

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)

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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.

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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.

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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.

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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:

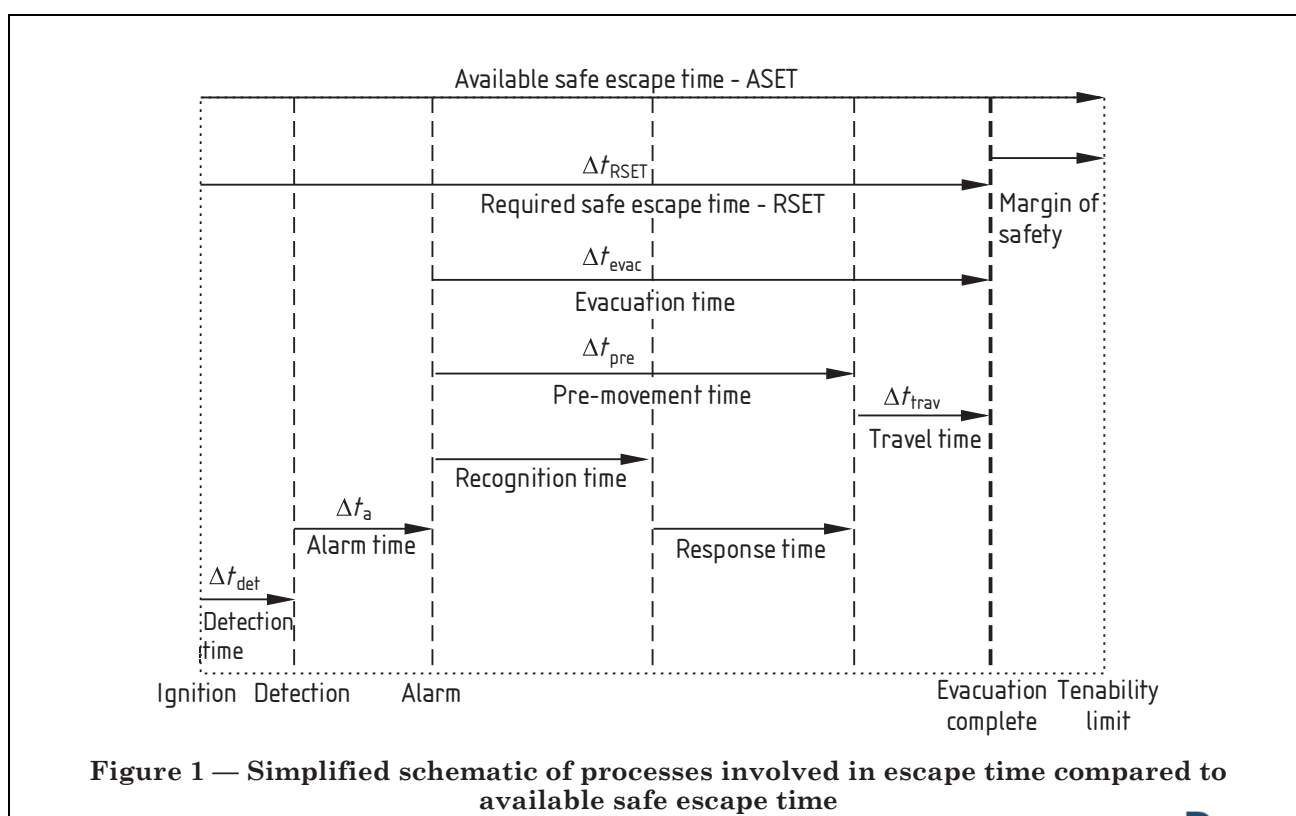
- Pre-movement behaviours*: those involved in the responses of occupants before they start to move through escape routes that fall into the category of “pre-movement” behaviours. Although pre-movement behaviours may involve periods when occupants are inactive, they also include a range of behaviours 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];
- 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.



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).

$$t_{\text{margin}} = t_{\text{ASET}} - t_{\text{RSET}} \quad (1)$$

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).

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

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: $[\Delta t_{\text{pre}} (\text{first occupants})]$;
- 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: $[\Delta t_{\text{pre}} (\text{occupant distribution})]$.

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 $[\Delta t_{\text{trav}} (\text{walking})]$ [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 [$\Delta t_{\text{trav (flow)}}$]. 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	Awake	Unfamiliar	High	One or few	Shop, restaurant, circulation space
B2	Awake	Unfamiliar	High	One with focal point	Cinema, theatre
Ci	Asleep Long term: individual occupancy.	Familiar	Low	Few	Dwelling Without 24 h on site management.
Cii	Managed occupancy:				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):

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

where:

$\Delta t_{\text{trav (flow)}}$ is the time of total occupant population to flow through 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 an 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 %.