. It is important to provide a very good standard of fire separation and compartmentation in hotels, and to prevent smoke penetration.

A good standard of detection, management and warning provision is likely to be important for occupants near the seat of the fire.

Evacuation and escape times cannot be calculated effectively. Evacuation times could range from 40 to 60 min, depending upon the situation.

H.5 Sleeping and familiar: Examples — Escape and evacuation times in a dwelling house, flat or maisonette

H.5.1 *Domestic dwellings*

Domestic dwellings have the advantage that they are small, with a simple layout and usually very familiar to occupants.

Detection and warning times depend upon whether there is an automatic detection and warning system and the system type. Where there is no automatic detection, and even in some scenarios where there is limited automatic detection, the time to detection can be close to the tenability limit for occupants, so that incapacitation can occur before occupants are able to escape. It is considered that multiple mains powered, linked detector/sounder sounders should improve detection times and survivability.

When one member of a household detects a fire cue or alarm their first actions are usually to investigate, but warning others is often a high priority, so that once detection has occurred, warnings to other occupants may be delivered within a short time. A problem is that since this depends upon untrained occupants warning times are difficult to define. Pre-movement times can also be long, especially with sleeping occupants or when cues are ambiguous, or inebriated.

a) Well managed system can only be defined in terms of warning system – linked detectors/sounders/mains – no data on response but estimated 5 to 10 min pre-movement.

b) Default – average home – assume one battery detector – 40 % working. If working assume 30 min, if not >30 min.

c) Basic home – no detection, bad maintenance: >30 min.

When a dwelling is an apartment or maisonette in an apartment block, the time required to evacuate other apartments or maisonettes (should this prove necessary) can be very long, depending upon the fire scenario. A reasonable default period might be an hour.

H.5.2 *HMO*

More complex and larger than dwelling, may be managed on site. Occupants likely to be less motivated than for dwelling.

In this behavioural scenario, where, if there is a high standard of detection and warning system, a warden on site and if there is a high standard of occupant training and fire safety management, it can be possible to obtain pre-movement times of a little as 15 min. When the standard of management and the fire safety culture is average, occupants can ignore alarms, especially if unwanted alarms are frequent. In such cases, 30 to 60 min might be a more realistic pre-movement time.

These cases give an indication of the factors likely to be important in the determination of pre-movement times in common occupancy classes. Indications of default pre-movement times have been presented and the logic behind them discussed.

The following sections contain suggested default values for design pre-movement times in a range of occupancies, with some accompanying notes. Suggested default times for a range of occupancies are presented in Table C.1. Three pre-movement times are suggested for each occupancy type, representing a very high standard of fire safety management and warning systems, an average-good standard and a barely adequate standard.

H.5.3 *Hotel, boarding house*

Occupants unfamiliar, cellular, complex, sleeping, variety of occupants.

All pre-movement times likely to be very long and variable.

— Level 1: Well managed: automatic detection and voice alarm, audited FSM drills and plans still relies on occupant response in the middle of the night: 30 min.

— Level 2: Average: 40 min.

— Level 3: Poor management: >40 min.

H.5.4 ***Hall of residence/residential college/hostel***

Familiar, complex, cellular sleeping.

— Level 1: Good, well managed, automatic detection and alarm, 30 min.

— Level 2: 40 min.

— Level 3: >40 min.

H.6 Institutional

H.6.1 ***Hospital, nursing home, old peoples' home, care home/centre***

For such places, it is reasonable to expect high staff numbers to be on duty and highly trained. They should respond quickly in case of alarm. However staff/occupant ratios are often low, so that some time is required for all occupants to be alerted. Also, occupants cannot be expected to respond to alarms themselves, especially at night. The concept of pre-movement time is therefore difficult to apply. For these occupancies with sleeping accommodation, it is therefore necessary to assume very long pre-movement times, irrespective of alarm/management system. In some cases residents will respond and evacuate. In others they will not.

— Well managed, automatic detection high staff ratio: 30 min.

— Low staff ratio, ad hoc staffing arrangements: 40 min.

H.6.2 ***Day centre, surgery, clinic, dentist, nursery, health centre***

For occupancies such as these, without sleeping accommodation, and with trained staff and many occupants in groups. It is to be expected that staff will respond quickly and sweep occupants to exits.

— Level 1: High staff ratio, well trained, automatic detection. Possibly voice alarm. Default pre-movement time for staff: One minute. Occupants: another two minutes. Total three minutes.

— Level 2: Five minutes.

— Level 3: 15 min.

H.6.3 ***Education: school, nursery school, adult training centre***

Staff should be trained but level of training can vary. Students should be aware of emergency procedures. Can contain restaurants, bars, etc.

— Level 1: Voice alarm. Automatic detection, regular drills good management. Sweep by staff. 3 min.

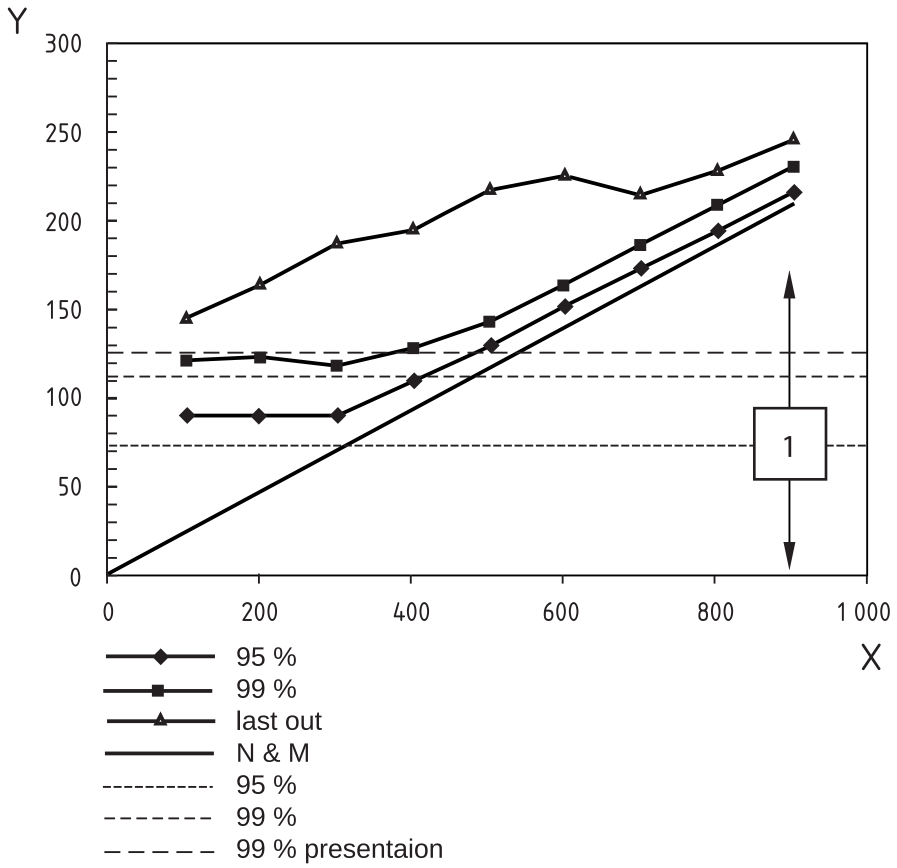
— Level 2: 10 min.

— Level 3: >15 min.

Annex I (informative)
Example of interactions calculations

Figure I.1 shows a worked example using the results of evacuation time calculations calculated with a computer simulation method (GridFlow [8]), for various occupancy levels of a simple square retail space (sides 42.4 m, direct travel distance 30 m) with four available exits. The model treats each occupant as an individual and walking speeds depend upon occupant density. For these calculations, a design population of 900 and the pre-movement time distribution obtained in the Sprucefield monitored evacuation [6] were used. In this case, the first occupants began to move almost immediately after the general alarm was sounded, so that the pre-movement time of the first few occupants to move is only a few seconds. Walking distances were computed for each occupant and a walking speed distribution with a mean of 1.2 m/s (s.d. 0.2, minimum 0.3 m/s).

Figure I.1 shows a number of features of an evacuation for different occupant populations. The red (Nelson and Mowrer) [10] line shows the time required for the occupant population to flow out of the enclosure, assuming the available exits were used to maximum flow capacity from the moment the alarm was sounded. This represents the minimum possible times required to evacuate the population ignoring the pre-movement and walking time components. The lower two horizontal broken lines show the theoretical 95th and 99th percentile pre-movement times of 95 s and 114 s, which are constant for the given distribution. The 99th percentile line plus a figure for average walking time of 13 s provides a presentation time of approximately 127 s, shown as the upper broken horizontal line, which represents the minimum time required to evacuate assuming unimpeded movement.



Key

X Time/s

Y Population of space

1 Design population

Figure I.1 — Phases of evacuation times for different populations in a square prescriptively designed retail enclosure with an area of 18 000 m^2 calculated using GridFlow with the Sprucefield pre-movement time distribution

The three lines with symbols show the times required for 95 %, 99 % and last out from full computer simulations for all individual occupants taking into account all interactions (including impeded movement) for different populations (average of 10 simulations for each point). The results show that at the design population of 900, the minimum flow time for the occupant population exceeds the 99 % pre-movement and presentation time limits by a considerable margin of 95 and 82 s.

The separation between the Nelson and Mowrer time and the actual 99 % evacuation time provides an approximate estimate of the time to queue formation of 20 s, which represents the presentation time of the first few occupants. The pre-movement times and walking times of the remainder of the population after the first 20 s have no further effect on the evacuation time of 99 % of occupants, which is determined simply by the maximum flow time required for the occupant population. This clearly indicates that, at the high (design) occupant densities, once the first few occupants begin to move, the evacuation is limited by (and therefore determined by) the physical dimensions of the exits plus a small period for the time required for queues to form [i.e. equation (4)].

When the occupant numbers are less than approximately one third of the design number, then the evacuation time depends on the pre-movement time of the last occupants to start to leave [i.e. equation (3)].

Bibliography

[1] The Building Regulations 2000. Approved Document B. Fire Safety. HMSO 2000.

[2] PURSER, D.A. *ASET and RSET: Addressing some issues in relation to occupant behaviour and tenability. Fire Safety Science, Proceedings of the seventh International Symposium.* EVANS, D.D. (ed). International Association for Fire Safety Science, 2003, pp. 91-102.

[3] CANTER, D. *Fires and Human Behaviour.* UK. David Fulton Publishers, 2nd edition, 1990.

[4] SIME, J. *Safety and the built environment. International Conference of Safety in the Built Environment (BUSI-88).* July 13-15, 1988. Portsmouth, England. New York, Routledge, Chapman and Hall, 1988.

[5] SIME, J. *An occupant response escape time (ORET) model. Human Behaviour in Fire — Proceedings of the First International Symposium.* pp. 299-308. University of Ulster 1998.

[6] PURSER, D.A. and BENSILUM, M. Quantification of behaviour for engineering design standards and escape time calculations. *Safety Science* 38:157-182 (2001).

[7] DD 240-1:1997, *Fire safety engineering in buildings — Part 1: Guide to the application of fire safety engineering principles.*

[8] BENSILUM, M. and PURSER, D.A. (2002) *GridFlow: an object-oriented building evacuation model combining pre-movement and movement behaviours for performance-based design. Fire Safety Science. Proceedings of the seventh International Symposium*. EVANS, D.D. (ed.). International Association for Fire Safety Science, 2003, pp. 941-952.

[9] PAULS, J. *Evacuation and other movement in buildings: some high-rise evacuation models, general pedestrian movement models and human performance data needs. In: Pedestrian and Evacuation Dynamics 2003. Proceedings of the 2nd International Conference.* GALEA, E.R. (ed.) University of Greenwich, 2003, pp. 75-88.

[10] NELSON, H.E. “BUD” and MOWRER, F.W. Emergency Movement. *The SFPE Handbook of Fire Protection Engineering (3rd ed.)*, DiNENNO, P.J. (ed.) National Fire Protection Association, Quincy, MA 02269, 2002, pp. 3/367-380.

[11] PROULX, G. Movement of people: the evacuation timing. *The SFPE Handbook of Fire Protection Engineering (3rd ed.)*, DiNENNO, P.J. (ed.). National Fire Protection Association, Quincy, MA 02269, 2002, pp. 3/342-366.

[12] PURSER, D.A. *Behaviour and Movement Interactions in Emergencies and Data Needs for Engineering Design. In: Pedestrian and Evacuation Dynamics 2003. Proceedings of the 2nd International Conference.* GALEA, E.R. (ed.) University of Greenwich 2003, pp. 355-370.

[13] PURSER, D.A. *Human behaviour in fire and other emergencies*. BRE Report 80893 2001.

[14] PURSER, D.A. and RAGGIO, A.J.T. *Behaviour of crowds when subjected to fire intelligence*. BRE Client Report CR 143/95 July 1995.

[15] RAGGIO, A. *Comparative efficiency of alarm bell and recorded messages when motivating groups of people to evacuate*. BRE Client Report CR 147/96 July 1996.

[16] PURSER, D.A. and BENSILUM, M. *Quantification of escape behaviour during experimental evacuations*. BRE Client Report CR 30/99 January 1999.

[17] SHIELDS, T.J., BOYCE, K.E. and SILCOCK, G.W.H. Towards the characterization of large retail stores. *Fire and Materials*. 23, 325-331.

[18] BELLAMY, L.L. and GETER, T.A.W. *Experimental Programme to investigate informative fire warning characteristics for motivating fast evacuation*. BRE Report BR 172. 1991.

[19] PROULX, G. and SIME, J. To prevent panic in an underground emergency, why not tell people the truth? In: COX, G., LANGFORD, B. (Eds), Fire Safety Science — Proceedings of the Third International Symposium. Elevier Applied Science, New York, pp. 843-852.

[20] BRYAN, J.L. *An Examination and Analysis of the Human Behavior in the MGM Grand Hotel Fire*, revised report. National Fire Protection Association, Quincy MA, 1983.

[21] FAHY, R. and PROULX, G. Unpublished analysis of World Trade Center data. National Fire Protection Association. Quincy MA, October 1994.

[22] PROULX, G., KAUFMAN A. and PINEAU, J. *Evacuation Time and Movement in Office Buildings*, Internal Report No. 711, National Research Council of Canada, Ottawa ON, March 1996.

[23] PROULX, G. and FAHY, R.F. *The time delay to start evacuation: review of five case studies. Proceedings of the fifth international symposium on fire safety science*. HASEMI, Y. (ed.) International Association for Fire Safety Science, 1997, pp. 783-794.

[24] PROULX, G., LATOUR, J.C., MCLAURIN, J.W., PINEAU, J., HOFFMAN, L.E. and LAROCHE, C. *Housing Evacuation of Mixed Abilities Occupants in Highrise Buildings*, Internal Report No. 706, National Research Council of Canada, Ottawa ON, August 1995.

[25] PROULX, G., LATOUR J. and MACLAURIN, J. *Housing Evacuation of Mixed Abilities Occupants*, Internal Report No. 661, National Research Council of Canada, Ottawa ON, July 1994.

[26] THOMPSON, P.A. and MARCHANT, E.W. A computer model for the evacuation of large building populations. *Fire Safety Journal*. Vol. 24, 1995, pp. 131-148.

[27] FRASER-MITCHELL, J.N. Lessons Learnt During the Development of CRISP2, a Monte-Carlo Simulation for Fire Risk Assessment. *INTERFLAM '96 — Proceeding of the 7th International Fire Conference*. C. Franks (ed). Interscience Communications Ltd., London, UK, 1996, pp. 631-639.

[28] GALEA, E.R., GWYNNE, S., OWEN, M., LAWRENCE, P.J. and FILIPIDIS, L. A comparison of predictions from the building EXODUS evacuation model with experimental data. *Proceedings of the First International Symposium on Human Behaviour in Fire*. 1998, pp. 711-720.

[29] BRYAN, J.L. Behavioural response to fire and smoke, in SFPE Handbook of Fire Protection Engineering, Second Edition, Ed. By P.J. DiNenno et al., Society of Fire Protection Engineers, Boston, MA and National Fire Protection Association, Quincy, MA, USA, (1995). Clause 3, Chapter 12, pp. 3-241 – 3-262.4.

[30] WOOD, P.G. *The behaviour of people in fires*. Fire Research Station, UK, Fire Research Note 953, 1972.

[31] BRYAN, J.L. *Smoke as a determinant of human behaviour in fire situations (project people)*. National Bureau of Standards, Washington D.C. USA Report NBS GCR-77-94.

[32] PURSER, D.A. Toxicity Assessment of Combustion Products. *The SFPE Handbook of Fire Protection Engineering 3rd ed*). DiNENNO, P.J (ed.), National Fire Protection Association, Quincy, MA 02269, 2002, pp. 2/83 – 2/171.

[33] JIN, T. *Visibility through fire smoke, Part 5. Allowable smoke density for escape from fire*. Report of Fire Research Institute of Japan, No. 42, 12 (1975).

[34] PURSER, D.A. Human tenability. *Proceedings of Technical basis for performance-based fire regulations*. Engineering Foundation Conference 7-11 January 2001. San Diego Ca USA.

[35] HOCKEY, S.M. and REW, P.J. (1996) *Human response to thermal radiation. Contract Research Report* No. 97/1996. HSE Books. PO Box 1999, Sudbury Suffolk CO10 6FS UK. p. 49.

[36] FRUIN, J.J. *Pedestrian planning and design*. Metropolitan Association of Urban Designers and Environmental planners Inc, 1971, New York.

[37] PREDTECHENSKII, V.V. and MILINSKII, A.I. *Planning for foot traffic in buildings* (translated from Russian). Stroizdat publishers, Moscow, 1969. English translation published for National Bureau of Standards and the National Science Foundation, Washington, by Amerind Publishing Co. Pvt. Ltd, New Delhi, India (1978).

[38] ANDO, K., OTA, H. and OKI, T. Forecasting the flow of people (Japanese), *Railway Research Review*. Vol. 45, 1988, pp. 8-14, in GWYNNE *et al.*

Further reading

GREAT BRITAIN. Fire Precautions Act 1971. London: The Stationery Office.

GREAT BRITAIN. Fire Precautions (Workplace) Regulations 1997 (as amended). London: The Stationery Office.

GREAT BRITAIN. The Building Regulations 1991. London: The Stationery Office.

GREAT BRITAIN. The Building Standards Scotland, 1990. Edinburgh: The Stationery Office.

NORTHERN IRELAND. The Building Regulations (Northern Ireland), 1994. Belfast: The Stationery Office.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001. Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001. Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

BSI
389 Chiswick High Road
London
W4 4AL