APPENDIX A1-1 AND A1-2: REVIEW OF PHYSICAL MEASURES AND INTERNATIONAL GUIDANCE DOCUMENTS

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[1] OFR, [2] Movement Strategies / GHD, [3]Efectis

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A1-1 Overview and objective

A1-1.1 Introduction

In June 2017, the Grenfell Tower fire resulted in the death of 72 residents, many others becoming homeless and a wider impact on the local community. The incident also posed a significant challenge to the operational capabilities of London Fire Brigade. In response to the Grenfell Tower fire, Dame Judith Hackitt conducted an independent review of Building Regulations and fire safety in England where she noted that "…*further research with the construction industry to understand who uses Approved Documents, how they are used and where they are used to influence how they should be developed in the future*…" was needed.

This report provides the first stage deliverable in a project that considers the means of escape in residential buildings as part the further research by MHCLG* on any future technical changes to Approved Document B (AD B). An abbreviated summary of the objective and associated tasks covered in this report is as follows:

- **Objective A1:** Establish building design principles underpinning evacuation strategies.
    - **Task A1_1:** Review literature on physical design measures which support or influence building evacuation. Examine literature that identifies non-residential / non-UK design measures that might be employed in a UK residential setting, and examine measures employed in mixed-use settings. Identify measures and underlying assumptions in relation to benefits on building evacuation and mitigation of fire conditions.
    - **Task A1_2:** Review regulations and authoritative guidance regarding means of escape in residential buildings, including UK and international resources.

In addition to the above two tasks, a third task (**Task A1_3**) has been carried out in parallel to identify current trends in residential buildings related to means of escape. The task, which is detailed in a separate report, has involved engagement with a group of industry professionals to understand future design and building use trends. It has also carried out a review of selected published articles in relevant trade journals, but not an extensive appraisal of the literature.

A1-1.2 Evacuation strategies

The fire safety strategy is a means to provide sufficient level of safety for building occupants. This strategy will define a design approach that considers the population present, the use of the building and the procedural resources available. The fire safety

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* The research was originally commissioned by the Ministry of Housing, Communities and Local Government (MHCLG) which subsequently became the Department for Levelling Up, Housing and Communities (DLUHC) which then transferred its fire safety responsibilities to the Health and Safety Executive (HSE).

strategy will also include occupant management strategy that could range from stay-put to full simultaneous egress. The result of an appropriate fire safety strategy will be foreseeable and acceptable fire scenarios, predictable building behaviour as well as adequately manged occupant population.

The achievable evacuation performance (e.g. the time for the population to reach safety) is a product of the physical design, the procedures in place, the population present and the conditions faced. it is not likely that addressing one aspect independently of the others will effectively mitigate the risks faced.

A1-1.2.1 Simultaneous evacuation

Simultaneous evacuation involves the concurrent broadcast of an alarm to all floors and the evacuation of all building occupants at the same time. The use of a simultaneous egress strategy does not, by default, give preference to those occupants close to the fire. It also places the maximum demand on the egress capacity of egress system (e.g., stairs and corridors). Components designed to accommodate simultaneous evacuation generally require greater capacity given this elevated demand (i.e., the resident population potentially arriving at the same time). This approach means that the building functionality will be disrupted, irrespective of the size of the incident once the alarm sounds and may impact on the operational ability of the fire and rescue services.

A1-1.2.2 Other evacuation strategies

Phased / staged / sequential procedures typically focus on (or at least prioritise) those residents in the immediate vicinity of the fire. This allows those people in immediate danger to access to egress routes at relatively low demand – making the most efficient use of the egress provisions available. Occupants from other locations may evacuate afterwards reducing the loading on the available egress routes. For small fires (or false alarms), the disruption can be kept to a minimum, enabling day-to-day operations to resume in short order. Those occupants within the zone being evacuated are given a local warning signal while those outside the evacuation zone are either notified of a developing incident and told to remain in place and await further instruction or are given no warning at all and continue routine activities.

One approach to phased evacuation is the initial evacuation of the fire floor along with a pre-determined number of floors above / below the fire floor. Other floors ‘defend-in-place’ and are not expected to evacuate (certainly not at that time unless they are exposed to fire or smoke). Alternatively, it may be that only the compartment of fire origin evacuates, e.g., those in a single apartment, and others on the fire floor remain in place. In the UK, this approach to the evacuation of residential buildings is often adopted and is referred to as a ‘stay put’ strategy. Given that a large proportion of the residents remain in place for the defend-in-place and stay put evacuation strategies, a greater onus is placed on building’s compartmentation, as it is important that people located outside the initial evacuation zone are unaffected by the incident until those within the affected zone have evacuated.

Occupants of the area of fire origin (e.g., apartment) are assumed to evacuate to a place of relative safety and then ultimate safety (initially inside the building and ultimately outside the building) and all other areas, either on the same level or above / below, remain in place. The compartmentation of the fire floor is assumed to be a defence for occupants elsewhere in the building. The defend-in-place approach is reliant on the level of fire and smoke resistant compartmentation between adjacent evacuation zones, requiring each dwelling to be constructed as its own fire compartment. It also requires that the occupants have confidence in this protection and remain in place as egress route capacity may only be able to only accommodate a fraction of the resident population.[†]

Progressive (or staged) evacuation is similar to a phased evacuation, except that those in the evacuation zone are evacuated to a safe area within the building remote from the fire location. Evacuees will either remain there or, if threatened further, be relocated to an alternative safe area with the building – hence the 'progressive' nature of an occupant's evacuation. The relocation of occupants can either be horizontal or vertical to a dedicated region depending on the design of the building, e.g., making use of a refuge area / floor. The evacuation of residents with mobility impairments usually adopts this approach even if the remainder of ambulant occupants evacuate by some other manner. Typically, this evacuation strategy is not applied to residential buildings but is a feature of hospitals and other institutional occupancies.

In tall residential buildings, the horizontal portion of egress is usually relatively short, with evacuees typically spending comparatively more time evacuating via the stairways. Although at a reduced risk, stair evacuees are still reliant on the building's ability to withstand the developing fire over time and for this protection to not be undermined (e.g., stair users leaving the stair door open compromising the tenability of the stair conditions).

Finally, some structures contain more than one occupancy type and therefore a sub-set of the overall phased evacuation procedure may also be present. It is common design practice to share the vertical egress components among the various occupancies present - by doing so, egress strategies are also mixed. Attention will be needed to the interaction between adjacent occupancies, and the evacuation strategies employed. The sharing of vertical escape routes between occupancies is beyond the realms of simple guidance and requires great care and competent consideration.

A1-1.3 Evacuation process

The type of evacuation strategy (along with any fire and rescue service operational activities) can potentially influence the movement of fire and smoke around a building. For example, where people move from one compartment to another they will need to travel through doors. In some cases, the doors may have self-closers installed and where doors

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[†] BS 9991 and AD B vol. 1 use 'stay put' to define the specific strategy of residential buildings and flats (e.g., not mentioned in AD B vol. 2 or BS 9999). 'Defend-in-place' is a broader term, to describe other variants of this approach (e.g. the fire floor / evacuation zones rather than flats). As such, the stay put strategy is assumed to be a sub-set of defend-in-place strategies.

do not have self-closers then there is the potential for people to leave them open. Active systems such as corridor ventilation, stairwell pressurisation etc. can somewhat mitigate the effects of smoke on occupant evacuation. The effectiveness of an evacuation strategy may also be subject to the occupant numbers that are expected to use the available evacuation provisions.

Emergency procedures can be designed to exploit the physical measures by encouraging evacuee response. However, the effectiveness of physical measures is not completely independent of evacuee behaviour. It is incumbent on residents knowing what the physical measures do, how they operate, and what needs to be done or not done to operate them. For instance, understanding the alarm signal, doors being left open / closed, detectors being functional, resident awareness, experience and capacity to use the measures provided, whether the lifts are available for evacuation and whether people are willing to use them. Occupants may not be aware be of the measures provided which could not only undermine the egress conditions of the evacuating resident in question, but it may also affect the surrounding evacuating population.

The provisions in many fire safety codes / standards / guidance do not explicitly account for the variation present in the awareness of measures in place, willingness to use them and capacity to use them – across the general population or within specific sub-populations. In reality, these elements will vary widely and will influence if, when and how people evacuate. It is also important to note that often measures do not act in isolation but form part of the system. For example, there is no benefit having a highly effective alerting system if there are no means of detecting a fire. This interaction of measures could be a flaw in some code-based approaches.

For effective fire engineering calculations, evacuation performance is typically assessed against fire development, as part of so called ASET / RSET comparison (Figure A1-1). The fire safety measures presented in this review affect the ability of occupants to follow a fire safety strategy in several ways. They provide means to increase the available time for escape, by reducing the pre-evacuation delay time and/or providing more effective movement. Some measures affect the development of a fire while others increase the time before occupants become exposed to fire products. However, none of the measures prevent fires from starting as this aspect is the remit of other fire safety design and legislation, e.g. by requiring certain products meet a specific standard of electrical safety. In the analysis of Hall [1] he examined what the impact on the number of fire fatalities and injuries in homes might be were more time available for escape. Depending on factors such as the initial activity of the victims, their behavioural response to the fire and their ability to make an escape he found that up to "*roughly one-half of fatal victims and roughly two-thirds of non-fatal victims are estimated as saveable with extra escape time*". This result assumed that sleeping victims in which no smoke alarm was present would have a working smoke alarm. However, Hall noted that the estimates had large uncertainty bands and depending on the assumptions made, the number of saveable deaths could be almost zero, thus "*Extra time alone would probably help only the victims who were attempting escape, and they represent only one-fourth of fatally and non-fatally injured victims*". Thus, the ability to 'save' victims by affording them extra escape time is not a straight-forward matter.

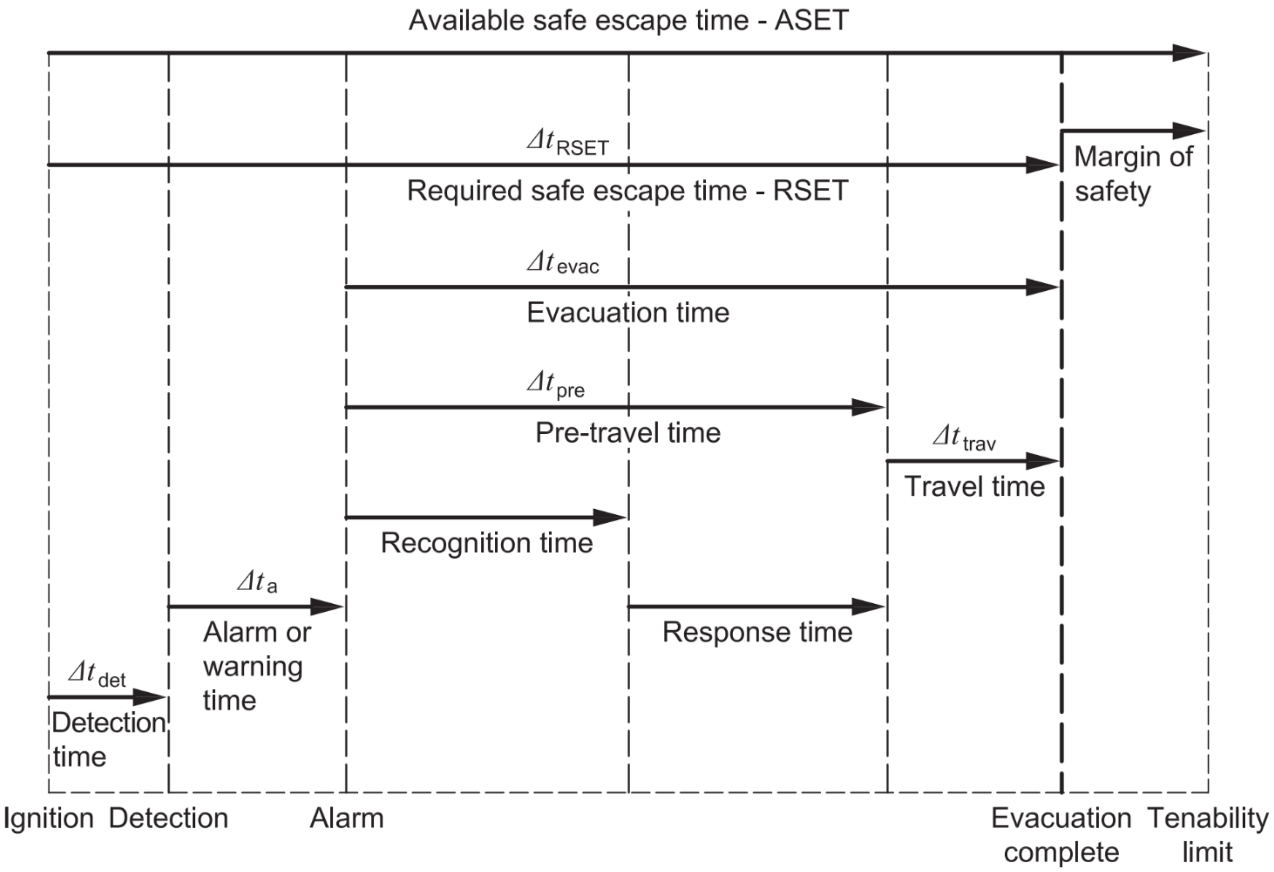

Figure A1-1 Required safe escape time (RSET) against available safe escape time (ASET), reproduced from BS PD 7974-6 [2]

A1-2 Review process

The focus of this review is to identify physical measures, and their associated attributes and design variants, which could affect evacuation from buildings in the event of a fire. The review is also intended to broadly highlight the benefits and limitations that different systems may provide. By undertaking the review, this allows for the consortium to in future identify any omissions from the existing fire safety guidance provided in AD B, which can be explored further in the later objectives.

The review is broken down into two phases: a review of fire safety research literature, where the review process for this is discussed in Section A1-2.1; and a review of international fire safety guidance documents and standards, with the process discussed in Section A1-2.2. This collective process has contributed to a robust review which draws upon the expertise and knowledge of the consortium, while capturing a wide range of literature and design approaches across the world. The process has ultimately been used to produce a final matrix of fire safety measures and their impact on evacuation, which is presented in Section A1-3.

The review detailed in this document is not intended to be an exhaustive review of all research publications available on the addressed topics, since it has been identified that this would require hundreds of thousands of documents to be reviewed in detail.

A1-2.1 Task A1_1 (literature review)

A1-2.1.1 Overall literature review process

The literature review process has been adapted from the work of Khan et al. [3] on conducting systematic reviews. A summary of the process is presented in Figure A1-2, with the relevant Khan et al. phases shown on the left, followed by a brief description of the process step and the associated tasks and actions.

A1-2.1.2 Step 1: initial development of review structure and matrix

The initial design pass identified the physical fire safety provisions categorised in Table A1-1. For this process, the categorisation has been informed by the existing knowledge base and expertise of the authors, along with two additional systematic methods:

- An informal review of OFR commercial fire strategies for non-residential, residential and mixed-use buildings across multiple jurisdictions. This approach has been adopted to gain an international perspective of fire safety design in practice, albeit based on a limited number of actual buildings developed in recent years.

- The physical provisions referred to have also been collated as a result of a high level review of international fire safety codes, guidance documents and standards including Approved Document B Volume 1 (AD B) [4], Building Standards Technical Handbook (STH) [5], British Standard BS 9991:2015 (BS 9991) [6], National Fire Protection Associate NFPA 101 Life Safety Code (NFPA 101) [7], New Zealand Acceptable Solutions for Buildings (C/AS2) [8], the International Building Code (IBC) [9], the National Building Code of Canada (NBC) [10] and the National Construction Code Volume One – Building Code of Australia (NCC) [11].

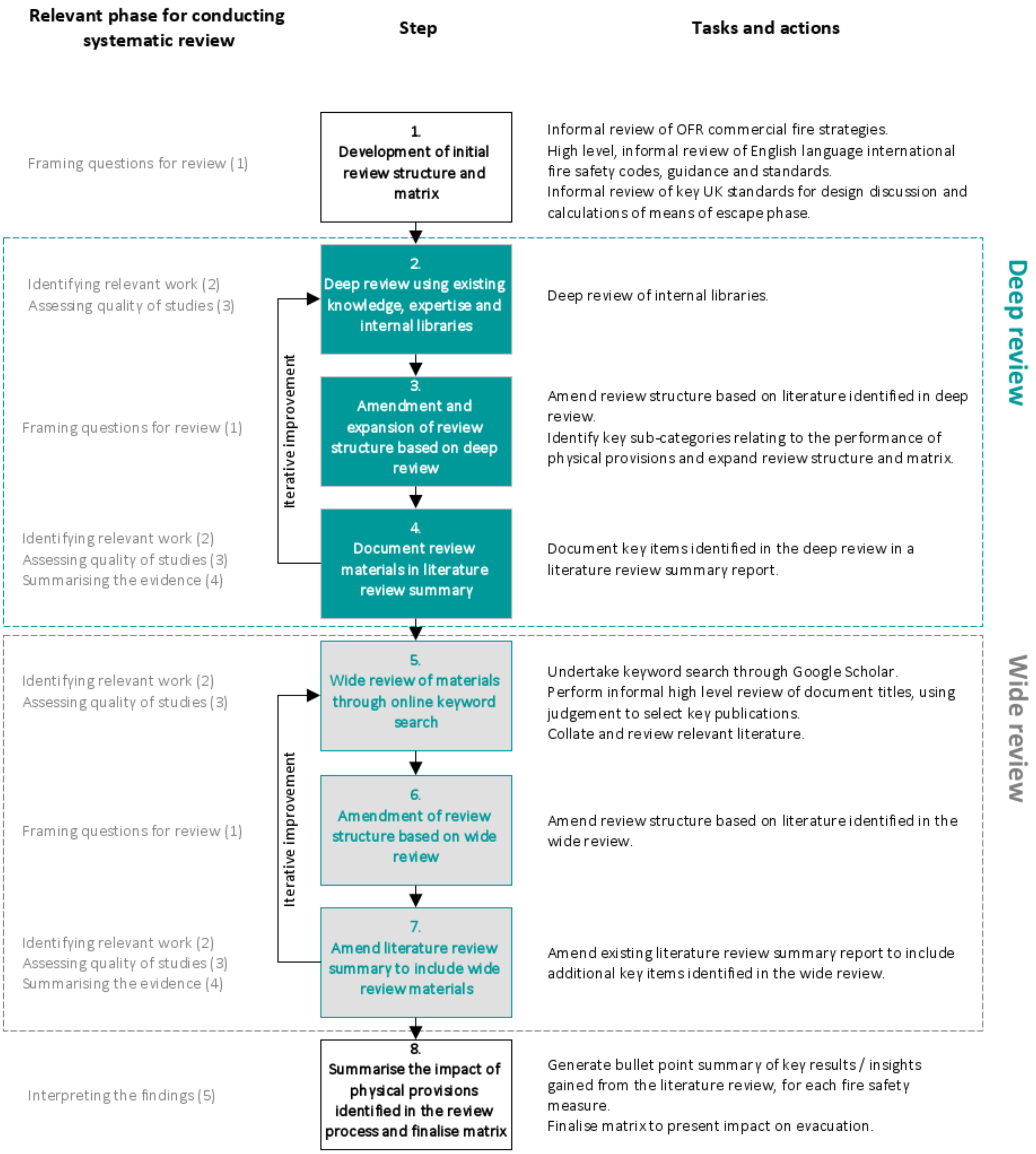

Figure A1-2 Schematic for the overall review process

Table A1-1 Main categories of the document for the physical fire safety provisions in residential buildings

Physical provisions	Description	Section
Active measures	Active measures refer to active fire safety systems that require some degree of action to operate. Their operation could be manual or automatic. **Measures:** detection, notification systems, audible alarms, visual alarms and beacons, staff intervention, suppression, smoke control and emergency lighting.	Sections A1-4.1 & A1-B.1
Passive measures	Passive measures refer to passive fire safety systems that do not require any action to operate, but instead provide an inherent means of fire safety through their incorporation in the building. **Measures:** fire separation, construction materials, structural design, signage and wall plans.	Sections A1-4.2 & A1-B.2
Horizontal egress	Horizontal egress refers to the physical provisions to occupant escape on one level of a building. It includes the impact of constrictions on movement flow. **Measures:** internal dwelling arrangements, corridors, doors, balconies and refuge points.	Sections A1-4.3 & A1-B.3
Vertical egress	Vertical egress provisions allow occupants to move down (or up) building levels. Movement may be through mechanical systems such as lifts / elevators or by self-movement. **Measures:** Stairs, evacuation lifts, movement devices and other means of vertical egress (escape windows, ladders etc.)	Sections A1-4.4 & A1-B.4
Firefighting*	Firefighting refers to measures intended to assist with fire and rescue services operations. Firefighting often involved the rescue of occupants and therefore has the potential to influence the evacuation procedures of the building. Firefighting may also impact the development of the fire, which in turn impacts conditions for escaping occupants. **Measures:** Fire mains and hydrants, firefighting lifts, and smoke clearance.	Sections A1-4.5 & A1-B.5

*** Note:** For the purposes of this process, firefighting provisions have been listed under a separate category, but some measures will fall into other categories, such as active and passive measures. Reference to firefighting provisions relates specifically to their impact on means of escape and not necessarily on firefighting operations, with the latter being covered under a separate research project.

With respect to the provisions detailed in Table A1-1, consideration has been given to their consequence on occupant escape, for the escape categories presented in Table A1-2. The categories have been selected by considering the common processes involved in the estimation of escape times discussed in Section A1-1.3, PD 7974-6:2019 [2] and the Society of Fire Protection Engineering (SFPE) Handbook [12], in particular the chapter relating to human behaviour in fire [13]. An additional category is added for the mitigation of fire conditions and its impact on occupant escape. It is important to note that the physical provisions are not independent topics, that they are integrated and co-dependent, for example active systems for example often rely on a fire scenario defined by passive measures. Similarly, the physical provisions may rely on or respond to the actions of occupants and / or emergency responders.

Table A1-2 Description of the influence of physical measures on means of escape in residential buildings

Escape phase category	Description
Pre-evacuation	
Recognition	Measures that alert individuals that an incident exists and affect the time to process the cues provided.
Preparatory actions – physical	Measures that affect the actions taken by individual to facilitate evacuation movement or enable individual to disengage with pre-incident activities.
Preparatory actions – situational awareness	Measures that affect the information-related processes that affect the actions taken to enhance understanding - both situational awareness, risk perception and available options. Actions (which may or may not involve movement) related to gathering and dissemination of information prior to evacuation movement.
Movement	
Wayfinding / route selection	Measures which qualitatively affect decision-making during evacuation movement, affecting the route awareness, assessment and use.
Physical travel	Measures which directly impact the physical actions of movement and movement performance, such as movement speed in corridors / stairs etc. and the associated flow.
Mitigation	
Ignition	Measures which impact the possibility of fire ignition and the initiation of a fire incident, with the likelihood of fire ignition having a direct consequence on whether: (a) occupants need to escape; and (b) the conditions occupants may face when escaping.
Fire growth and spread	Measures which affect the progression and severity of the fire where, as above, this may impact the occupants' need to escape and the conditioned faced when escaping.
Smoke spread	Measures which affect the progress and severity of smoke spread where, as above, this may impact the occupants' need to escape and the conditioned faced when escaping. Smoke spread has been separated from fire spread due to differences in how smoke may impede escape.

A1-2.1.3 Steps 2 to 4: Deep review using existing knowledge, expertise, and internal libraries

The authors are in possession of a library of information which has been collated over their years of experience and involvement in the discipline, with a pre-existing awareness of much of the literature and historical development of physical provisions and their impact on evacuation. This knowledge has been used in the initial steps to form the ‘deep review’ process, from which a ‘wide’ systematic review can later be used to fill any gaps. For this, relevant citations have been extracted from internal libraries.

The deep review is also intended to identify the attributes of a provision which are deemed to affect performance, as well as ‘design variants’, which are the different types of the physical provision which are available. As a means of limiting the review, the listed attributes have been limited to those identified as most significant to performance, while the design variants are limited to those most commonly faced when undertaking the literature review.

The deep review process has been documented in the detailed literature review shown in Appendix B, which discusses the key items of literature for each physical measure. Each paragraph in the detailed literature review has been numbered consecutively to assist with cross-referencing.

A1-2.1.4 Steps 5 to 7: Broader review of public materials through online keyword search

Given the potential for a vast quantity of documents to be identified using single-word keyword online searches, this work has used an approach to filter the documents down to a more refined pool, from which the authors have used their judgement to select appropriate documents or undertake additional searches where needed. The online search tool Google Scholar has been used to assist in the wide review process, adopting high-level keywords and Boolean logic to address synonymous terms. Further information on the broad review search methods can be found in Appendix A1-A.

The review process has been documented in the detailed literature review summary shown in Appendix A1-B. The content of the deep review included in this section has been supplemented with the material identified in the wide review.

A1-2.1.5 Step 8: Documenting the impact of physical provisions identified in the review process

After the deep review and wide review have been written and documented in Appendix B, a final impact summary table has been produced and attached to each measure which highlights:

- The attributes deemed to affect the performance.
- The key design variants.
- How the measure affects the evacuation process.
- Key qualitative or quantitative results and insights identified in the review.

These summary tables are presented in Section A1-4. The summary tables have then been combined into a final collective matrix, which is presented in Section A1-3.

A1-2.2 Task A1_2 (review of guidance documents and standards)

The review of global fire safety codes of practice, guidance and standards (referred to collectively hereafter as ‘fire safety documents’) focusses on physical measures recommended or required for ‘high-rise’ residential buildings in the relevant jurisdictions. For the purposes of this portion of the review, a ‘high-rise’ building is any building where the uppermost occupied storey is above 18 m from the building access level (excluding roof-top plant areas or any storey consisting exclusively of plant rooms). This is the definition used in the Home Quality Mark (HQM) technical manual [14] and is consistent with common ‘trigger heights’ in UK fire safety documents for various design elements, although other documents and jurisdictions will have different definitions, such as NFPA 101 [7] stating that high-rise refers to any building over 75 ft (23 m) (for an equivalent definition of building height given in AD B). For the review, the following points have been considered:

- The expectations of fire safety documents will vary for different building design ‘triggers’. One of the more commonly considered triggers is the height of the building. Therefore, the summary of provisions is separated out by three main starting trigger height bands: (a) buildings > 10 m and up to 23 m; (b) buildings >25 m and up to 37 m; and (c) buildings >45 m. The three triggers are specified as a range because each fire safety document may have slightly different starting trigger heights, and therefore these have been collated to cover similar range of heights between the documents. Thus, a starting trigger height of say 18 m falls into band (a) but would then apply to all buildings above 18 m not just up to 23 m. The three bands represent the more common trigger heights for buildings in the UK, although it is acknowledged that documents like AD B include a substantially greater number of trigger heights for different provisions.

- The fire safety document review specifically summarises provisions within dwellings / apartments and any areas of the building which form the common escape route (e.g., common corridors, common lobbies, and stairs). Ancillary areas, plant rooms, basements, retail areas etc. are excluded. This has been done to simplify the review and focus on areas of fire safety building design which are specific to residential means of escape.

- Each of the review tables typically includes three to five key design elements across the fire safety documents for each of the identified physical measures, as well as relevant document clause/s. The list is therefore not exhaustive. It is acknowledged that many of the nuances and variations of the fire safety documents may not be captured in this tabulated, simplified approach. However, to capture all these nuances would be a lengthy process, outside the scope of the task, and to reach the necessary level of detail may ultimately be detrimental when trying to compare across the different documents.

The international fire safety document review considers the English language documents listed in Table A1-3, using the latest available version for each. The main trigger heights identified within each document are listed in Table A1-4. In some instances, only one or two obvious trigger heights have been identified and therefore values for trigger height bands 2 or 3 may not be included.

The final output for the review of the fire safety documents can be found in Section A1-5. Throughout the review, terminology has been taken directly from the relevant document, rather than being written in a consistent terminology.

Table A1-3 Guidance documents and standards considered in the fire safety document review

Document short form	Primary jurisdiction / country	Full document title	Limits
AD B	England	Approved Document B Volume 1: Dwellings (2019)	Limited to common building situations
STH	Scotland	Building Standards Technical Handbook: Domestic (2019)	Only suitable up to 60 m
BS 9991	UK	BS 9991 Fire Safety in the Design, Management and Use of Residential Buildings (2015)	Buildings taller than 50 m should include a qualitative design review (QDR) to BS 7974 and consider performance-based evidence of solutions
NFPA 101	USA	NFPA 101 Life Safety Code (2021)	No limit
C/AS2	New Zealand	Acceptable Solutions for Buildings (2019)	Only suitable for buildings up to 20 storeys, 85 m
IBC	USA ('International')	International Building Code (2018)	No limit
NBC	Canada	National Building Code of Canada (2015)	No limit
NCC	Australia	National Construction Code Volume One, Building Code of Australia (2019)	No limit

Table A1-4 Trigger heights for the guidance documents and standards considered in this review

Document short form	Trigger Height 1	Trigger Height 2	Trigger Height 3
AD B	18 m	30 m	50 m
STH	18 m	-	-
BS 9991	18 m	30 m	50 m
NFPA 101	18 m	23 m	51 m
C/AS2	10 m	25 m	-
IBC	18 m	37 m	50 m
NBC	13 m	25 m	-
NCC	17 m	25 m	-

A1-3 Review matrix

Table A1-5 Review matrix which provides high level summary of active measures and how they impact escape

	Active measures							Passive measures				Horizontal egress					Vertical egress				Firefighting		
	Detection	**Audible alarm**	**Visual alarm / beacons**	**Staff / resident intervention**	**Emergency lighting**	**Suppression**	**Smoke control**	**Fire separation**	**Construction materials**	**Structural design**	**Signage / wall plans**	**Internal dwelling arrangement**	**Corridors**	**Doors**	**Balconies**	**Refuge points**	**Stairs**	**Evacuation lifts**	**Movement devices**	**Other**	**Fire mains and hydrants**	**Fire-fighting lifts**	**Smoke clearance**
Report section	**A1-4.1.1 A1-B.1.1**	**A1-4.1.2 A1-B.1.3**	**A1-4.1.3 A1-B.1.4**	**A1-4.1.4 A1-B.1.5**	**A1-4.1.5 A1-B.1.6**	**A1-4.1.6 A1-B.1.7**	**A1-4.1.7 A1-B.1.8**	**A1-4.2.1 A1-B.2.1**	**A1-4.2.2 A1-B.2.2**	**A1-4.2.3 A1-B.2.3**	**A1-4.2.4 A1-B.2.4**	**A1-4.3.1 A1-B.3.1**	**A1-4.3.2 A1-B.3.2**	**A1-4.3.3 A1-B.3.3**	**A1-4.3.4 A1-B.3.4**	**A1-4.3.5 A1-B.3.5**	**A1-4.4.1 A1-B.4.1**	**A1-4.4.2 A1-B.4.2**	**A1-4.4.3 A1-B.4.3**	**A1-4.4.4 A1-B.4.4**	**A1-4.5.1 A1-B.5.1**	**A1-4.5.2 A1-B.5.2**	**A1-4.5.3 A1-B.5.3**
Pre-evacuation																							
Recognition	✓	✓	✓	✓																			
Preparatory actions – physical		✓	✓																				
Preparatory actions – awareness		✓	✓	✓	✓						✓					✓							
Evacuation movement																							
Wayfinding / route selection		✓	✓		✓					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Physical travel			✓							✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Mitigation																							
Ignition									✓	✓													
Fire growth and spread				✓		✓		✓	✓	✓		✓									✓	✓	
Smoke spread							✓	✓	✓	✓		✓											✓

A1-4 Literature review summary

A1-4.1 Active measures

A1-4.1.1 Fire detection

Table A1-6 Summary of fire detection attributes, variants, and impact on evacuation performance

<table>
<tr><td colspan="2">Attributes deemed to affect performance</td><td colspan="6">Detection mechanism, multi-sensor devices, location / spacing of devices</td></tr>
<tr><td colspan="2">Design variants</td><td colspan="6">Heat, smoke, carbon monoxide (CO), other combustion gases, visual, flame, odour, sound</td></tr>
<tr><th colspan="3">Pre-evacuation</th><th colspan="2">Evacuation movement</th><th colspan="3">Mitigation</th></tr>
<tr><th>Recognition</th><th>Preparatory actions – physical</th><th>Preparatory actions – awareness</th><th>Wayfinding / route selection</th><th>Physical travel</th><th>Ignition</th><th>Fire growth and spread</th><th>Smoke spread</th></tr>
<tr><td>✓</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Impact summary</td><td colspan="6">• Automatic fire and smoke detection is a substitute / enhancement to the ability of people to become aware of the likely presence of fire.
• Automatic detection can increase the likelihood of successful fire suppression, escape and survivability, but this may not always be the case.
• Type of detector in terms of the sensor/s and processing algorithms can affect the effectiveness.
• Installing automatic fire and smoke detection appears to provide a similar benefit to building occupants irrespective of their vulnerability.</td></tr>
</table>

A1-4.1.2 Audible alarms

Table A1-7 Summary of audible alarm attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Volume / audibility / intensity (dBA), content message, message length, number of repetitions, intelligibility (voice), consistency of message, type of voice, periodicity, frequency (Hz), tone type, ambient noise, coverage, connectivity, language used (voice), accuracy of content (voice), familiarity / credibility of voice.					
Design variants		Bell T-3, voice – recorded, voice – live / public address, directional, white noise					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
✓	✓	✓	✓				
Impact summary		• Provides a means to support the resident's awareness that they may be at risk from an incident. • The type of audible message will determine whether it is intended solely as an alert, or whether the type of incident, the severity of the incident, the population affected, and the required response is communicated. • The resident population may not perceive equivalent signals / messages, given issues of alarm coverage, connectivity, sensory impairments, activities being performed at the time, and / or background noise. • It cannot be taken for granted that all people will have access to the same information or act on this information in the same way.					

A1-4.1.3 Visual alarms and beacons

Table A1-8 Summary of visual alarm attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Colour, brightness, content (screen), length of message (screen), background lighting coverage, frequency / periodicity					
Design variants		Strobe, LED, screen, mobile device					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
	✓		✓				
Impact summary		• Not all populations will be able to receive audible signals. These are then particularly vulnerable to prolonged pre-evacuation delays (i.e., before commencing evacuation) • Where individuals have hearing impairments, there is background noise or other limitations (e.g., people wearing headphones), visual alarms may provide another option to alert individuals. • The effectiveness of visual alarms is limited by it being confined by spatial size / design. • Care must be shown in the design of visual alarms so as to not cause adverse reactions, especially in vulnerable populations (e.g., those with cognitive issues or epilepsy).					

A1-4.1.4 Staff / resident intervention

Table A1-9 Summary of staff / resident intervention attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Staff, occupants, manual call points, first-aid firefighting					
Design variants		Training, occupant role and expectations, leadership, credibility, location					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
✓	✓	✓	✓	✓		✓	
Impact summary		• Staff intervention ○ Staff could be in the building or remotely and could take on a number of roles in the event of a fire including notification of occupants, assisting with the movement of vulnerable occupants. ○ Training, credibility, leadership qualities can all be important factors in the effectiveness of staff. ○ The presence of staff can reduce the overall evacuation time of occupants in a building. • Manual call points (MCPs) ○ Unclear what the evacuation benefit of installing MCPs into buildings. ○ Malicious damage and activation may limit the benefit of placing MCPs into the common area of residential buildings. • First-aid firefighting ○ First-aid firefighting can be achieved using various means including extinguishers, blankets and other ‘sundry means’ ○ Operation of extinguishers may be able to reduce the severity of a fire at its early stage (or extinguish it), particularly where the user is trained. ○ It is suggested that the hand-held fire extinguishers may promote occupants moving towards the fire and remaining close to it for longer – potentially increasing their exposure.					

A1-4.1.5 Emergency lighting

Table A1-10 Summary of emergency lighting attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Brightness, visibility of other physical elements, colour, location					
Design variants		Floor or ceiling locations, lux					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
		✓	✓				
Impact summary		• Emergency lighting reduces likelihood of 'panic'. • Reduced lighting levels slow movement speeds. • Emergency lighting may not provide much benefit when smoke is present in evacuation routes, particularly when compared to specific safety way guidance systems.					

A1-4.1.6 Suppression

Table A1-11 Summary of suppression attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Nozzle / head location and spacing, thermal sensitivity of nozzles / heads, type of suppressant (water, gas, foam etc.), flow rate (discharge density), suppressant source, means of activation					
Design variants		Sprinklers, watermist, foam, gaseous agents, chemical agents					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
						✓	
Impact summary		• Suppression systems assist escape by restricting fire growth and spread, reducing severity of conditions faced by building occupants. • Suppression can substantially improve the likelihood of occupants surviving in apartment fires.					

A1-4.1.7 Smoke control

Table A1-12 Summary of smoke control attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance	Vent and shaft areas, locations, orientations, volumetric flow rates, pressure differentials, means of operation, system reliability						
Design variants	Natural vents, natural smoke shafts, mechanical extract, pressurisation, depressurisation						
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
							✓
Impact summary	• Smoke control assists evacuation by reducing the extent of smoke development (e.g., in the fire-affected enclosure) or limiting smoke spread to other enclosures. • Smoke control in residential design typically focusses on protecting common escape routes, such as corridors and stairs. Such systems are reliant on fire and smoke spread being limited to a single storey. • The effectiveness of provisions can be highly susceptible to external conditions, such as wind and temperature. • The effectiveness of provisions can be highly susceptible to external conditions, such as wind and temperature. Commissioning and maintenance can also affect system reliability and efficacy.						

A1-4.2 Passive measures

A1-4.2.1 Fire separation

Table A1-13 Summary of fire separation attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Resistance rating (stability / loadbearing capacity), resistance rating (integrity), resistance rating (insulation), enclosure area / volume					
Design variants		Fire-rated walls, fire-rated slabs, fire-rated doors (and smoke seals), fire-rated glazing, fire shutters / curtains					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
						✓	✓
Impact summary		• Fire separation reduces fire and smoke spread by restricting the size of the enclosure of fire origin. • Fire separation is used to separate and protect important means of escape areas, such as corridors and stairs. • A potential source of smoke spread through fire separation lines is doors, which can be propped or wedged open, or may leak smoke even when closed. Automatic release hold-open devices and other such devices can be introduced to reduce the likelihood of this occurring, as well as smoke seals to reduce the extent of leakage.					

A1-4.2.2 Construction materials

Table A1-14 Summary of construction material attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Reaction-to-fire properties					
Design variants		Ignitability, energy release, smoke and toxic product yields					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
					✓	✓	✓
Impact summary		• The type of construction materials used in buildings could affect the severity of a fire in terms of energy release and/or smoke and/or toxic product generation. • Measures such as fire separation and smoke control systems can be used to reduce the affect that the combustion of construction materials may have on evacuation.					

A1-4.2.3 Structural design

Table A1-15 Summary of structural design attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Resistance rating (stability / loadbearing capacity), contribution to fuel load					
Design variants		Concrete, steel, composite, timber					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
			✓	✓	✓	✓	✓
Impact summary		• The ability of the structural design to maintain stability is important in allowing sufficient time for occupants to escape and the fire and rescue service to attack the fire. • Structural elements have the potential to contribute to fire development and facilitate fire spread.					

A1-4.2.4 Signage and wall plans

Table A1-16 Summary of signage and wall plan attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Colour, size, brightness, language used, font, graphics, employed content, dynamic elements, lighting levels					
Design variants		Emergency exit routes, information, warning, mandatory, prohibition, fire equipment, supplementary					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
		✓	✓				
Impact summary		• Emergency signage is intended to enable residents to locate emergency egress components. • The effectiveness is reliant on the individual's ability to perceive, understand and make use of the information available. • The likelihood of seeing / noticing the sign is reduced by the presence of smoke. • Additional dynamism / flashing lights can make signs more noticeable and include updated information.					

A1-4.3 Horizontal egress

A1-4.3.1 Internal dwelling arrangements

Table A1-17 Summary of internal dwelling arrangement attributes, variants, and impact on evacuation performance

<table>
<tr><td>Attributes deemed to affect performance</td><td colspan="7">Room enclosure, access room enclosure, location of cooking facilities, internal travel distance, number of available exits</td></tr>
<tr><td>Design variants</td><td colspan="7">Protected entrance hall apartment, open plan apartment, multiple-storey apartment, apartments with restricted travel distances, apartments with multiple exits</td></tr>
<tr><td colspan="3">Pre-evacuation</td><td colspan="2">Evacuation movement</td><td colspan="3">Mitigation</td></tr>
<tr><td>Recognition</td><td>Preparatory actions – physical</td><td>Preparatory actions – awareness</td><td>Wayfinding / route selection</td><td>Physical travel</td><td>Ignition</td><td>Fire growth and spread</td><td>Smoke spread</td></tr>
<tr><td></td><td></td><td></td><td>✓</td><td>✓</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>Impact summary</td><td colspan="7">• Restrictions on internal dwelling arrangements can be used to limit occupant travel distances and / or provide multiple routes of escape.
• Internal room separation can be used to reduce fire and smoke spread.
• The effectiveness internal separation is dependent on occupants’ behaviours with doors, where occupants may have habits of propping doors open.
• Open plan design is generally shown to be less favourable for supporting occupant escape from apartments unless accommodated for by other fire safety provisions.</td></tr>
</table>

A1-4.3.2 Corridors

Table A1-18 Summary of corridor attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Width, length (travel distance), height, changes in direction (complexity), occupancy characteristics					
Design variants		Private, communal, public					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
			✓	✓			
Impact summary		• Wider corridors generally produce a higher rate of occupant flow depending on the density of occupants. • Occupant handedness and length of corridor legs will impact decision making. The overall appearance the corridor, and spatial familiarity, will also impact decision making. • Occupant density, age and weight all have the potential to impact movement speed and occupant flows in corridors.					

A1-4.3.3 Doors

Table A1-19 Summary of door attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Width, height, swing direction, leaf configuration, modes of operation, door handle type, occupancy characteristics					
Design variants		Single leaf, double leaf, automatic, self-closing					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
			✓	✓			
Impact summary		• Door provisions impact on occupant escape time as well as the potential for smoke spread between enclosures. • Wider doors generally enable a higher rate of occupant flow, depending on the density of occupants. • Push doors are shown to reduce door operation time compared to pull doors, irrespective of handle type. The type of handle is shown to have a minimal impact, although limited data does indicate that push ‘panic’ bars may reduce operation time. • The physical presence of a door can impact flow when compared to an equivalent opening.					

A1-4.3.4 Balconies

Table A1-20 Summary of balcony attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Type, use					
Design variants		Open or closed; private, communal, public; egress path; refuge					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
			✓	✓			
Impact summary		• Balconies can form part of a means of escape or as a place of refuge. • Weather conditions may affect their effectiveness.					

A1-4.3.5 Refuge points

Table A1-21 Summary of refuge point attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Capacity, means of access / egress, location, supporting signage, level of protection (time), ventilation / heating, sanitation, (emergency) power, provisions, emergency supplies, communication and monitoring systems					
Design variants		Refuge floor, lobby area, refuge (room)					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
		✓	✓	✓			
Impact summary		• Refuges may provide a means for those incapable of traversing stairs to find a place of relative safety. • Residents would likely need to be reassured that the refuge provides sufficient safety levels, to encourage its use. • Although more common internationally, the rising number of people in with mobility impairments in residential properties may lead to refuges being examined.					

A1-4.4 Vertical egress

A1-4.4.1 Stairs

Table A1-22 Summary of stair attributes, variants, and impact on evacuation performance

<table>
<tr><td colspan="2">Attributes deemed to affect performance</td><td colspan="6">Riser height, tread depth / going, gradient, handrail presence / dimensions, flight length, step area, landing capacity, effective width, configuration, lighting levels, direction of use, edge markings, associated signage, headroom, nosing, surface</td></tr>
<tr><td colspan="2">Design variants</td><td colspan="6">Internal / external, emergency stairs, dog-leg, spiral, curved, scissor, L-shaped, straight, pressurised</td></tr>
<tr><th colspan="3">Pre-evacuation</th><th colspan="2">Evacuation movement</th><th colspan="3">Mitigation</th></tr>
<tr><th>Recognition</th><th>Preparatory actions – physical</th><th>Preparatory actions – awareness</th><th>Wayfinding / route selection</th><th>Physical travel</th><th>Ignition</th><th>Fire growth and spread</th><th>Smoke spread</th></tr>
<tr><td></td><td></td><td></td><td>✓</td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Impact summary</td><td colspan="6">• Stair design may limit capacity in terms of the flow and occupancy (the number of people that can simultaneously occupy the stair).
• The gradient of the stair will influence the achievable movement rate.
• Evacuee behaviours will influence further the flow on the stair – potentially further reducing the achievable rates.
• Extended use of stair can lead to fatigue and eventually reduce movement rates.
• Those with some health issues and movement impairments will not be able to use stairs during an emergency.
• It is imperative that stairs are kept tenable to ensure effective movement and reduce the potential for falls. If they are not sufficiently protected and become filled with smoke they can act as a route along which smoke can move and therefore reach other locations in the structure.
• Stairs may be used by emergency responders accessing the building.</td></tr>
</table>

A1-4.4.2 Evacuation lifts

Table A1-23 Summary of evacuation lift attributes, variants, and impact on evacuation performance

<table>
<tr><td colspan="2">Attributes deemed to affect performance</td><td colspan="6">Water tolerance, lift capacity, door operation (opening), door operation (closing), dwell time, speed, floor sequence, emergency use, emergency operation, staff operated, internal communication, associated signage (route to lift and those who should use lift), associated training, existence of associated refuge lobbies, monitoring of internal conditions, emergency power, lift / shaft fire resistance, building height (and occupant location within building), existing / former guidance on use during fire emergency, position of lift within structure [15], [16]</td></tr>
<tr><td colspan="2">Design variants</td><td colspan="6">Non-emergency, emergency, freight</td></tr>
<tr><th colspan="3">Pre-evacuation</th><th colspan="2">Evacuation movement</th><th colspan="3">Mitigation</th></tr>
<tr><th>Recognition</th><th>Preparatory actions – physical</th><th>Preparatory actions – awareness</th><th>Wayfinding / route selection</th><th>Physical travel</th><th>Ignition</th><th>Fire growth and spread</th><th>Smoke spread</th></tr>
<tr><td></td><td></td><td></td><td>✓</td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Impact summary</td><td colspan="6">• Lifts are not typically employed in emergencies. However, they have been used in situations even where it was not recommended.
• Effectiveness will be sensitive to the design / operation of the lift and the procedural measures in place.
• May be a more familiar means of egress to many (i.e., people might not normally use the stairs).
• As with stairs, ineffective lift design can both lead to the lift being unavailable and also provide a route for smoke to travel to other spaces within the structure.</td></tr>
</table>

A1-4.4.3 Movement devices

Table A1-24 Summary of movement device attributes, variants, and impact on evacuation performance

<table>
<tr><td colspan="2">Attributes deemed to affect performance</td><td colspan="6">Number of operators required / available, number of hands required to use, manoeuvrability, training required, effort required (likelihood of fatigue and number of stops required to rest), passenger capacity, dimensions (footprint), weight, carry weight</td></tr>
<tr><td colspan="2">Design variants</td><td colspan="6">Walking stick, crutch, walking frame, electric wheelchair, manual wheelchair, stretcher, mattress, evacuation chair (with and without extended handle), wheeled evacuation chair, carry chair, sheet, rollator, bed, buddy / warden / firefighter</td></tr>
<tr><th colspan="3">Pre-evacuation</th><th colspan="2">Evacuation movement</th><th colspan="3">Mitigation</th></tr>
<tr><th>Recognition</th><th>Preparatory actions – physical</th><th>Preparatory actions – awareness</th><th>Wayfinding / route selection</th><th>Physical travel</th><th>Ignition</th><th>Fire growth and spread</th><th>Smoke spread</th></tr>
<tr><td></td><td></td><td></td><td>✓</td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Impact summary</td><td colspan="6">• Influences the rates at which evacuees move, the routes that can be used, the flow of people around the device, the number of devices that can be stored at a refuge.
• Influenced by availability and skill level of operators.
• As elderly /impaired population numbers increase, so the presence of movement devices normally seen in specialist settings might become more prevalent.</td></tr>
</table>

A1-4.4.4 Other means of vertical escape (escape windows, ladders etc.)

Table A1-25 Summary of other means of vertical escape attributes, variants, and impact on evacuation performance

<table>
<tr><td colspan="2">Attributes deemed to affect performance</td><td colspan="6">Alternatives to stairs and lifts</td></tr>
<tr><td colspan="2">Design variants</td><td colspan="6">Hatches, ladders, ropes, chutes, windows</td></tr>
<tr><th colspan="3">Pre-evacuation</th><th colspan="2">Evacuation movement</th><th colspan="3">Mitigation</th></tr>
<tr><th>Recognition</th><th>Preparatory actions – physical</th><th>Preparatory actions – awareness</th><th>Wayfinding / route selection</th><th>Physical travel</th><th>Ignition</th><th>Fire growth and spread</th><th>Smoke spread</th></tr>
<tr><td></td><td></td><td></td><td>✓</td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Impact summary</td><td colspan="6">• Ladders have limited value as a means of escape.
• Under specific circumstances windows provide a viable means of egress.</td></tr>
</table>

A1-4.5 Firefighting

A1-4.5.1 Fire mains and hydrants

Table A1-26 Summary of fire mains and hydrant attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Location, number of outlets, water charge, pump, tank size, flow capacity, system maintenance					
Design variants		Wet fire mains, dry fire mains, stair riser, lobby / corridor riser					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
						✓	
Impact summary		• Fire mains and hydrants assist the fire and rescue service in attacking the fire. This is an important action which can limit fire growth and spread. • Location of fire mains and the achievable water flow density will alter the effectiveness of fire and rescue service operations in extinguishing fires.					

A1-4.5.2 Firefighting lifts

Table A1-27 Summary of firefighting lift attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Capacity, door operation (opening and closing), speed, operational procedure, emergency intercom system, back-up power supply, location					
Design variants		Firefighting lift with dedicated lobby, firefighting lift in common corridor, external lifts, pressurised lifts					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
				✓		✓	
Impact summary		• The presence of firefighting lifts in tall buildings substantially reduces the time taken for the fire and rescue service to reach the fire, potentially aiding in the mitigation of fire growth. • Firefighting lifts can be used in rescue operations and to assist in escape.					

A1-4.5.3 Smoke clearance

Table A1-28 Summary of smoke clearance attributes, variants, and impact on evacuation performance

Attributes deemed to affect performance		Vent and shaft areas, locations, orientations, volumetric flow rates, pressure, means of operation, system reliability					
Design variants		Natural vents, mechanical extract, jet / impulse fans					
Pre-evacuation			**Evacuation movement**		**Mitigation**		
Recognition	**Preparatory actions – physical**	**Preparatory actions – awareness**	**Wayfinding / route selection**	**Physical travel**	**Ignition**	**Fire growth and spread**	**Smoke spread**
							✓
Impact summary		• Smoke clearance systems can often be manually activated and therefore may not directly assist escape, but they can help facilitate the clearance of smoke following fire extinguishment. • Certain smoke clearance provisions may be detrimental to means of escape if activated, by interfering with the smoke layer.					

A1-5 Review of guidance documents and standards

A1-5.1 Active measures

Table A1-29 Summary of guidance and standard recommendations for active measures.

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
Fire detection			
AD B (England)	**Required / recommended:** Yes **Detector type(s):** Not specified **Location(s):** Apartment **Other comments:** Minimum Grade D2 Category LD3, refers to BS 5839-6 **Clause/s:** 1.1-1.4	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Required / recommended:** Yes **Detector type(s):** Optical smoke alarms recommended in principal habitable rooms and circulation spaces, Ionisation smoke alarms outside bathrooms. **Location(s):** Apartment **Other comments:** Minimum Grade D, refers to BS 5839-6, alarms to conform to BS EN 14604:2005 **Clause/s:** 2.11, 2.11.3, 2.11.4	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
BS 9991 (UK)	**Required / recommended:** Yes **Detector type(s):** Not specified **Location(s):** Flat **Other comments:** Refers to BS 5839-6, and BS 5829-1 for systems in common areas **Clause/s:** 10.1	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Required / recommended:** Yes **Detector type(s):** Smoke alarms **Location(s):** Dwelling Unit **Other comments:** Refers to NFPA 70 and NFPA 72, fire alarm system initiated by activation of sprinklers **Clause/s:** 9.6.1.3, 9.6.2.10, 30.3.4.2.3, 30.3.4.5	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** Yes **Detector type(s):** Domestic smoke alarm **Location(s):** Apartment **Other comments:** **Clause/s:** Table 2.2a, Table 2.3	**Required / recommended:** Yes **Detector type(s):** Smoke detector, Type 1 or 2 **Location(s):** Apartment **Other comments:** Automatic fire alarm system with smoke detectors and manual call points **Clause/s:** Table 2.2a, Table 2.3	As per buildings > 25 m
IBC (USA)	**Required / recommended:** Yes **Detector type(s):** Smoke alarms **Location(s):** Habitable rooms **Other comments:** Refers to NFPA 72 **Clause/s:** 907.2, 907.2.9.1-907.2.9.3, 907.2.10.	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NBC (Canada)	**Required / recommended:** Yes **Detector type(s):** Smoke alarms **Location(s):** **Other comments:** Smoke detectors within public corridors, refers to NFPA 13D **Clause/s:** 3.2.4.3, 3.2.4.1	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Required / recommended:** Yes **Detector type(s):** Not specified **Location(s):** Within hallways, along egress paths **Other comments:** Refers to AS 1670.1 **Clause/s:** E2.2a 2-5	As per buildings > 17 m	As per buildings > 17 m
Audible alarms			
AD B (England)	**Required / recommended:** Yes **Alarm type:** Not specified **Location(s):** Flat **Other comments:** Refers to BS 5839-6 and BS EN 14604 **Clause/s:** 1.1-1.4	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Required / recommended:** Yes **Alarm type:** Not specified **Location(s):** Flat **Other comments:** lists locations of alarms in regards to doors **Clause/s:** 2.11.7	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended:** Yes **Alarm type:** Not specified **Location(s):** Flat **Other comments:** Refers to BS 5839-6:2013 **Clause/s:** 10.1	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NFPA 101 (USA)	**Required / recommended:** Yes **Alarm type:** Not specified **Location(s):** Flat **Other comments:** Refers to NFPA 70 and NFPA 72**Clause/s:** 9.6.1.3, 9.6.2.10, 30.3.4.2.3, 30.3.4.5	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** Yes **Alarm type:** Not specified **Location(s):** Flat **Other comments:** **Clause/s:** Table 2.2a	As per buildings > 10 m	As per buildings > 10 m
IBC (USA)	**Required / recommended:** Yes **Alarm type:** Not specified **Location(s):** Dwelling unit **Other comments:** Alarms should be interconnected and audible over background noise **Clause/s:** 907.2.10.5	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Required / recommended:** Yes **Alarm type:** Single or two-stage system **Location(s):** Sleeping rooms, connecting hallways **Other comments:** conforming to CAN/ULC-S531 **Clause/s:** 3.2.4.3, 3.2.4.20, 3.2.4.21	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Required / recommended:** Yes **Alarm type:** Not specified **Location(s):** Flat **Other comments:** Refers to AS 3786 **Clause/s:** E2.2a.3, E2.2a.7	As per buildings > 17 m	As per buildings > 17 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
Visual alarms and beacons			
AD B (England)	**Required / recommended: Not mentioned** **Alarm type:** N/A **Location(s):** N/A **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Required / recommended: Not mentioned** **Alarm type:** N/A **Location(s):** N/A **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended: Not mentioned** **Alarm type:** N/A **Location(s):** N/A **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Required / recommended: Mentioned** **Alarm type:** N/A **Location(s):** N/A **Other comments:** visible signals to be installed for hearing impaired **Clause/s:** 9.6, 30.3.4.3.1	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended: Not mentioned** **Alarm type:** N/A **Location(s):** N/A **Other comments:** None **Clause/s:**	As per buildings > 10 m	As per buildings > 10 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
IBC (USA)	**Required / recommended:** Mentioned **Alarm type:** N/A **Location(s):** N/A **Other comments:** Must have the ability to support visual alarms within dwellings if needed **Clause/s:** 907.5.2.3.3	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Required / recommended:** Not required **Alarm type:** N/A **Location(s):** N/A **Other comments:** **Clause/s:** 3.2.4.19	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Required / recommended:** Not required **Alarm type:** N/A **Location(s):** N/A **Other comments:** sprinkler activation must be linked to a fire indicator panel with audible and visual signal in a fire station or monitoring service in accordance with AS 1670.3 **Clause/s:** D2.7.e, D2.22, E2.2d.3	As per buildings > 17 m	As per buildings > 17 m
Staff intervention			
AD B (England)	**Staff presence required / recommended:** Not mentioned **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Staff presence required / recommended:** Not mentioned **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
BS 9991 (UK)	**Staff presence required / recommended:** **Generally assumed not present** **Other comments:** None **Clause/s:** Table 1	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Staff presence required / recommended:** **Not mentioned** **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Staff presence required / recommended:** **Not mentioned** **Other comments:** None **Clause/s:**	As per buildings > 10 m	As per buildings > 10 m
IBC (USA)	**Staff presence required / recommended:** **Not mentioned** **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Staff presence required / recommended:** **Not mentioned** **Other comments:** None **Clause/s:**	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Staff presence required / recommended:** **Not mentioned** **Other comments:** None **Clause/s:**	As per buildings > 17 m	As per buildings > 17 m
Emergency lighting			
AD B (England)	**Required / recommended:** **Yes** **Location(s):** All escape routes **Other comments:** Refers to BS 5266-1 **Clause/s:** 3.41-3.44	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
STH (Scotland)	**Required / recommended:** Yes **Location(s):** All escape routes, protected lobby and protected zone **Other comments:** Refers to BS 5266-1 and BS EN 1838:2013 **Clause/s:** 2.10.3	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended:** Yes **Location(s):** All escape routes **Other comments:** Refers to BS 5266-1 **Clause/s:** 44.2	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Required / recommended:** Yes **Location(s):** All escape routes **Other comments:** **Clause/s:** 30.2.9	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** Yes **Location(s):** Within exitways **Other comments:** **Clause/s:**	As per buildings > 10 m	As per buildings > 10 m
IBC (USA)	**Required / recommended:** Yes **Location(s):** All escape routes **Other comments:** Minimum duration on battery of 90 minutes **Clause/s:** 1008.3.5	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Required / recommended:** Yes **Location(s):** All escape routes **Other comments:** **Clause/s:** 3.2.7.3	As per buildings > 13 m	As per buildings > 13 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NCC (Australia)	**Required / recommended:** Yes **Location(s):** All escape routes, not within individual sole-occupancy units **Other comments:** **Clause/s:** EP4.1	As per buildings > 17 m	As per buildings > 17 m
Suppression			
AD B (England)	**Required / recommended:** Required **Type(s):** Not explicit but commonly refers to 'sprinklers' **Location(s):** Apartments and other non-fire-sterile rooms (excludes stairs, corridors, and landings) **Other comments:** Refers to BS 9251 **Clause/s:** 7.4	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Required / recommended:** Required **Type(s):** Not explicit but commonly refers to 'sprinklers' **Location(s):** Flats, ancillary rooms and spaces **Other comments:** Refers to BS 9251	As per buildings > 18m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended:** Not required **Type(s):** Sprinkler or water mist **Location(s):** Flats and common areas, excluding corridors and staircases **Other comments:** Refers to BS 9251 **Clause/s:** 11.2, Table 2	**Required / recommended:** Required **Type(s):** Sprinklers **Location(s):** Flats and common areas, excluding corridors and staircases **Other comments:** Refers to BS 9251:2014 **Clause/s:** 11.2, Table 2	As per buildings > 30m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NFPA 101 (USA)	**Required / recommended:** Required **Type(s):** Sprinkler **Location(s):** **Other comments:** Refers to NFPA 13, where sprinklers are fitted, automatic heat detectors are not required **Clause/s:** 9.7, 30.3.5	As per buildings > 18m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** Not required **Type(s):** Sprinkler **Location(s):** **Other comments:** **Clause/s:** Table 2.2a	**Required / recommended:** Required **Type(s):** Sprinkler **Location(s):** **Other comments:** **Clause/s:** Table 2.2a	As per buildings > 25 m
IBC (USA)	**Required / recommended:** Required **Type(s):** Automatic sprinkler system **Location(s):** Provided throughout **Other comments:** Refers to NFPA 13 for design and installation **Clause/s:** 903.2.8, 903.3, 903.3.1-903.3.8	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Required / recommended:** Recommended **Type(s):** Sprinkler **Location(s):** **Other comments:** Not required when with non-combustible materials, required when made from combustible material **Clause/s:** 3.2.2.48, 3.2.2.50, 3.2.5.12	**Required / recommended:** Required **Type(s):** Sprinkler **Location(s):** **Other comments:** **Clause/s:** 3.2.2.47	As per buildings > 25 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NCC (Australia)	**Required / recommended:** Required **Type(s):** Fire Sprinkler System **Location(s):** Provided throughout **Other comments:** Allows concessions in increased travel distances and reduce fire rating of non-loadbearing walls **Clause/s:** E1.5a.1	**Required / recommended:** Required **Type(s):** Fire Sprinkler System **Location(s):** Unclear – described within AS 2118.4 **Other comments:** Must comply with AS 2118.4 **Clause/s:** E1.5.2	As per buildings > 25 m
Smoke control			
AD B (England)	**Required / recommended:** Required **Type(s):** Natural or mechanical **Location(s):** Common lobbies, corridors, and stairs **Other comments:** Refers to BS EN 12101-6 for mechanical ventilation **Clause/s:** 3.50-3.54	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Required / recommended:** Required **Type(s):** Natural or mechanical **Location(s):** Escape stair, firefighting stair, firefighting lobby, protected corridor and lobby **Other comments:** refers to BRE 2002, refers to BS 5588-9:1999 for mechanical ventilations **Clause/s:** 2.9.15, 2.9.16, 2.14.6	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended:** Required **Type(s):** Natural or mechanical **Location(s):** Common lobbies, corridors, and stairs **Other comments:** Refers to BS EN 12101-6 and SCA guidance **Clause/s:** 14, 14.1.4, 14.2.2, Annex A	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NFPA 101 (USA)	**Required / recommended:** Required **Type(s):** Natural or mechanical **Location(s):** **Other comments:** **Clause/s:** 7.2.3, 7.2.3.7, 7.2.3.8	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** Not required	**Required / recommended:** Required **Type(s):** Natural, mechanical, and pressurisation **Location(s):** **Other comments:** **Clause/s:** Table 2.2a	As > 25 m
IBC (USA)	**Required / recommended:** Required **Type(s):** Natural or mechanical **Location(s):** Common lobbies, corridors, and stairs **Other comments:** Refers to NFPA 4, requires rational supporting analysis **Clause/s:** 909.1, 909.4-909.8, 910.1, 910.3-910.5	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Required / recommended:** Required **Type(s):** Natural or mechanical **Location(s):** **Other comments:** **Clause/s:** 3.2.4.12	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Required / recommended:** Required **Type(s):** Mechanical **Location(s):** **Other comments:** should be activated at time of alarm **Clause/s:** E2.2b.2, E2.2b.3, E2.2b.5	As per buildings > 17 m	As per buildings > 17 m

A1-5.2 Passive measures

Table A1-30 Summary of guidance and standard recommendations for passive measures.

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
Fire Separation			
AD B (England)	**Apartment is fire-rated enclosure:** Yes (60REI min) **Corridor is fire-rated enclosure:** Yes (60REI min) **Stair is fire-rated enclosure:** Yes (90REI min) **Other comments:** None **Clause/s:** Table B3/B4	**Apartment is fire-rated enclosure:** Yes (60REI min) **Corridor is fire-rated enclosure:** Yes (60REI min) **Stair is fire-rated enclosure:** Yes (120REI min) **Other comments:** None **Clause/s:** Table B3/B4	As per buildings > 30 m
STH (Scotland)	**Separating walls:** long fire resistance duration **Other comments:** DTH says that compartmentation does not apply to domestic buildings **Clause/s:** 2.2.2, 2.2.7	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Apartment is fire-rated enclosure:** Yes (60REI min) **Corridor is fire-rated enclosure:** Yes (60REI min) **Stair is fire-rated enclosure:** Yes (90REI min) **Other comments:** Refers to AD B 8.27 **Clause/s:** 17	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NFPA 101 (USA)	**Apartment is fire-rated enclosure:** Yes 30 minutes minimum **Corridor is fire-rated enclosure:** Yes 30 minutes minimum **Stair is fire-rated enclosure:** Yes **Other comments:** further fire rated protected outlined in NFPA 220 **Clause/s:** 7.1.3.2.1, 8.2.1.2, 30.3.6.1.2, 30.3.7.2	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Fire Safety Precautions:** Yes 30/30/30 **Stair is fire-rated enclosure:** Yes 30/30/30 **Other Comments:** **Clause/s:** Table 2.4, Figure 4.8	As per buildings > 10 m	As per buildings > 10 m
IBC (USA)	**Separating walls:** not less than 1 hour **Corridors:** ½ hour **Other comments:** Allowance on reduction of fire resistance if sprinklers present in certain construction types **Clause/s:** 420.2, 708.3, 1020.1 (419, 420, 508.2.4, 508.3.3)	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Apartment is fire-rated enclosure:** Yes (1 hour) **Corridor is fire-rated enclosure:** Yes (1 hour) **Stair is fire-rated enclosure:** **Other comments:** Designed in conformance with NBC **Clause/s:** 3.3.1.1, 3.2.2.47	As per buildings > 13 m	As per buildings > 13 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NCC (Australia)	**Apartment is fire-rated enclosure:** Yes (-/60/60 (structural adequacy/integrity/insulation)) **Corridor is fire-rated enclosure:** Yes (-/60/60) **Stair is fire-rated enclosure:** Yes (-/90/90) **Other comments:** **Clause/s:** C1.1.3, Table 3	As per buildings > 17 m	As per buildings > 17 m
Construction materials			
AD B (England)	**Restrictions on external wall materials:** Yes (non-combustible) **Restrictions on internal wall materials:** Yes (dependant on location and size) **Other comments:** Refers to BS EN 13501-1:2007+A1:2009, and BS EN 15102 **Clause/s:** Regulation 7, Chapter 10, Table 4.1	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Restrictions on external wall materials:** Yes (non-combustible) **Restrictions on internal wall materials:** Yes (dependant on location and size) **Other comments:** restriction of materials on buildings over 11m tall, must meet European classifications **Clause/s:** 2.5.1, 2.7.1	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
BS 9991 (UK)	**Restrictions on external wall materials:** Yes (limited combustibility) **Restrictions on internal wall materials:** Yes (dependant on location and size) **Other comments:** Refers to BR135, BS 8414-1, BS 8414-2, further guidance in BS 9999 **Clause/s:** 18.2, Figure 17, 20.1	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Restrictions on external wall materials:** **Restrictions on internal wall materials:** Yes **Other comments:** **Clause/s:** 30.3.3.2, 10.2	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Restrictions on external wall materials:** Yes (limited combustibility) **Restrictions on internal wall materials:** Yes **Other comments:** **Clause/s:** 4.17, Table 4.3, 5.8, Table 5.5	As per buildings > 10 m	As per buildings > 10 m
IBC (USA)	**Restrictions on external wall materials:** Yes (non-combustible materials) **Restrictions on internal wall materials:** Yes **Restrictions on internal frame materials:** Yes (must be non-combustible) **Other comments:** Dependant on construction type, refers to ASTM E83 for interior trim and finishes **Clause/s:** Table 504.4, 603.1,Table 803.13, 805.1.1-805.1.3, 806.1, 806.7	As per building > 18 m	Only applicable for Type IA construction with sprinklers (at 180 ft/54.9 m) For building height > 55 m structural members require further fire protection

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NBC (Canada)	**Restrictions on external wall materials:** Yes (combustible materials allowable if sprinklered throughout) **Restrictions on internal wall materials:** Yes (dependant on material properties) **Restrictions on internal frame materials:** Yes (combustible materials allowable if sprinklered throughout) **Other comments:** fire rating required for external walls materials depend on unprotected openings percentage **Clause/s:** 3.1.5.5.1, 3.1.5.6.1, 3.1.5.12, 3.1.13.7, 3.2.2.9, 3.2.2.50, Table 3.2.3.7	**Restrictions on external wall materials:** Yes (non-combustible material) **Restrictions on internal wall materials:** Yes (dependant on material properties) **Restrictions on internal frame materials:** Yes (non-combustible material) **Other comments:** fire rating required for external walls materials depend on unprotected openings percentage **Clause/s:** 3.1.5.5.1, 3.1.5.6.1, 3.1.5.12, 3.2.2.50, Table 3.2.3.7	As per buildings > 25 m
NCC (Australia)	**Restrictions on external wall materials:** Yes (non-combustible) **Restrictions on internal wall materials:** Yes (non-combustible if fire-resisting) **Restrictions on internal frame materials:** Yes (combustible materials allowable if sprinklered throughout) **Other comments:** **Clause/s:** C1.1, C1.9, C1.10	**Restrictions on external wall materials:** Yes (non-combustible material) **Restrictions on internal wall materials:** Yes (non-combustible if fire-resisting) **Restrictions on internal frame materials:** Yes (non-combustible material) **Other comments:** **Clause/s:** C1.1, C1.9, C1.10	As per building > 25 m
Structural design			
AD B (England)	**Structural Frame:** 90R **Floors:** 90REI **Other comments:** **Clause/s:** Table B3/B4	**Structural Frame:** 120R **Floors:** 120REI **Other comments:** **Clause/s:** Table B3/B4	As per buildings > 30 m
STH (Scotland)	**Structural Frame:** Long fire resistance **Floors:** Long fire resistance **Other comments:** **Clause/s:** Table 2.1	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
BS 9991 (UK)	**Structural Frame:** 60R (if sprinklered) **Floors:** 60REI (if sprinklered) **Other comments:** **Clause/s:** Table B3/B4	**Structural Frame:** 120R **Floors:** 120REI **Other comments:** **Clause/s:** Table B3/B4	As per buildings > 30 m
NFPA 101 (USA)	**Structural Frame:** **Floors:** **Other comments:** Refers to NFPA 220 **Clause/s:** 8.2.1.2	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	Internal geometry of the building is required to determine required structural stability, minimum 60/60/60, irrespective of building height	As per buildings > 18 m	As per buildings > 18 m
IBC (USA)	**Structural Frame Fire Resistance:** up to 2 hours **Floors:** up to 2 hours **Other comments:** Assuming Type IB construction **Clause/s:** Table 601, 603	As per buildings > 18 m	For building > 50 m, structural members must have addition fire protection
NBC (Canada)	**Structural Frame:** not less than 1 hour **Floors:** not less than 1 hour **Other comments:** **Clause/s:** 3.2.2.48, 3.2.2.50	**Structural Frame:** not less than 2 hours **Floors:** not less than 2 hours **Other comments:** **Clause/s:** 3.2.2.47	As per building > 25 m
NCC (Australia)	**Structural Frame:** 90/-/- (structural adequacy/integrity/insulation) **Floors:** 90/90/90 **Other comments:** **Clause/s:** C1.1.3, Table 3	As per buildings > 17 m	As per buildings > 17 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
Signage and wall plans			
AD B (England)	**Signage required / recommended:** Required **Wall plans required / recommended:** Not mentioned **Signage location(s):** Every exit / doorway on a common escape route **Other comments:** Refers to BS ISO 3864-1, BS 5499-4 and HSE guidance on signs and signals **Clause/s:** 3.45	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Signage required / recommended:** Required **Wall plans required / recommended:** Not mentioned **Signage location(s):** **Other comments:** Storey identification and dwelling indicator signs **Clause/s:** 2.14.9 (Table 2.6)	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Signage required / recommended:** Yes **Wall plans required / recommended:** Not mentioned **Signage location(s):** Firefighting shafts, firefighting stairs **Other comments:** Refers to AD B, **Clause/s:** 4, 50.2.1, 50.3.2.1	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Signage required / recommended:** Yes **Wall plans required / recommended:** Not mentioned **Signage location(s):** Stairways **Other comments:** **Clause/s:** 7.2.2.5.4	As per buildings > 13 m	As per buildings > 13 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
C/AS2 (NZ)	**Signage required / recommended:** Yes **Wall plans required / recommended:** Not mentioned **Signage location(s):** All building features **Other comments:** **Clause/s:** 3.16.1	As per buildings > 10 m	As per buildings > 10 m
IBC (USA)	**Signage required / recommended:** Yes **Wall plans required / recommended:** Not mentioned **Signage location(s):** Floor landings **Other comments:** Refers to ICC A117.1 **Clause/s:** 1023.9-1023.10	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Signage required / recommended:** Yes **Wall plans required / recommended:** Not mentioned **Signage location(s):** **Other comments:** **Clause/s:**	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Signage required / recommended:** Yes **Wall plans required / recommended:** Not mentioned **Signage location(s):** Floor landings, egress doors **Other comments:** Refers to ICC A117.1 **Clause/s:** D3.63, E4.5, E4.7, E4.8	As per buildings > 17 m	As per buildings > 17 m

A1-5.3 Horizontal egress

Table A1-31 Summary of guidance and standard recommendations for horizontal egress.

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
Internal dwelling arrangements			
AD B (England)	**Number of dwelling exits required:** 1 **Single direction of travel:** 9 m (dependent on internal arrangement) **Multiple directions of travel:** No restriction **Protected hall / access room required:** Yes (when single direction of travel exceeds 9 m) **Other comments:** None **Clause/s:** 3.18	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Number of dwelling exits required:** 1 **Single direction of travel:** 9 m **Multiple directions of travel:** No restriction **Protected hall / access room required:** Yes **Other comments:** If open plan, suppression is required **Clause/s:** 2.9.5, 2.9.7	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
BS 9991 (UK)	**Number of dwelling exits required:** 1 **Single direction of travel:** 9 m (20 m if sprinklers present) **Multiple directions of travel:** No restriction **Protected hall / access room required:** Yes (when single direction of travel exceeds 9 m) **Other comments:** Allows for open plan flats with certain restrictions, suppression and AFD **Clause/s:** 9.4.2	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Number of dwelling exits required:** 1 **Single direction of travel:** 125 ft (38 m) with sprinklers **Protected hall / access room required:** **Not mentioned** **Other comments:** None **Clause/s:** 30.2.6, 30.2.5.4.2, 30.2.6.3.2	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Number of dwelling exits required:** 1 **Single direction of travel:** **Not mentioned** **Protected hall / access room required:** **Not mentioned** **Other comments:** **Clause/s:** Table 3.1	As per buildings > 10 m	As per buildings > 10 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
IBC (USA)	**Number of dwelling exits required:** 1 **Max distance of travel:** 125 ft **Protected hall / access room required:** Not required **Other comments:** Cooking facilities to in accordance with 917.2 of IMC **Clause/s:** 1020.1, Table 1006.2.1	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Number of dwelling exits required:** 1 **Single direction of travel:** **Not mentioned** **Protected hall / access room required:** **Not mentioned** **Other comments:** None **Clause/s:** 3.3.1.5	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Number of dwelling exits required:** 1 **Single direction of travel:** **Not mentioned** **Protected hall / access room required:** **Not mentioned** **Other comments:** **Clause/s:** DP6	As per buildings > 17 m	As per buildings > 17 m
Corridors			
AD B (England)	**Single direction of travel:** 7.5 m **Multiple directions of travel:** 30 m **Minimum width:** Not specified **Minimum height:** 2 m **Other comments:** None **Clause/s:** 3.26-3.27, 3.38	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
STH (Scotland)	**Single direction of travel:** 10 m **Multiple directions of travel:** 30 m **Minimum width:** Not specified **Minimum height:** Not specified **Other comments:** At least 2 escape routes available **Clause/s:** 2.9.10	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Single direction of travel:** 7.5 m (15 m with sprinklers) **Multiple directions of travel:** 30 m (60 m with sprinklers) **Minimum width:** Not specified **Minimum height:** 2 m **Other comments:** mechanical smoke ventilation and sprinklers can be used to increase travel distance **Clause/s:** 7.4, Figure 7	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Single direction of travel:** 50 ft (15 m) with sprinklers **Multiple directions of travel:** 200 ft (61 m) with sprinklers **Minimum width:** 36 inches (915 mm) **Minimum height:** Not specified **Other comments:** **Clause/s:** 30.2.5.4, 30.2.6.3.1, 30.2.3.4	As per buildings > 18 m	As per buildings > 18 m

Document	**Trigger Height 1**	**Trigger Height 2**	**Trigger Height 3**
C/AS2 (NZ)	**Single direction of travel:** 20 m (25 m to final exit) **Multiple directions of travel:** 50 m (180 m to final exit) **Minimum width:** 850 mm **Minimum height:** **Other comments:** Travel distance dependant on detector and alarm system, for type 1 or 2, sprinklers must be present for single direction travel **Clause/s:** Table 3.1, Table 3.1a, Table 3.2, Table 3.4	**Single direction of travel: Not permitted** **Multiple directions of travel:** 50 m (180 m to final exit) **Minimum width:** 850 mm **Minimum height:** **Other comments:** Travel distance dependant on detector and alarm system, for type 1 or 2 **Clause/s:** Table 3.1, Table 3.1a, Table 3.2, Table 3.4	As per buildings > 25m
IBC (USA)	**Single direction of travel:** 50 ft (15.2 m) **Multiple directions of travel:** Not stated **Minimum width:** 0.2 inch per occupant, but no less than 44 inches **Other comments: Clause/s:** 1005.3.2, 1020, Table 1020.2	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Single direction of travel:** **Multiple directions of travel:** 30 m **Minimum width:** 1.1 m **Minimum height:** 2.05 m **Other comments:** **Clause/s:** 3.4.2.4, 3.4.2.5, 3.4.3.2, Table 3.4.3.2-A, 3.4.3.4	As per buildings > 13 m	As per buildings > 13 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NCC (Australia)	**Single direction of travel:** 6 m **Multiple directions of travel:** 20 m **Minimum number of exits:** 1 **Minimum width:** 1 m **Minimum height:** 2 m **Other comments:** **Clause/s:** D1.2, D1.4, D 1.5, D1.6	**Single direction of travel:** 6 m **Multiple directions of travel:** 20 m **Minimum number of exits: 2** **Minimum width:** 1 m **Minimum height:** 2 m **Other comments:** not less than 9 m and not more than 45 m apart **Clause/s:** D1.2, D1.4, D 1.5, D1.6	As per building > 25 m
Doors			
AD B (England)	**Minimum width (apartment exit):** Not specified **Minimum width (storey exit):** Not specified **Swing direction:** Open in direction of escape whenever reasonably practicable **Other comments:** None **Clause/s:** 3.90-3.96	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Minimum width (apartment exit):** Not specified **Minimum width (storey exit):** Not specified **Swing direction:** Not specified **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
BS 9991 (UK)	**Minimum width (apartment exit):** Not specified **Minimum width (storey exit):** Not specified **Swing direction:** Either double swing, or with a vision panel **Other comments:** Refers to BS 3800 for door swing **Clause/s:** 8.6, 24.1.1-24.1.9	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Minimum width (apartment exit):** **Minimum width (storey exit):** 32 inches (810 mm) **Swing direction:** direction of egress **Other comments:** **Clause/s:** 7.2.1.2.3.2, 7.2.1.4.2	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Minimum width (apartment exit):** 760 mm **Minimum width (storey exit):** 875 mm **Swing direction:** open in the direction of escape **Other comments:** **Clause/s:** Table 3.1a, 3.15.3	As per buildings > 10 m	As per buildings > 10 m
IBC (USA)	**Minimum width (apartment exit):** Not specified **Minimum width (storey exit):** Not specified **Swing direction:** Either double swing, or with a vision panel **Other comments:** Doors cannot reduce the width by more than 7 inches **Clause/s:** 1005.7.1	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NBC (Canada)	**Minimum width (apartment exit):** Not specified **Minimum width (storey exit):** 800 mm **Swing direction:** in direction of travel to exit **Other comments:** **Clause/s:** 3.3.1.11, Table 3.4.3.2-A	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Minimum width (apartment exit):** Not specified **Minimum width (storey exit):** 750 mm **Swing direction:** In direction of egress **Other comments:** Cannot encroach by more than 100 mm **Clause/s:** D1.6.f(iii), D2.20	As per buildings > 17 m	As per buildings > 17 m
Balconies			
AD B (England)	**Acceptable for use in horizontal escape: Yes** **Minimum escape width:** Not specified **Other comments:** Guarding to be provided with reference to Approved Document K. Should lead directly to external exit **Clause/s:** 2.13-2.14	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Acceptable for use in horizontal escape: Yes** **Minimum escape width:** Not specified **Other comments:** Must be protected, travel distance should not exceed 40 m if one-way, unlimited if two-way, if more than 2 m wide requires 300 mm smoke channel **Clause/s:** 2.9.10, 2.9.23	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
BS 9991 (UK)	**Acceptable for use in horizontal escape:** Yes **Minimum escape width:** Not specified **Other comments:** No limit on travel distance, requires fire-resistant construction up to 1.1 m, if more than 2 m wide requires 300 mm smoke channel **Clause/s:** 7.3	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Acceptable for use in horizontal escape:** Yes **Minimum escape width:** Same as corridor **Other comments:** edge must be not less than 50% open **Clause/s:** 7.5.3.2	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Acceptable for use in horizontal escape:** Yes **Minimum escape width:** **Other comments:** Requires fire rating of adjacent wall, can be used if sprinklered **Clause/s:** 3.11, Figure 3.20, 3.13.5	**Acceptable for use in horizontal escape:** No **Minimum escape width:** **Other comments:** **Clause/s:** 3.13.5	As per buildings > 25 m
IBC (USA)	**Acceptable for use in horizontal escape:** Yes **Minimum escape width:** Same as corridor **Other comments:** edge must be not less than 50% open **Clause/s:** 1021	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Acceptable for use in horizontal escape:** Yes **Minimum escape width:** Not specified **Other comments:** **Clause/s:** 23.3.4.4 (6)	As per buildings > 13 m	As per buildings > 13 m

Document	**Trigger Height 1**	**Trigger Height 2**	**Trigger Height 3**
NCC (Australia)	**Acceptable for use in horizontal escape:** **Yes** **Minimum escape width:** Not specified **Other comments:** **Clause/s:** C3.11.g, D2.5	As per buildings > 17 m	As per buildings > 17 m
Refuge points			
AD B (England)	**Required / recommended:** **Not mentioned** **Location(s):** N/A **Dimensions:** N/A **Voice communication system provided:** N/A **Other comments:** Refers to BS 5839-9 for voice communication systems **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Required / recommended:** **Not mentioned** **Location(s):** N/A **Dimensions:** N/A **Voice communication system provided:** N/A **Other comments:** Refers to BS 5839-9 for voice communication systems **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
BS 9991 (UK)	**Required / recommended:** Mentioned **Location(s):** N/A **Dimensions:** N/A **Voice communication system provided:** N/A **Other comments:** refuge space within protected stairways may require space for wheelchair depending on occupancy, refers to BS 9999 **Clause/s:** 8.3	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Required / recommended:** Required **Location(s):** N/A **Dimensions:** 1 space of 30 in by 48 in per 200 occupants **Voice communication system provided:** Yes **Other comments:** **Clause/s:** 7.2.12, 7.2.12.2.5	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** Not mentioned **Location(s):** N/A **Dimensions:** N/A **Voice communication system provided:** N/A **Other comments:** **Clause/s:**	As per buildings > 10 m	As per buildings > 10 m

Document	**Trigger Height 1**	**Trigger Height 2**	**Trigger Height 3**
IBC (USA)	**Required / recommended:** **Required for every 200 occupants** **Location(s):** With direct access to stair or elevator **Dimensions:** 30 by 48 inches **Voice communication system provided:** N/A **Other comments:** areas of refuge require two-way communication **Clause/s:** 1009.6	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Required / recommended:** **Recommended** **Location(s):** N/A **Dimensions:** N/A **Voice communication system provided:** N/A **Other comments:** **Clause/s:** A-3.3.1.7, 3.3.1.7	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Required / recommended:** **Not mentioned** **Location(s):** N/A **Dimensions:** N/A **Voice communication system provided:** N/A **Other comments:** **Clause/s:**	As per buildings > 17 m	As per buildings > 17 m

A1-5.4 Vertical egress

Table A1-32 Summary of guidance and standard recommendations for vertical egress.

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
Stairs			
AD B (England)	**Minimum number of stairs:** 1 **Minimum width:** 1100 mm **Other comments:** For only 1 stair, must meet conditions of 3.26-3.27, otherwise min of 2 **Clause/s:** 3.26-3.27, 3.59	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Minimum number of stairs:** 2 **Minimum width:** 1100 mm **Other comments:** Table 2.3 contradicts and says only one stair necessary **Clause/s:** 2.9.9	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Minimum number of stairs:** 1 **Minimum width:** 750 mm (1100 mm if also a firefighting stair) **Other comments:** **Clause/s:** 27, 28	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Minimum number of stairs:** 2 **Minimum width:** dependant on occupant load **Minimum headroom:** 6 ft 8 in (2030 mm) **Other comments:** minimum measures for riser dimensions **Clause/s:** 7.1.5.3, 7.2.2.2.1.1, 7.2.2.2.1.2	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
C/AS2 (NZ)	**Minimum number of stairs:** 2 **Minimum width:** 1000 mm **Other comments:** 1 route of escape acceptable if sprinklers are fitted and <25 m **Clause/s:** Table 3.1a, 3.3.2 (b)	**Minimum number of stairs:** 2 **Minimum width:** 1000 mm **Other comments:** 25 < height < 34 **Clause/s:** 3.2.1, 3.3.2	**Minimum number of stairs:** 2 **Minimum width:** **Other comments:** if escape heights exceeds 34 m, stairs can be no wider than 1500 mm **Clause/s:** 3.2.1, 3.3.4
IBC (USA)	**Minimum number of stairs:** 2 **Minimum width:** 0.3 inch per occupant, not less than 44 inches (7.6 mm per occupant, not less than 1118 mm) **Minimum headroom:** 80 inches (2030 mm) **Other comments:** Treads and risers to have specific dimensions for residential R2 **Clause/s:** 1005.3.1, Table 1006.3.2, 1011, 1011.2, 1011.3, 1011.5.2	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Minimum number of stairs:** 2 **Minimum width:** 1.1 m **Other comments:** **Clause/s:** Table 3.4.3.2-A, 3.4.6	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Minimum number of stairs:** 1 **Minimum width:** 1100 mm **Other comments:** limitations on number of risers, and dimensions of risers and goings **Clause/s:** D1.7, D2.2, D2.4, D2.13	As per buildings > 17 m	As per buildings > 17 m
Evacuation lifts			
AD B (England)	**Required / recommended:** **Not mentioned** **Minimum number:** N/A **Location(s):** N/A **Other comments:** None	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
STH (Scotland)	**Required / recommended:** Not mentioned **Minimum number:** N/A **Location(s):** N/A **Other comments:** None	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended:** Sometimes required **Minimum number:** Depends on number of occupants **Location(s):** N/A **Other comments:** Refers to BS 9999 **Clause/s:** 8.4	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Required / recommended:** Sometimes required **Minimum number:** N/A **Location(s):** N/A **Other comments:** Refers to ASME A17.1 **Clause/s:** 7.15	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** Not mentioned **Minimum number:** N/A **Location(s):** N/A **Other comments:** None	As per building > 10 m	As per building > 10 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
IBC (USA)	**Required / recommended:** Recommended **Minimum number:** Enough to evacuate entire building within 1 hour **Location(s):** N/A **Other comments:** Refers to ASME A18.1, ASME A17.1, require lobby with not less than 1 hour fire resistance **Clause/s:** 1009.4, 1109.8, 3001.4, 3008.1-3008.10	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Required / recommended:** Not mentioned **Minimum number:** N/A **Location(s):** N/A **Other comments:** It is not advised that elevators are used for egress without the assistance of firefighters **Clause/s:** A-3.3.1.7	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Required / recommended:** Recommended **Minimum number:** 1 **Location(s):** N/A **Other comments:** None **Clause/s:** DP7, EP3.2, EP3.4, E3.4,	**Required / recommended:** Required **Minimum number:** 1 **Location(s):** N/A **Other comments:** if two or more passenger lifts, must be at least two evacuation lifts, at least one emergency lift per shaft **Clause/s:** DP7, EP3.2, EP3.4, E3.4,	As per buildings > 25 m
Movement devices			
AD B (England)	**Required / recommended:** Not mentioned **Location(s):** N/A **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
STH (Scotland)	**Required / recommended: Not mentioned** **Location(s):** N/A **Other comments:** None **Clause/s:** N/A	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended: Not mentioned** **Location(s):** N/A **Other comments:** None **Clause/s:** N/A	As per buildings > 18 m	As per buildings > 18 m
NFPA 101 (USA)	**Required / recommended: Not mentioned** **Location(s):** N/A **Other comments:** Escalators shall not constitute part of a means of egress **Clause/s:** 7.2.7	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended: Not mentioned** **Location(s):** N/A **Other comments:** None **Clause/s:** N/A	As per building > 10 m	As per building > 10 m
IBC (USA)	**Required / recommended: Not mentioned** **Location(s):** N/A **Other comments:** Where movement by bed needs to be allowed for, corridor width needs to be minimum of 96 inches wide **Clause/s:** Table 1020.2	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NBC (Canada)	**Required / recommended: Not mentioned** **Location(s):** N/A **Other comments:** None **Clause/s:**	As per building > 13 m	As per building > 13 m
NCC (Australia)	**Required / recommended: Not mentioned** **Location(s):** N/A **Other comments:** N/A **Clause/s:** N/A	As per buildings > 17 m	As per buildings > 17 m
Other means of escape (escape windows, ladders etc.)			
AD B (England)	**Required / recommended: Only for <4.5 m** **Type(s):** Escape windows **Other comments:** Escape windows for storeys under 4.5 m from ground level **Clause/s:** 2.1-2.3	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Required / recommended: Only for <4.5 m** **Type(s):** Escape windows **Other comments:** Escape windows for storeys under 4.5 m from ground level **Clause/s:** 2.9.4	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended: Only for <4.5 m** **Type(s):** Escape windows **Other comments:** Escape windows for storeys under 4.5 m from ground level **Clause/s:** 2.9.4	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NFPA 101 (USA)	**Required / recommended:** **Not allowed** **Type(s):** Fire escape ladders, alternating tread devices **Other comments:** Not suitable for general dwelling use, only ancillary maintenance use **Clause/s:** 30.2.2.10, 30.2.2.11	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** **Not mentioned** **Location(s):** N/A **Other comments:** None **Clause/s:** N/A	As per buildings > 18 m	As per buildings > 18 m
IBC (USA)	**Required / recommended:** **Not required** **Type(s):** N/A **Other comments:** Not required as there have to be two internal exits and a sprinkler system **Clause/s:** 1030.1	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Required / recommended:** **Not mentioned** **Location(s):** N/A **Other comments:** None **Clause/s:** N/A	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Required / recommended:** **Only for <25 m** **Type(s):** External stair or ramp **Other comments:** **Clause/s:** D1.8	As per buildings > 17 m	As per buildings > 17 m

A1-5.5 Firefighting

Table A1-33 Summary of guidance and standard recommendations for firefighting measures.

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
Fire mains and hydrants			
AD B (England)	**Fire mains required / recommended:** Yes **Private hydrant required / recommended:** No (unless erected more than 100 m from existing hydrant) **Fire mains type(s):** Dry or wet riser **Fire mains location:** Within firefighting lobby or in stair **Other comments:** Refers to BS 9990 for design of fire mains and hydrants **Clause/s:** 14.1-14.11	As per buildings > 18 m	As per buildings > 18 m except, **Fire mains type(s):** Wet riser only
STH (Scotland)	**Fire mains required / recommended:** Yes **Fire mains type(s):** Dry or wet riser **Fire mains location:** Within firefighting lobby or stair **Other comments:** Hydrant needs to be within 100m of the building, refers to BS 9990:2015 for design of dry mains **Clause/s:** 2.13.2, 2.14.7	As per buildings > 18 m	As per buildings > 18 m except, **Fire mains type(s):** Wet riser only

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
BS 9991 (UK)	**Fire mains required / recommended:** Yes **Private hydrant required / recommended:** No (unless erected more than 90 m from existing hydrant) **Fire mains type(s):** Dry or wet riser **Fire mains location:** Within firefighting lobby or stair **Other comments:** Refers to BS 9990 for design of fire mains and hydrants **Clause/s:** 51.1, 51.2	As per buildings > 18 m	As per buildings > 18 m except, **Fire mains type(s):** Wet riser only
NFPA 101 (USA)	**Fire mains required / recommended:** Yes **Private hydrant required / recommended:** **Fire mains type(s):** **Fire mains location:** **Other comments:** refers to NFPA 13 and 14, **Clause/s:** 9.10, 11.9.3.2	**Fire mains required / recommended:** Yes **Private hydrant required / recommended:** **Fire mains type(s):** Class I standpipe **Fire mains location:** **Other comments:** **Clause/s:** 11.8.3.2	As per building > 23 m
C/AS2 (NZ)	**Fire mains required / recommended:** Yes **Private hydrant required / recommended:** No **Fire mains type(s):** **Fire mains location:** **Other comments:** Refers to NZS 4510 **Clause/s:** 6.3.2	As per building > 10 m	As per building > 10 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
IBC (USA)	**Fire mains required / recommended:** Yes **Private hydrant required / recommended:** No (unless erected more than 90 m from existing hydrant) **Fire mains type(s):** Class III standpipe **Fire mains location:** Within firefighting lobby or stair **Other comments:** Standpipe system, refers to NFPA 14, **Clause/s:** 403.4.3, 905, 905.3.1-905.3.8	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Fire mains required / recommended:** Yes **Private hydrant required / recommended:** No **Fire mains type(s):** **Fire mains location:** **Other comments:** Dry standpipe not connected to water supply is not acceptable, refers to NFPA 14 **Clause/s:** 3.2.5.8, 3.2.5.9	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Fire mains required / recommended:** Yes **Private hydrant required / recommended:** No **Fire mains type(s):** **Fire mains location:** **Other comments:** Not required if there is a dry hydrant present **Clause/s:** EP1.3, E1.3, E1.5a.3	As per buildings > 17 m	As per buildings > 17 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
Firefighting lifts			
AD B (England)	**Required / recommended:** Yes **Minimum number:** 1 (2 when storey floor area is > 900 m^2) **Location(s):** Within firefighting lobby or common corridor **Fire Resistance:** REI120 from accommodation and REI60 from inside shaft **Other comments:** None **Clause/s:** 15.1-15.11	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Required / recommended:** Yes **Minimum number:** 1 **Location(s):** Within protected zone **Fire Resistance:** medium fire resistance duration **Other comments:** Refers to BS EN 81-72:2015 and BS EN 81-Part 20 or Part 50 **Clause/s:** 2.14.4	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended:** Yes **Minimum number:** 1 (2 when storey floor area is > 900 m^2) **Location(s):** Within firefighting lobby or common corridor **Fire Resistance:** REI120 from building and REI60 from inside shaft **Other comments:** Refers to BS 9999, BS EN 81-72 **Clause/s:** 49, 50.2.1, 50.2.2, 50.3.2.2	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NFPA 101 (USA)	**Required / recommended:** Unclear **Minimum number:** **Location(s):** **Fire Resistance:** **Other comments:** refers to NFPA 72 **Clause/s:** 7.15.3.3.1	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** Yes **Minimum number:** **Location(s):** **Fire Resistance:** **Other comments:** Refers to NZS 4332 **Clause/s:** 6.3.3	As per buildings > 10 m	As per buildings > 10 m
IBC (USA)	**Required / recommended:** Yes **Minimum number:** 1 **Location(s):** Fire service assess elevator lobby **Fire Resistance:** Lobby enclosure to have fire-resistance rating of not less than 1 hour, and doorways to have ¾ hour fire door assembly **Other comments:** Capacity of not less than 3,500 lbs (1,590 kg), installed in accordance with ASME A17.1 **Clause/s:** 403.6.1, 3007.1, 3007.6,	As per buildings > 18 m except, **Minimum number:** 2	As per buildings > 37 m
NBC (Canada)	**Required / recommended:** Yes **Minimum number:** 1 **Location(s):** **Fire Resistance:** not less than 1 hour **Other comments:** None **Clause/s:** 3.2.6.5	As per buildings > 13 m	As per buildings > 13 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NCC (Australia)	**Required / recommended:** Not required **Minimum number:** **Location(s):** **Fire Resistance:** **Other comments:** **Clause/s:** EP3.2	**Required / recommended:** Yes **Minimum number:** **Location(s):** **Fire Resistance:** -/90/90 (structural adequacy/integrity/insulation) **Other comments:** **Clause/s:** EP3.2	As per buildings > 25 m
Smoke clearance			
AD B (England)	**Required / recommended:** No (although inherent to smoke control provisions) **Type(s):** N/A **Location(s):** N/A **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
STH (Scotland)	**Required / recommended:** Not mentioned **Type(s):** N/A **Location(s):** N/A **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
BS 9991 (UK)	**Required / recommended:** Yes **Type(s):** N/A **Location(s):** N/A **Other comments:** Should include provision of facilities to release, or extract, smoke and heat from the building or site **Clause/s:** 49	As per buildings > 18 m	As per buildings > 18 m

Document	Trigger Height 1	Trigger Height 2	Trigger Height 3
NFPA 101 (USA)	**Required / recommended:** Not mentioned **Type(s):** N/A **Location(s):** N/A **Other comments:** None **Clause/s:**	As per buildings > 18 m	As per buildings > 18 m
C/AS2 (NZ)	**Required / recommended:** Not mentioned **Type(s):** N/A **Location(s):** N/A **Other comments:** None **Clause/s:**	**Required / recommended:** Yes **Type(s):** N/A **Location(s):** N/A **Other comments:** Smoke control in air handling system **Clause/s:** Table 2.2a	As per building > 25 m
IBC (USA)	**Required / recommended:** Yes **Type(s):** Natural or mechanical **Location(s):** N/A **Other comments:** **Clause/s:** 403.4.7, 909.16	As per buildings > 18 m	As per buildings > 18 m
NBC (Canada)	**Required / recommended:** Required **Type(s):** Natural or mechanical **Location(s):** Vents at top of stair shafts **Other comments:** 2 hours after the fire, the lowest exit level should contain not more than 1% contaminated air from fire floor **Clause/s:** 3.2.6.2	As per buildings > 13 m	As per buildings > 13 m
NCC (Australia)	**Required / recommended:** Not mentioned **Type(s):** N/A **Location(s):** N/A **Other comments:** None **Clause/s:**	As per buildings > 17 m	As per buildings > 17 m

A1-6 Conclusions

The review has identified the range of physical measures that can be included in buildings that are likely to affect the means of escape as part of a fire safety strategy. The review has also summarised the different approaches to fire safety design around the world for each of the different measures, with reference to relevant guidance documents and standards.

It is important to reiterate that the physical measures discussed in this report do not operate in isolation, but form part of a coupled system which supports the overall fire safety of a building. It is for this reason that they cannot be assessed independently, based solely on the observations of this review, and further studies are needed to assess how they may interact with each other to help facilitate escape. This interaction of measures, and the impact on occupant escape, will be explored in the next part of the project using modelling tools, including evacuation models. This modelling may also be used to explore the knowledge gaps and differences across fire safety documents summarised in the following sections. The tools will be used to identifying the consequences of these interactions and their impact on evacuation performance.

A1-6.1 Knowledge gaps

- On the basis of the documents reviewed there appears to be little research that investigates whether the installation of automatic smoke and heat detection systems provides an additional benefit to vulnerable occupants when compared with other population groups. Further work should be carried out to revisit the literature in more detail to see whether this conclusion remains valid and to consider whether additional research is warranted to further explore this finding.
- Smoke control has been highlighted as being relatively unreliable when compared to other passive and active fire safety measures, such as compartmentation and sprinkler protection. The studies which identify this lack of reliability were carried out in the range of 10 to 25 years ago, and it would be useful to determine to what extent they may remain applicable for modern buildings (e.g., whether progress in smoke control design and any additional robustness measures could have improved reliability). It would also be valuable to explore the performance benefit smoke control provides for means of escape compared to other provisions, especially when accounting for the potential differences in reliability.
- Although not in wide use, there are several directional signage technologies available that have been specifically designed to aid emergency evacuation. Given the relative newness of these technologies and the rarity of their installation it would be beneficial to investigate these systems in more detail to examine their effectiveness.

- With the recent advent of documents such as the London Plan and its expectation on the use of lifts for evacuation would suggest that further work in this area would be beneficial. Research on the likelihood that people will use lifts in an emergency, how changing technologies and education may alter people's perception of using lifts, the management and operation of lifts should all be further investigated.

- Modern technology provides multiple means of communication between building occupants, between building systems and between systems and people. Further work should be considered on what impact this can have on the evacuation strategies available to building occupants – how might building systems more effectively communicate with occupants and first responders? How might occupants use social media tools to communicate amongst themselves and first responders? etc.

- There appears to be limited literature available on mobility impaired occupants and their operation of doors, such as when unlocking doors and escaping from an apartment. This could subsequently affect their escape time, as well as tenability conditions should the door from a fire affected room be opened for a prolonged period to assist in escape. This would indicate that further research in this area is needed.

- Within the scope of human interaction, it would be beneficial to extend knowledge on the communication between alarm type and other occupant factors (activity, experience, etc.) when related to pre-evacuation time and the impact of staff type and authority on occupant reaction to instructions.

- Finally, a clearer understanding of the impacts of the maintenance of social groups; fatigue / ill-health / obesity and the use of mobile devices on travel speeds would help to better assess the likely escape time that might be required in the event of a fire.

A1-6.2 Differences between AD B and international documents

The comparison between AD B, and UK guidance more generally, to other documents and standards around the world has highlighted some key differences in the design approach to residential buildings:

- AD B allows for a single stair when a building is greater than 11 m in height, whereas other guidance documents typically recommend that at least two stairs be provided.

- AD B appears to be the only guidance document where the recommended fire resistance rating of the stair enclosure increases as a function of building height (i.e., when above 11 m). It could be hypothesised that this is linked to the point above, such that greater importance is placed on protection of the stair when single stair buildings are allowed for.

- AD B recommends that dwellings with internal bedrooms or above a certain size (i.e., where travel distances are greater than 9 m) be provided with an internal protected corridor / entrance hall. In contrast, other documents allow for a much greater flexibility in the design of the internal arrangement of dwellings, with no expectation that a protected corridor be provided.
- There is approximately a 50/50 split between the documents on whether refuge points should be included for standard residential accommodation, with AD B providing no recommendation that they need to be provided.

The impact of the above points on means of escape are to be considered in the next phase of the project.

A1-7 References

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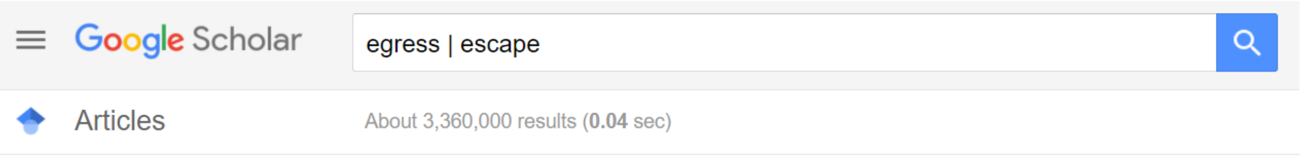
Appendix A1-A – Summary of online search methods

The online search tool Google Scholar has been used to assist in the wide review process. Google Scholar has been selected ahead of Scopus and Web of Science due to its capability to capture a wider range of materials, including important 'grey literature' (i.e., materials produced by institutions and published outside of traditional academic channels). It is important to note that, while advanced methods can be used to refine the searches in this tool, the Google Scholar search is restricted by a 256-character limit. Therefore, a certain degree of judgement has been applied in undertaking the searches and highlighting any important materials.

As an example, a search for the word 'detection' produces 6 910 000 results. However, many of the results are not applicable to this project, such as 'detection' in high blood pressure treatment or 'edge detection'. Therefore, to reduce the search results down, the inclusions and exclusions presented in Table A1-A1 have been used.

When selecting keywords there has been a recognition that some words are used synonymously and therefore the search has accounted for this. The strategy has been to use the same group of high-level keywords for each measure under investigation in which a Boolean logic has been applied to address synonymous terms, using OR functions (using the '|' symbol) alongside AND functions where appropriate. Boolean functions refer to switching functions which assume a two-element output, such as true or false. In this instance, an OR function will output as true when any specified input is true, while an AND function will output as true only when all inputs are true. For example, to find all materials containing either the words 'egress' or 'escape', then an OR function would be used (*egress | escape*, presented in Figure A1-A1). Alternatively, materials could be searched which must contain both these words uses an AND function (e.g. *egress escape*).



egress | escape

About 3,360,000 results (**0.04** sec)

Figure A1-A1 An example of an OR function being used in Google Scholar

In addition to the Boolean functions, some terms may be either singular or plural and thus the '*' wildcard symbol has been used to include both. This common high-level keyword set has then been used in conjunction with specific keywords appropriate to each of the measures.

The terms in Table A1-A1 are intended to produce results which are focussed on fire safety and escape in residential buildings. An exclusion term of -wild* has been used to specifically reduce the amount of content around wildfires etc. Additional exclusion terms were considered but ultimately had to be omitted due to the Google Scholar character restrictions impacting searches.

No restriction was placed on the date of publication of references as much of the key findings on evacuation have an extensive historical background. As such the review has identified material as far back as 1881 [17] that has relevance to current buildings.

Table A1-A1 Common high-level keywords and search terms for Google Scholar search

Common high-level keywords	Boolean search term
Always included	fire* | smoke
	house*| dwelling*| flat*| apartment*| residential | domestic
	egress | escape| evacuation
Always excluded	-wild*
	Patents and citations (*excluded as checkboxes*)

The search process and its impact on number of hits is presented in Table A1-A2, using the search term detection as an example. The inclusions and exclusions result in a total number of final search results which is approximately 1% of the original search. However, the final number of hits (72 400) is still considerable. Therefore, in some cases, additional searches and author judgement has been required to identify relevant works. This process has not been formally documented herein.

Table A1-A2 Example of search refinement using inclusions and exclusions

Boolean search term	Number of hits
detection	6 910 000
detection (fire* | smoke)	2 640 000
detection (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic)	416 000
detection (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation)	151 000
detection (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*	81 200
detection (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild* (*patents and citations excluded*)	72 400

Appendix A1-B – Detailed literature review

A1-B.1 Active measures

1. Within the context of this review active measures include detection systems; notification including audible, visual, staff / resident intervention; emergency lighting; suppression and smoke control.

2. Care needs to be exercised on the over-reliance of warning systems in which there are a high rate of false alarms. Kinateder et al. [18] note that "*An overuse of warnings and false alarms may consequently lead to a desensitization of occupants and may reduce their perceived risk during a real emergency*" which would suggest leading to a delay in evacuation. Proulx [19] "*The fire alarm signal is probably the least reliable cue of a fire since there are a large number of false alarms, test alarms or prank alarms in some buildings that have reduced the credibility of this signal as an indication of a real fire*". The topic of false alarms (also sometimes referred to as 'nuisance alarms' or 'unwanted alarms') is discussed further in the sections below.

A1-B.1.1 Fire detection

- **Search term**: detection (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 72 400

3. The key question reviewed in this section is: how does the provision of automatic fire detection measures (be that by heat, smoke, or a combination) affect evacuation? When reviewing the literature, it is often difficult to separate the effect of detection with the effect of providing an alerting function. This is particularly true when examining the performance of smoke alarms as these devices combine the fire detection and occupant alerting functions.

4. The various forms of fire and smoke detection used in buildings (and elsewhere) have been summarised by Spearpoint [20]. Different detection technologies have certain benefits and limitations meaning they are often more suitable for specific applications.

5. The ability to detect the presence of fire is a vital part of an overall fire safety strategy. It is through fire detection that building occupants can be alerted, other fire safety measures can be activated, and the fire and rescue services can be summoned. Although humans are able detect the likely presence of fire through the ability to feel heat, see flames, see and smell smoke and hear a fire, they are not always available or reliable. Indeed, the close proximity of such fire effluent can indicate that environmental conditions are or will soon become untenable. Although published at a time when modern detection systems were not

prevalent, the Post-War Building Studies [21] noted that “*Fires are usually detected by direct personal observation, the discoverer warning occupants of the buildings to enable them to escape and calling the fire service*…” but goes on to say “*although satisfactory enough during day-time when most premises are occupied, is less so by night when buildings may be unoccupied or the occupants asleep*”. Instead, various automatic measures are installed in buildings as a substitute (and enhancement) to these human abilities.

6. There appears to be very little research available on how reliable humans are at detecting fires, and how that compares to the use of automatic means. In the work of Kahn [22] he suggests that “…*humans, even when asleep, may be able to detect certain low particulate smoke types more effectively than smoke detector alarms*.” However, Kahn was not able to quantify this possible difference in effectiveness. Xiong et al. [23] similarly found that “*People who survived* [accidental residential fires] *were more likely to wake up to non-smoke alarm fire cues (e.g. glass breaking, smoke) than a smoke alarm cue, even if a working smoke alarm was in the house*.”

7. The BS 5839 series of standards provides information on the design, installation, commissioning and maintenance of fire detection and alarm systems, where Part 6 [24] is for domestic premises. The standard notes that “…*it is considered that the level of fire risk in domestic premises* […] *is unlikely ever to be sufficiently low to obviate the need for some form of fire detection and fire alarm system*.” Various grades and categories of systems are defined in the standard with minimum requirements recommended for different types of premises.

8. Heat detection systems are the oldest ‘modern’ technology used to detect a fire. Heat detection involves the principles of heat transfer and in particular conduction and convection processes. More modern detection technologies employ the phenomenon in which the electrical properties of materials to change when heated. Flames can be detected using electro-magnetic radiation signals at infra-red, visible and/or ultra-violet wavelengths. The characteristic flicker frequencies of flames can also be used as a means of detection, as well as the use of imaging technology.

9. There are various mechanisms which can be used to detect the presence of smoke in the form of soot particulates. One approach is to use a combination of a light transmitter and receiver to create a beam that can be obscured by the presence of particles, alternatively, the ability of particles to scatter light from a transmitter to a receiver can be used. Ionisation smoke sensors measure the change in current between two charged plates in a chamber where the presence of particles (such as soot) capture ionised air molecules.

10. Fires can generate a range of combustion gases which include H_2O, CO, CO_2, HCl, HCN, HF, H_2S, NH_3 and various oxides of nitrogen depending on the fuels burning and the combustion conditions. When these products are transported as a constituent of smoke then sensors can be used to detect the presence of one or more of these combustion gases. Gas sensors are generally only used in specialised applications although the availability of CO detectors has become more common over the past decade or so.

11. In addition to what is listed above, there has been some consideration on whether the characteristic ‘cracking’ sounds in heated materials such as a wall lining might also be used to automatically detect whether there was a fire. It has also been suggested that ultra-sonic waves could be used as a means of identifying the presence of a fire.

12. When considering the impact of fire detection on evacuation then there are a number of factors that may have an impact including:

- How soon a fire might be detected which will likely include the sensor type/s within a device and the type of fire (i.e. flaming, smouldering, smoke generation characteristics), along with the physical distribution of devices within a space.
- Use of multi-sensor devices and/or advanced detection algorithms.
- Nuisance (false) alarms, as discussed above and elsewhere.
- Reliability (device failures, human intervention that disables devices, etc.)

13. Lui and Kim [25] note that “*The rapid detection of smoke at very low levels can maximize the probability for successful fire suppression, escape and survivability*.” Studies cited by Rasbash et al. [26] suggest that automatic detection systems could reduce the fatality rate by 0.0024 p.a. for single occupancy dwellings and 0.0021 p.a. for multiple-occupancy dwellings, or up to 0.0042 p.a. when assessing data from the US.

14. Gottuk et al. [27] highlight the potential benefit of using advanced fire detection algorithms where they state: “*For many of the sources expected in a residential fire (e.g., smoldering fabric, polyurethane foam, and flaming cardboard) the combined alarm algorithm would afford the occupants several extra minutes of time to escape compared to smoke detectors alone*.”

15. Bukowski et al. [28] found that “*Smoke alarms of either the ionization type or the photoelectric type consistently provided time for occupants to escape from most residential fires*”. However, this conclusion was reliant on several findings in which occupants follow fire safety advice such as sleeping with doors close, using interconnected devices, pre-planning and practicing evacuation. Bukowski et al. [28] noted that the installation does not protect against intimate ignition scenarios. They found that smoke alarms in bedrooms increased escape times, especially against smouldering fires. Aspirated photo-electric detector responded after other photo-electric devices, but results were limited. Finally, the work found that residential sprinklers activated after heat detectors and thus residential sprinkler installations should always include smoke detectors.

16. Previously, Spearpoint [29] showed that there is a correlation between a decrease in fire deaths and the percentage of dwellings in the UK and in the US with smoke detectors. However, there might be other factors that contribute to the change such as the introduction of furniture flammability regulations. In the recent study by Ahrens [30] it is found that the death rate per 1000 structure fires is 55% lower in homes with working smoke alarms compared to homes without alarms or where they failed to operate.

17. Shelley and Spearpoint [31] investigated the benefits to escape time of using heat, smoke and CO detectors compared to fast response sprinklers in the case of fires in TV sets (of the older CRT style). The research examined a scenario in which the fire occurred

in a living space in which someone sleeping in an adjoining bedroom would need to travel through. As would be expected, the smoke and CO detectors activated sooner than the devices that responded to heat. Shelley and Spearpoint found that "…*the heat detector does not provide a sufficient level of safety to allow an occupant to escape the apartment*…". Similarly, "…*the fast response residential sprinkler system does not provide a sufficient level of safety to allow an occupant to escape from the apartment*…" to the TV fire scenarios.

18. Where the population of buildings include vulnerable occupants there could be a benefit to installing detection (and warning) measures. For example, Marshall et al. [32] found that smoke detectors were equally effective in both low- and high vulnerability populations. However, it was further noted that the high-vulnerability group was more likely to survive if, in addition to a smoke detector, a potential rescuer was present.

19. However, somewhat counter to the points made previously on the benefits of providing automatic fire detection (and warning) Bruck and Thomas [33] found that "*many fire fatalities where the effective operation or not of a smoke alarm is likely to have been irrelevant in determining whether or not a person survived the fire*". Bruck and Thomas suggest the reasons for this finding relates to the immediate intimacy of a person with the fire, the location of the device not fulfilling its operational function and/or the inability of a person to escape due to cognitive or physical impairments.

20. Smoke detectors can be powered with self-contained batteries and/or the mains supply. Battery only devices may rely on the replacement of cells unless the cells are sufficiently long-life or are charged by a connection to the mains or similar. Previous work [34] has examined the performance of different power supply technologies. Ahrens [30] provides a comprehensive picture of the performance of smoke alarms in the US in terms of power supply types, reasons for non-operation etc. The study found that in fires in which a battery only powered smoke alarm failed to operate around 80% had missing, flat or disconnected batteries.

A1-B.1.2 Notification systems

21. The following section acts as an introduction to the subsequent sections for audible alarms, and visual alarms and beacons (Sections A1-B.1.3 and A1-B.1.4).

22. The provision of information via notification systems compensates for deficiencies in the existing information levels in the occupant population. Visual, audible and tactile notification systems can be employed, as they increase the likelihood of reaching the occupant population given the different conditions that might arise and the abilities of the occupants themselves. The success of these approaches is dependent upon the resolution of a number of questions, prior to the occupant appropriately responding to the incident [35], [36]:

- Is the information produced by the notification system received?
- Is the information perceived by the occupant as representing an emergency?
- Does the information lead the occupant to identify an appropriate response?
- Is the individual then able and willing to perform this response?

23. The time that residents take to initiate their evacuation movement can be difficult to estimate. In the past, this delay was often not included in an engineering analysis at all [37]. Although this simplified the evacuation calculation, it also potentially underestimated the expected evacuation times. In the calculation of an expected total time to evacuate a building, it is now common practice for engineers to include some time to account for a delay to the start of evacuation. It is presently understood that the pre-evacuation time will vary according to situational, structural, procedural, organizational, behavioural, and environmental factors present.

24. Initially, notification requires that the resident population divert their attention away from the activities in which they are engaged. The success of this is initially associated with the clarity of the reception of the alarm signal / message. Members of the population who do not clearly receive it may misinterpret or ignore the signal / message entirely [38], [39]. This is reliant both on individual (e.g., hearing levels, activity, status) and environmental factors (e.g., spatial configuration, background noise, etc.). Residents are then required to comprehend the significance of the signal / message provided; i.e., that they receive it and then accept that it represents an actual event. To attract the attention of the population, the signal/message needs to clearly and believably denote the occurrence of an emergency incident. The population needs to be able to differentiate between the emergency information and other information from adjacent systems (on other floors, from other companies, non-emergency systems, security alarms, background pollution, etc.) [40]. Any difficulty in doing this might significantly hinder their response.

25. The approach employed as part of the procedure to inform the target population may include a range of technologies, each of which carries different types of information, suggests different degrees of urgency and which have different degrees of comprehension and intelligibility. Typically, these are systems that alert that something has happened using sirens, bells, horns (or dedicated tones such as the T-3 fire alarm system, where tone levels are modulated to produce an intermittent sound deemed to be better able to attract attention and differentiate the sound from other non-fire alarm systems) and / or provide information beyond simply an alert using a voice notification (either live or pre-recorded). In many non-residential structures, staff form a key component within the procedural response. It is widely recognized that the presence of well-trained, engaged, authoritative and informed staff presents the most effective means to initiate occupant response [41], [42]. Although it should be acknowledged that such resources are typically found in non-residential occupancies, such as office or assembly occupancies.

26. To comprehend the significance of the signal / message, the population must believe that it signifies a real and imminent threat. The accuracy of this perception is influenced by the frequency with which the system is tested, the frequency of malfunctions, and the frequency of false alarms [43], [38]. If these events occur too frequently then they may detract from the way occupants respond.

27. Therefore, notification systems need to be heard, recognised, and believed to the extent that an engaged group stops what they are doing to attend to the information provided to them and then respond to it. Ideally, they should also provide information on the nature of the incident and guidance on the required response, in support of the training provided [35],

[36]. The provision of accurate and timely information to the population is more likely to convince them of an incident than a signal alone and may aid them during their response. A signal might alert them of an incident but provide no further information. It is now widely accepted that ineffective behaviour is more likely when the provision of detailed information is delayed, ambiguous, or avoided altogether, causing a delayed response [35], [36]. During such a delay, conditions might deteriorate further resulting in less time in which to decide and fewer alternatives from which to choose. In contrast, a more informed population is better able to assess the situation and respond accordingly. The same logic is then applied to the evacuee as to the safety manager: timely information helps appropriate actions.

28. The process of managing an evacuation is also aided by the evacuees knowing what they are doing and why [44]. Given that it is now considered desirable to inform the evacuees of the incident, the question then becomes how to do so most effectively.

29. The longer that the incident has to develop, the greater the risk posed to the resident population [45]. The prolonged incident may increase the chances of people encountering cues that encourage response; however, it may also reduce potential routes, worsen environmental conditions, and contract the procedural timeline when safe egress is possible. Therefore, it is important for the entire emergency response that the population is notified of the incident as quickly as possible, that they believe this information and that sufficient information is provided to them to encourage an appropriate response (i.e., in support of the procedure). The procedure can then be implemented more quickly. Ironically, this quick response is still important even for those who are initially expected to remain behind. They may still be required to evacuate at some stage, and will then be able to do so earlier in the timeline of the fire, when the egress routes have cleared.

30. The evacuation process requires the occupant population recognise that an incident is sufficiently hazardous to require a change in their behaviour, such that they respond. It is critical that accurate information is provided. The worst situation would be where there was no information available, or where inaccurate information was provided, especially where it came for a source perceived as credible (e.g., a member of staff).

31. The building type and layout provides the spatial environment within which the event occurs. It may determine the nature of the occupants, the resources employed, the hazards present, and the social / organisational hierarchy present and may influence the types of actions expected. As such, it is a primary influence upon the scenario. The spatial organization impacts familiarity and use of the space by an occupant both before and during an incident. Occupants are more likely to spend time obtaining information or devising a plan of action in a complex building or in a building where wayfinding is difficult or unfamiliar (e.g. where occupants do not normally locate or use stairs during their routine ingress/egress). The way the building is designed may provide occupants with visual access to the behaviour of others, to the original incident or to procedural attempts at notifying them as the target population.

32. Occupants may have situational or innate characteristics that reduce their alertness. Occupants may be asleep, intoxicated, or impaired all of which might reduce the information available to them. In situations where occupants focus their attention on a

particular point, e.g., listening to music on headphones, attention may be diverted from critical environmental and procedural cues. Similarly, in environments where aural or visual background noise is present, the cues available to the population regarding an incident may be confounded and confused, delaying their response. Occupants may also be committed to their actions, potentially having committed resources to the performance of this action, making them reluctant to interrupt it based on ambiguous cues (e.g., just stepping into a bath).

33. Training is a characteristic of the organisational structure within a building, since training should be specifically tailored to each building evacuation procedure present. That is not to say that the populations do not bring more general experience to an incident; however, this is more difficult to predict and quantify within the engineering process. The likelihood and nature of occupant training will depend on the occupancy type; for instance, in public buildings, occupants are unlikely to be trained for that specific building, whereas some form of training is likely to be the norm for office spaces (although the sophistication of this training may vary significantly). Such dedicated training is unlikely for residential properties; however, lessons learned from training in other occupancy types may be integrated into a resident’s evacuation response. The potential for enhancing performance through training is assumed in non-residential properties.

34. The number of false alarms in a building is an important determinant of the efficiency of this system to warn occupants. If the number of false alarms is high, it could be expected that the pre-travel time will be extended since occupants are unlikely to look for information and will be less receptive to other cues [19]. Conversely, occupants who are familiar with a building, who have participated in evacuation drills, and who are aware of the evacuation procedure are more likely to start evacuation rapidly. What is not well understood is the point at which the performance of drills and training exercises starts to make the occupant population sceptical of the information being provided [46].

35. The nature of the relationship between the occupant and the surrounding population will influence how information is perceived, and the actions subsequently performed [19]. It will influence the responsibility felt by an occupant for those around them, information exchange, perceived risk and the preparatory actions that might be performed before movement to safety is initiated.

36. The nature and severity of the incident will influence the type of cues provided to the population. Their proximity to the incident will influence access to these cues, the degree of ambiguity and the perceived sense of risk derived from the cues received.

37. The population can be a source of information, with their actions indicating their interpretation of the incident and the options available. However, research has also suggested delayed responses in the presence of others, given their identity and actions [47]. These influences have been referred to as informational and normative social influence [48]. They may also limit viable responses, should routes become overloaded or congestion develops, discouraging the use of certain routes.

38. As discussed, an extended pre-evacuation time is often the most significant component of the evacuation process. It is possible that when occupants are asleep the pre-travel times could be even more prolonged. Comprehensive reviews of the research literature on arousal from sleep have previously been conducted by Bruck and colleagues [49]–[52]. These found variation in the performance of different systems (e.g. bed shakers, strobes, alarms) that was dependent on positioning of the alarm system and the status of the individuals involved (e.g. intoxicated, deep sleep, etc.). This is of particular concern for residential properties.

39. Families may include young children - old enough to recognise an alarm signal, but not capable of identifying an appropriate response. Therefore, parents may have to spend time finding children who have responded to fire alarm and are not in the expected location (e.g. move from a bed to hiding in a wardrobe). This may delay the overall time to leave the flat and move to the stairwell [40].

40. It is apparent that many of the factors above are situational and social, and fall beyond the influence of safety managers and designers. For instance, the actions being performed, the status of an individual or who they are with will all influence how someone responds to alarm cues but cannot be affected by the safety managers or designers. However, they provide the context within which any notification system operates and the potential for people to be in different situations should be acknowledged when assessing the effectiveness of different measures.

A1-B.1.3 Audible alarms

- **Search term**: (“audible alarm” | “audible alarms”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 1 240

41. NFPA 72 [53] represents a recent model code that represents a repository of our best understanding of the impact of notification systems. It provides guidance on the impact of audible, visual, textual and tactile notification systems. Regarding audible systems it accounts for several performance attributes:

- Audibility of the signal / message in relation to ambient sound (e.g. +15 dB above ambient noise in public mode and +10 dB above ambient noise in private mode).
- Coverage of the sound / volume in relation to location / separation / room use (e.g. +15 dB or 75 dB in bedrooms – whatever is the greatest) [54].
- The difference between alerting and notification.
- The pattern of signals (e.g. when signals sound and go quite – T3).
- Intelligibility of the content (where voices are used), with tests for assessing sufficiency.

42. Beyond these elements, there is an array of attributes that affect the audibility and influence of different messages. For instance, the periodicity (e.g., time between signals), distribution of frequencies using (e.g., swooping sound) and the familiarity / authority of the voice used [55] might all affect whether a signal is noticed, received and interpreted. The style and content of a voice message influences whether the residential population

understands the content. Content should be kept as simple and direct as possible. This is especially the case where the very young / old are expected, or where there is a sizable population of non-native speakers [56]–[58].

43. A range of audible notification systems are available [59], [60], [61]. These have been broadly grouped in Table A1-B1 along with the factors that influence their impact on the target population and the type of message / signal that they provide. These different technologies (used in conjunction with other procedural resources such as visual alarms and staff), can both initiate a response and also inform that response depending on the technology being deployed.

44.In recent years advances have been made in the development and implementation of audible systems – including the development of new tones (T-3), voice alarm technologies, combined approaches (e.g. using tones and voice together) and making the systems more adaptive, local and managed. The developments have had varied impacts, some of which were dependent upon several issues beyond the notification performance itself, such as the connectivity of the systems in place and issues of maintenance and reliability. In designing and implementing such systems it is critical to first understand their effectiveness at notifying the population and then focus their technological development toward the needs of the occupants served. Given the variation in an occupant population, audible systems must address their various capabilities to ensure comprehensive coverage and enhance effectiveness.

Table A1-B1 Audible alarm types, reproduced from Gwynne [62]

Audible alarm type	Attributes that affect impact	Indication
Siren / horn / bell	Volume / intensity, length, repetitions, frequency, tone type, coverage, periodicity (i.e. gap between message)	Indicates that an event has occurred.
T-3 signal (assuming familiarity)	Volume / intensity, length, repetitions, frequency, tone type, coverage, periodicity, familiarity	Indicates that an emergency has occurred, assuming that T-3 is suggestive of an emergency.
Voice recording	Volume/ audibility, content message, message length, number of **repetitions, intelligibility**, consistency of message, type of Voice, periodicity, ambient noise, coverage, connectivity, language used, accuracy of content	Indicates that an incident has occurred and may also provide response guidance. The nature of the incident and the response will need to fall within the library of stored messages.
Live announcement / paging	Volume/ audibility, content message, message length, number of **repetitions, intelligibility**, consistency of message, type of voice, periodicity, ambient noise, coverage, connectivity, language used, accuracy of content, familiarity / credibility of voice	Indicates that an incident has occurred and may also provide real-time response guidance. Assuming that a procedure exists to determine the response, the method is flexible enough to provide relevant information.

45. It is now recognized that the evacuation process is not simply initiating the evacuation and then controlling the ensuing response; instead, it is viewed as a multi-faceted event where people respond in different ways according to the incident scenario and the information available. More importantly, it cannot be assumed that (a) a population will respond immediately or uniformly to a cue, or (b) that notification systems are equivalent in their capacity to initiate a response.

46. The occupant response to notification (e.g. the alarm) will be affected by the degree of preparation and training. For instance, a population benefits both from recognising the sound of the alarm and understanding what needs to be done in response to it. The benefits of such practice are constrained by their frequency (where drills might eventually provoke alarms to be seen as indicating a drill rather than a real incident). Along with false alarms caused by technical issues, frequent false positives will eventually increase the time for a population to respond (i.e. the effectiveness of the alarm). However, extensive preparation is not always possible. This may be due to the limited resources available (e.g. if the occupancy is a single family dwelling it may not have sophisticated technology in place) or the time available in order to prepare (e.g. visiting populations will have limited

time to prepare). Local preparations can be made. Individual families might develop a plan based on the resources and information available to them. However, this will still involve them relying on their own actions (rather than the actions of staff), possibly on a relatively simple ‘stand-alone’ notification systems and will not ensure a consistent response across a building. It is expected that in most UK residential building that consistent preparation across the occupant population is not present.

47. Given that preparation may be insufficient, a greater burden is placed upon the notification technology (typically an audible alarm) and its capacity to quickly effect an evacuation. The initial shock of a serious and very real incident developing in someone's residence will not only require the occupants to be convinced of the need to evacuate, but to be convinced in sufficient time to select an appropriate response. Ideally, the alarm has to alert evacuees and guide them where possible to limit the time taken to respond and to instruct the nature of the response. This is only available with certain technologies.

48. The emergency procedure should be enacted once notification has taken place. It should follow the pre-determined approach. For instance, if an immediate evacuation is required then the population should immediately start to move. However, there will inevitably be a delay in doing so and often a significant delay [63], [59], [64], [65].

49. Over the last 20+ years, an array of data has been collected to describe the extent of pre-evacuation times; i.e. the time between receiving a cue that a fire exists and then initiating movement to a place of safety. Much of this data relates to the impact of notification systems (in isolation or in combination) on delays in a population starting to evacuate. Undoubtedly, these datasets are collected in different ways and reflect different situations. However, they do give a sense of the scale of the delays that might be experienced and that the importance of this factor. It has an impact on the importance of physical movement, as extensive initial delays may reduce the time available for residents to reach a place of safety.

50. To give a sense of the scale of such delays, we present a selection of these data-sets according to whether they occurred in residential / non-residential properties and UK / non-UK responses [66], [67], [68], [69], [70], [71], [60], [59], [42], [72], [73], [64], [74], [75], [65], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87]. These are shown in Table A1-B2. These reflect the set of averages across each dataset (either the mean or median) and therefore reduces the distribution of reported values.

51. It is apparent that residential pre-evacuation delays are more extensive – by approximately a factor of three. This is to be expected given that non-residential properties include workplaces (i.e. excluding the very young, the elderly, the sick, the intoxicated and the sleeping). The compiled data also indicates that the UK have reduced pre-evacuation times in non-residential settings. This may partially be a symptom of the non-UK data including data from a range of different countries and also including several extreme events (e.g. MGM Grand Fire, Forest Laneway fire). Most importantly, the data suggests that the pre-evacuation period can extend to several minutes. It is certainly non-zero and therefore should be addressed in guidance provided in some form. This is also recognised in various regulatory approaches – including the UK, Australia, etc. There has been some good recent

work on UK residential behaviours and evacuation performance [88], but there is still limited dedicated pre-evacuation data.

Table A1-B2 Pre-evacuation times by location and building type

Building type	Location	
	Non-UK	UK
Non-Residential (s)	277 [10-3600] N=49	54 [17-150] N=26
Residential (s)	945 [39-11480] N=17	

52. This data has also been recompiled to account for the impact of different alarm systems on the pre-evacuation times of the population. These exclude differences in occupancy and location to focus on the alarm types: tone/bell alarms, alarms with a voice components and staff. Table A1-B3 shows that the presence of voice alarms significantly reduces the average time to commence evacuation – moving from three minutes to one minute. It suggests that the presence of active staff compensate for the benefits of voice alarm; e.g. that the presence of staff with a tone/bell affects decision-making in the same way as a voice alarm. Finally, the presence of staff alone (with no other notification system in place) performs comparably to a tone/bell system. However, the staff performance may also include elements of their movement (rather than just their communication activities) and so this may be conservative.

Table A1-B3 Pre-evacuation times by alarm type

Parameter	Alarm Type			
	Tone/Bell	Voice	Alarm / Staff*	Staff
Pre-evacuation time (s)	185 [18-582] N=21	65 [10-194] N=34	65 [25-150] N=12	156 [89-220] N=5

*Typically bell or tone.

53. As noted by Hoskins and Mueller [89]: *‘Current fire alarm system design practices might be inadequate at triggering the necessary human behaviors to expedite an immediate response to the situation. Properly designed voice messages could lead to a better response, but still have limitations. A building occupant will make a decision when they feel that they have received all of the information they are going to need.’*

54. Two recent studies have provided extensive compilations of pre-travel data. Lovreglio et al. [90] compiled pre-travel data from nine fire incidents and 103 evacuation drills involving 13,591 evacuees (see Figure A1-B1), across 16 countries including the UK. It is apparent that the residential pre-evacuation delays range widely and can represent a prolonged period of time.

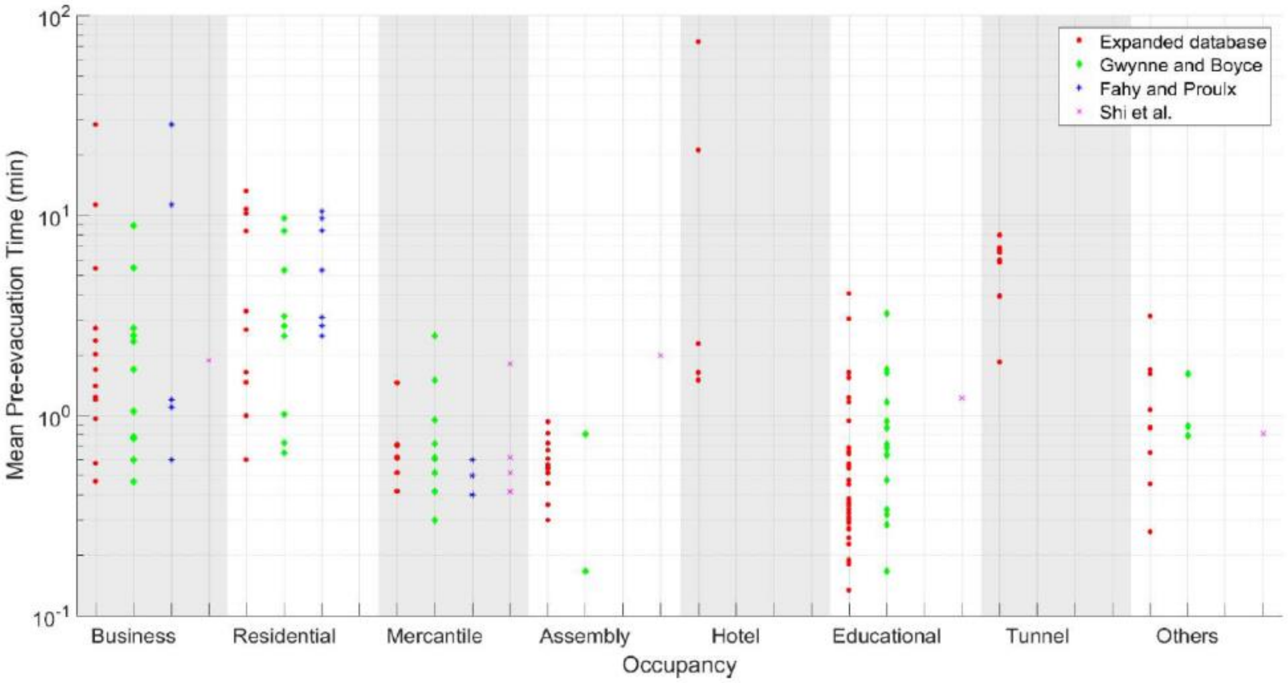


Figure A1-B1 Pre-evacuation datasets sorted by occupancy type, reproduced from Lovreglio et al. [90]

55. Geoerg et al. [91] reviewed the pre-evacuation delays of individuals with physical, cognitive- or age-related impairments (see Figure A1-B2). Although the results vary widely been data sources, it is again apparent that the initial delay experienced by those with impairments might form a substantial period and might further extend the evacuation time already prolonged by movement issues – data-set averages ranging between 4.7 s and 850 s, with an overall average of 75 s. These included experiments/drills and situations where assistance was frequently present.

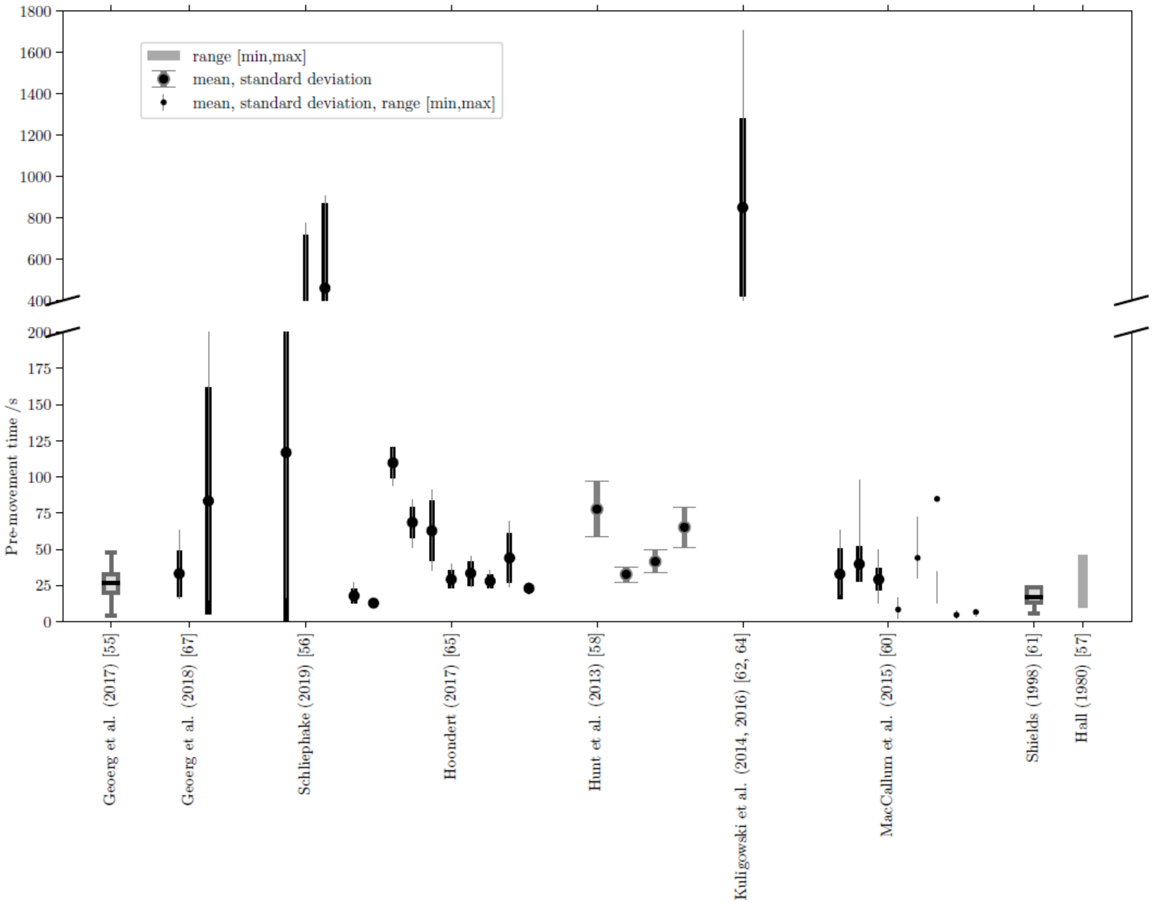


Figure A1-B2 Pre-evacuation datasets of those with impairments, reproduced from Geoerg et al. [91]

56. Several studies have been completed to examine the impact of alarm systems on waking individuals. This is particularly important for residential properties. Bruck [60] examined the effectiveness of various systems on sleeping individuals along with other factors that might affect the impact of such systems (e.g., intoxication). It is possible that when occupants are asleep the pre-travel times could be even more prolonged. They noted this literature falls into two categories: investigations into arousal thresholds to different sleep given different sound stimuli; the second focused on the response of individuals in fire situations. The latter is more relevant here. The average time for the sleeping population to respond (across devices and experiments), ranged from 11 to 381s, with an average of 381s. A more detailed discussion of the work conducted by Bruck et al. is presented in the next section to allow comparison with the effectiveness of strobe alarms.

A1-B.1.4 Visual alarms and beacons

- **Search term**: (“visual alarm” | “visual alarms” | beacon*) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 33 800

57. Residential properties may contain people with hearing impairments and the elderly whose hearing is degrading over time. As such, traditional audible alarms may not always be sufficient to notify them of an emergency, or be delayed in doing so. Given this, other

means of notification may need to be explored. This may include residential bed shakers, vibrating pagers, modified phone access, or warden arrangements. Here we briefly address visual alarms.

58. A range of visual notification systems are available [62]. These have been broadly grouped in Table A1-B4 along with the factors that influence their impact on the target population and the type of message / signal that they provide. These different technologies (used in conjunction with other procedural resources such as audible alarms and staff), can both initiate a response and also inform that response depending on the technology being deployed.

Table A1-B4 Visible alarm types, reproduced from Gwynne [62]

Visible Alarm Type	Attributes that affect impact	Indication
Strobe	Colour, brightness, background lighting, coverage, frequency / periodicity	Indicates that an event has occurred
LED dynamic sign	Colour, brightness, content, length of message, background lighting, coverage	Indicates that an event has occurred and may allow limited information to be provided
Display screen	Colour, brightness, content, length of message, background lighting, coverage	Indicates that an event has occurred and may allow information to be provided on the required response

59. Strobe lighting (and the use of visual alarms in general) is more prevalent in the US. NFPA 72 outlines requirements for the use of strobes, pulse lights and other visual signals in residential properties. These addresses issues of coverage (requiring documentation of where it is and it is not provided), performance characteristics (e.g. brightness – 1000 cd, colour – white, and pulse length – 20-100 milliseconds/maximum 20 milliseconds in length), photometrics, location, spacing (in rooms and corridors). NFPA 72 also allows for a performance-based approach to ensure a design that meets a performance criterion (0.0375 lumens/ft^2) for all appliances. Additional guidance is provided for sleeping areas.

60. BS 9999:2008 [92] also provides several references to visual notification:

- 45.3: The fire alarm evacuation signal normally consists of a continuous signal by means of bells, sirens, hooters, flashing beacons, etc., which indicates that all persons are required to evacuate the premises immediately. In premises where a staged evacuation/alarm system is used, the staff should be instructed, on being alerted, to take up their pre-arranged emergency positions before the general alert is given. Where a phased evacuation is being implemented, staff with specific responsibilities, e.g. fire marshals/fire wardens, should proceed to their allotted duties to supervise the evacuation procedure. Where voice alarms or other forms of communication such as visual display screens are available, more informative messages may be provided. In some buildings, consideration needs to be given to the selection of additional languages that might be appropriate. Whatever system is used it should be clear and unambiguous.

- Table 8: In some circumstances where people are in an unfamiliar building the provision of a voice and/or visual alarm system can help reduce evacuation time.

61. High-intensity light sources, such as strobe lights, are used to provide emergency alarm signalling to the hearing impaired. In the US, strobes are required to be synchronized in situations where a person would otherwise be exposed to more than two flashes per second, preventing potential seizures. The Americans with Disabilities Act (ADA) recommends the use of visual notification (strobes) for the sleeping areas of people with hearing impairments [93], [94]. Requirements for this technology are outlined in UL 1971, Signalling Devices for the Hearing Impaired. Most major smoke alarm manufacturers offer smoke alarm models with strobe lights, including First Alert, Gentex Corporation, and Kidde. Strobe lights may either be integrated into the smoke alarm or may be an accessory that connects to the alarm.

62. Features available on smoke alarms with strobes are fairly consistent. These alarms generally feature a 177-candela strobe, in addition to a piezoelectric audible alarm yielding 85 – 90 dB at 10 feet. More sophisticated visual notification systems may be available in public spaces (see above). In the future, these might involve the use of existing technologies (screens, LED displays, etc.) that were already present within a space and could then be used as part of the notification system. A variation of this approach is outlined [95] where existing video displays are used to notify people of an event. More sophisticated integrated systems can be employed to distribute information to a variety of handheld and desktop devices (including PC and radio).

63. Burkart et al. [96] review the regulation of alerting systems for the evacuation of deaf populations in Australia. They reported several incidents where hearing impaired people experienced problems being alerted – in the absence of appropriate alerting (visual) systems. They presented these as indicative examples.

- Tasmania (2003), a deaf man died when his house caught on fire. He was unable to hear his audible fire alarm sounding or his neighbours knocking on the windows. The Tasmanian Fire Service (TFS) regional fire investigator said, “It was very unfortunate the man could not hear it [the alarm],” while the TFS community education consultant stated that a specialised alerting system “*might have helped*” since flashing lights are effective enough to awaken sleeping individuals.
- Dallas, Texas (2005), two deaf parents could not hear the fire alarm sounding, and only awoke when the fire was already engulfing their home. The father and his 6-year-old and 7-year-old sons were able to jump to safety out of a second-floor window; however, his wife, 3-year-old child, and 10-month-old child died.
- At a Russian boarding school for deaf children in April of 2003, a fire killed 28 children between 6 and 14 years of age and seriously injured 17 others while rescuers attempted to individually awaken the students who could not hear the audible alarms.

64. Bruck and Thomas [97] examined the effectiveness of different notification devices on sleeping individuals with various conditions or impairments. Being asleep is a strong risk factor for fire fatality (e.g. [98], [99]), the ability of different sections of the residential

population to wake to their smoke alarm is an issue of importance. Among the people at particular risk of not waking to an auditory smoke alarm are the hard of hearing. In some cases, such people purchase alternative alerting devices which may send a visual signal (e.g. a strobe light) or a tactile signal which vibrates. Standards exist for the intensity of a strobe light for emergency notification [53], with an intensity of 177 or 110 candela (cd) specified, depending on placement. However, several studies of their efficacy in alerting sleepers suggest that only about a third of hard of hearing people or people with normal hearing will awaken to strobe lights of similar intensities [100], [101]. The British Standard, BS 5446-3 (Detection and alarm devices for dwellings. Specification for fire alarm and carbon monoxide alarm systems for deaf and hard of hearing people 2015) [102] relates to a smoke alarm “kit” for people with hearing impairment which combines the normal UK smoke alarm with a vibration pad (a bed shaker) and a flashing light. The minimum intensity specified for the flashing light is quite low (15 cd). Bruck and Thomas [97] tested the waking effectiveness of several different auditory signals, a bed shaker, a pillow shaker and a strobe light in a sample of hard of hearing people. A range of different intensity levels were tested for each signal. Each device was tested separately. 38 volunteers aged 18-77 years participated (16 males, 22 females) with an average hearing loss of 25-70 dB in both ears (i.e. mild to moderately severe hearing loss). No deaf individuals participated. The main conclusions were: Under the testing conditions a 520 Hz square wave T-3 sound was the single most effective signal, awakening 92% of hard of hearing participants when presented at or below 75 dBA for 30 seconds and awakening 100% at 95 dBA. Under the testing conditions the bed shaker and pillow shaker devices, presented alone, awoke 80-83% of the hard of hearing participants at the intensity level as purchased (vibrating in intermittent pulses). Strobe lights, presented alone, were not an effective means of waking this population, with only 27% waking to the lowest strobe light intensity. There was tentative evidence that people may respond differently to different types of signals, suggesting that a bedroom alarm “kit” that combined two types of sensory signals may be more effective than one signal.

A1-B.1.5 Staff / resident intervention

65. Although the human occupants are not a physical measure ‘fitted’ to a building they still have to the potential to intervene with a fire and have an impact on an evacuation process. These interventions are distinct from the processes of occupant movement through constrictions, down flights of stairs etc. which are covered extensively elsewhere in this report.

66. This section considers the impact of staff intervention, the operation of manual call points and the use of hand-held first-aid firefighting measures on the evacuation of a building. Arriving firefighters will also aid. Their actions are describing throughout this document in relation to the physical measure to which it is related (e.g. stairs, lifts, etc.).

A1-B.1.5.1 Staff intervention

- **Search term**: ("occupant intervention” | "staff intervention”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 150

67. Research indicates that the most effective means of informing an individual of an incident is through the presence of a well-informed, well-trained, assertive and respected member of staff instructing occupants of the incident [41], [61], [103]. If a member of staff is not present, then other means of influencing the evacuation need to be provided. In their absence it is critical that an information vacuum be avoided. It may then reasonably be assumed that the effectiveness of a member of staff provides an upper bound for any other technological solution; i.e. it is unlikely that a technological solution will surpass the effectiveness of a well-trained, well-informed human solution both in terms of initiating and responding to the incident. The flexibility and credibility of committed staff can then act as a benchmark for the performance of notification technologies.

68. Staff may physically interact with occupants or maybe remote, either within the same building or be elsewhere. In many residential buildings it is likely that there are no permanent staff on-site and so will not be present in the event of a fire.

69. At a minimum, wardens / staff can be expected to act like mobile notification systems that are able to provide physical assistance where possible [41]. Much like notification systems, their impact on the effectiveness will be dependent on residents having access to them, paying attention to them, understanding any information provided, and believing this information. It is suggested that the likelihood of paying attention and believing the information is somewhat linked to perceived authority and experience. Emergency responders might then be thought of clearly recognisable and credible experts in an evacuation. The effectiveness of other staff/wardens might then be described relative to the impact of firefighter instructions on the scene.

70. Staff might be notified of an incident via direct observation, via an automatic detection and notification system (Sections A1-B.1.1 and A1-B.1.2) or by interacting with building occupants.

71. In some buildings there may be staff dedicated to providing a fire watch in which “…*staff continually patrol all floors and the exterior perimeter of the building in order to respond to a fire, assist in calling the fire service and assisting with the evacuation of occupants of the building*”. Following on from the Grenfell Tower fire the provision of a ‘waking watch’ has been recommended by the NFCC for blocks of flats which had a ‘stay put’ policy but this is deemed inappropriate due to significant fire safety risk issues [104].

72. Wardens who have the task of checking that areas of a building are clear of occupants will likely be the last people to exit a building. This was the case in the study of tall building evacuations by Kuligowski et al. [105] and suggested that the exit capacity of the main body of occupants was not crucial since it was the wardens that presented the ultimate time to clear the building.

73. Jones and Hewitt [106] examined survivor transcripts of a fire in a 27 storey multi-use tower. Groups frequently formed during the evacuation – either using existing roles (of authority) or emergent roles, especially where no existing authority existed. Hewitt and Jones examined the dynamics of these groups and specifically the leadership roles. They found that typically groups typically following the pre-existing leadership hierarchy until the leader in question demonstrated incompetency or inexperience, at which point new leadership might emerge. They noted: “*The data seem to indicate that the presence of leadership and the form that it takes do affect the evacuation strategy adopted by a particular group. For the most part, the leadership of the groups studied corresponded to the roles assigned by the organization. In other words, the influence on group actions exercised by certain individuals was strongly related to the position these people occupied in the organizational hierarchy. Evidence of this is provided by the behaviour of group members who accepted the legitimacy of this arrangement, relinquished decision- making to these individuals and generally followed their directions despite later voicing opinions that some of the decisions made were not the most appropriate ones*[*…*where] *an imposed leader failed to retain his influence over part of the group…*[t]*he split that developed was apparently influenced by the group's perception of their respective competence and effectiveness*.”

74. The willingness to following the advice given by leaders (e.g. marshals, wardens, etc.) according to perceived authority and expertise was also noted in the King’s Cross Underground Station fire in 1987, where information was provided by London Underground staff (at the time held in relatively low regard during an emergency situation) and by British Transport Police (deemed reliable in an emergency). Passengers were more likely to follow the advice provided by the police even if (in this instance) it was more generic in nature [103].

75. Several studies exist that demonstrate the reliance of vulnerable populations on the actions of staff. For instance, Lofqvist et al. [107] examined evacuation preparedness in intensive care units in Sweden, while Cuesta et al. examined evacuation preparedness in intensive care units in Spain [107]. In both instances, the young children present and the patients suffering from numerous health issues and impairments were reliant both on the actions and information of the staff present. Gwynne et al. [108] looked at the evacuation of a university campus and a small hospital and found that in both cases the initial movement of the students / patients was highly influenced by a recognisable member of staff. Indeed, staff were physically required to enable evacuation or were key information sources to confirm that an evacuation was required in support of the alarm that was already sounding. This supports the findings shown in Table A1-B3, which indicate that the presence of staff can raise a basic alarm up to the performance of a live voice. Conversely, Table A1-B3 also suggests that staff alone (with no other notification system in place) might take time to arrive at a location and may prolong people initiating their response if there are no other cues present. This is evident from the average pre-evacuation time of 156 s produced when staff where the only source of notification in comparison with voice systems or simple alarms with staff, which produced average times of 65 s.

76. Proulx examined evacuation performance across five drills (in residential and office properties) and several real incidents in Canada and the USA. She noted that the

residential properties types took longer to initiate their movement [73]. Although the population response was influenced by several underlying factors (demographic, situational, etc.), Proulx noted as explanation for the additional time taken for the residential evacuations: *"Office buildings often have Fire Wardens who have received specific training. The Fire Wardens are responsible for prompting the evacuation and directing occupants of a floor or an area of a floor. There is no similar system in residential buildings to motivate occupants to respond quickly."*

77. In the analysis of several unannounced trial evacuations in retail stores Samochine et al. [42] found that "…*the behaviours of staff in the event of an emergency can make a significant contribution to the timely evacuation and, hence, life safety potential of occupants*". In a series of trial evacuations in a university library Galea et al. [72] found that "…*the average evacuation time for occupants notified by the alarm system is 4.5 times longer than the response time for occupants notified by staff intervention*". It is not clear whether these findings translate to residential buildings.

78. Connell [109] and Shields et al. [110] both looked at the impact of groups and staff on the evacuation of the WTC during 9/11. Connell reviewed first person newspaper accounts and media reports to identify influential factors during the WTC evacuation. As part of this, a leader was identified as someone who initiated and shaped the evacuation process (including the impact of responders and floor fire marshals). Connell found that evacuating groups typically maintained assigned leadership roles, with leaders taking decisions that influenced the people around them; where there was a lack of such leadership, others emerged to assume such roles. This suggests the need for someone taking decisions and also the value of having a (credible) person assigned to such a role.

79. Staff may take on the role of assisting occupants during evacuation and may be needed to help with the use of certain types of specialised movement device (Section A1-B.4.3). Shields et al. [110] identified the reliance of those WTC evacuees with pre-existing mobility issues on those around them. They interview six survivors and found these evacuees especially relied on those with training and experience – either designated to assist or those who had experience (in this case often due to surviving the 1993 WTC bomb attack).

80. Where building staff are available at the time of a fire they may be available to undertake first-aid firefighting (see Section A1-B.1.5.3).

81. Where lifts are to be available for evacuation then, depending on the specific design, the cars might be remotely assisted or be directly controlled by a driver who could be under the supervision of other staff whose role it is to manage the building evacuation [111].

A1-B.1.5.2 Manual call points

- **Search term**: ("manual fire alarms" | "manual call points" OR "break glass") (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 495

82. Manual call points (sometimes referred to a ‘break glass alarms’ or similar) are installed into buildings to allow occupants to manually raise an alarm should they become aware of a potential fire. Clearly these devices requite that an operator become aware of a fire, for example by themselves seeing, smelling etc. the fire, or through communication with other occupants. The operator then needs to decide to active the device by either specifically moving to it or operating it when an opportunity arises during their escape.

83. Manual call points (MCPs) need to be appropriately located within a building so that they are clearly visible, operable by occupants with a range of capabilities, and distributed so that the required distance to travel to reach a device is not deemed excessive. For reasons noted above, devices are generally placed on escape routes.

84. According to Wong [112], when discussing buildings in Hong Kong, “*Most residential buildings have installed manual call points as a basic fire alarm protection system to give early warnings of fire*.” In results from a 4-year survey of three 35-storey high-rise residential buildings Wong noted that the greatest number of false activations occurred because of broken devices, and this was mainly as the result of vandalism, accounting for almost 57% of incidents. However, faults with the fire control panel accounted for the greatest number of hours of system downtime.

85. Chagger and Smith [113] recommend the use of protective covers with adequate signage and the installation of CCTV where malicious activation of MCPs occurs.

86. It is not clear how often MCPs are activated in fires and whether their use has afforded any benefit over the installation of automatic fire detection systems. Given the modern prevalence of mobile communication devices, such as phones and tablets, there has been discussion within sectors of the industry on whether installing manual call points in buildings is still worthwhile.

87. In an analysis of the activation of fire protection measure in the Gisborne District of New Zealand by Haertel [114] she found that “…*manual fire alarms play a small role in the premises that are not connected to the NZFS and that various forms of smoke detection are the predominant form of fire detection and alarm system activation*”. However, the sample dataset used in the study was relatively small and so care should be taken to draw too many conclusions.

88. As already illustrated by Wong [112], there may need to be consideration when installing manual call points (and other fire safety measures) of the possibility of malicious operation and/or damage. Johnson and Bressington [115] suggested that manual call points be eliminated from retail areas of buildings because of the possibility of malicious damage. Installing manual call points in the common areas of residential buildings maybe subject to similar issues and is probably the reason they are not typically found in multiple-unit residential buildings in the UK but that may not be the case elsewhere.

A1-B.1.5.3 First-aid firefighting

- **Search term**: extinguisher (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 18 600

89. Various means of first-aid firefighting are available to occupants including portable hand-held extinguishers, fire blankets, along with ‘sundry means’ such as buckets of water or sand, smothering, etc. [26]. In the study by Greene and Andres [116] only 5% of fires were put out using a hand-held fire extinguisher compared with 18.7% by putting water on the fire, 15.8% by smothering and 6.6% using baking soda, salt, flour etc.

90. Rasbash et al. [26] note that in some instances an initial fire attack by occupants has resulted in injuries or fatalities.

91. Hand-held fire extinguishers may be available to occupants (or first responders) to allow them to suppress a fire. Various types of firefighting media are available for hand-held extinguishers (including water, carbon dioxide, dry powder, foam, etc) and the effectiveness depends on the type of fire being tackled. The location of an extinguisher in relation to the fire affects the likelihood of the device being used [116].

92. The provision of hand-held extinguishers can present a dilemma within the expectations of people to evacuate in the event of a fire. On the one hand having fire extinguishers may allow a fire to be sufficiently suppressed so that “*the severity of the fire is reduced*” [117], which means evacuation might not be necessary or an occupant gains additional time should they subsequently decide to escape. However, the act of using the extinguisher my increase the hazard to the occupant and they may have been better off to have made an immediate escape.

93. Getting access to and preparing to operate a hand-held fire extinguisher takes time in which the fire may be able to increase in severity.

94. Bruck and Thomas [33] report on the ability of people to use fire extinguishers and blankets in trials. Differences were noted between male and female participants along with the different level of success achieved using the two types of equipment. Bruck and Thomas found that “*The blanket use was more successful than the fire extinguisher, with 22% of the participants unable to use the latter due to being unable to remove the safety tag*…”. Ramachandran et al. [117] also found that people are “…*are less successful with extinguishers than with other first aid methods*”.

95. Various authors have noted the success of using a fire extinguisher depends on previous training and experience, e.g. [117], [26]. Rasbash et al. [26] suggest that someone trained to use a fire extinguisher would be successful extinguishing a fire three or four times larger than an untrained operator. Recently there has been considerable interest in using virtual reality [118] as a means to train people to use fire extinguishers without the need to expose them to potentially hazardous fires.

96. Runefors et al. [119] suggest there have been studies that "…*have been unable to find a significant effect on life safety of fire extinguisher (even if they concluded that they are usually cost effective due to reduced property damage)*".

A1-B.1.6 Emergency lighting

- **Search term**: "emergency lighting" (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 2 580

97. CIBSE Guide E [120] notes that "*Where there is a clearly defined escape route, a visibility of 10 m* […] *is normally considered reasonable*". Similarly, Purser and McAllister [121] suggest for travel distances that visibility through smoke be taken as 5 m for small enclosures and 10 m for large enclosures, according to the work of Jin and Rasbash.

98. Emergency lighting in buildings is used to provide illumination to escape paths in the event of the failure (or absence) of sufficient artificial or natural light. The absence of sufficient illumination my slow the movement of people or mean that occupants might not use a particular escape path. Lighting helps people avoid hitting objects and also allows them to see other measures such as reflective signage, doors etc.

99. Emergency lighting might be used to illuminate smoke free egress routes but could also play a role in routes that become affected by smoke.

100. This section of the report does not address the effects of directional signage (which may or may not be illuminated) and this is covered in Section A1-B.2.4.

101. Paragraph 304 of the Post-War Building Studies [21] notes that "*Adequate artificial lighting should be provided to all staircases and exits*" and also "*that some form of artificial lighting should be available on the escape route*" when discussing roof exits in paragraph 284. However, the document does not specify what is deemed to be adequate. Melinek and Booth [122] recommended that the provision of emergency lighting may reduce the likelihood of panic [sic].

102. Boyce [123] found that at a mean illuminance of 1.0 lx movement in an escape route was little different to normal lighting conditions but at 0.2 lx people experienced some difficulty. In the review by Ouellette and Rea [124] (which considered the work of Boyce) it was noted that "*the number of collisions with large obstacles in the escape path consistently show good performance at illuminance levels as low as 0.5 lx*" although the hesitancy of occupants in avoiding obstacles reduced their movement speed. Any reduction below 300 lx compromises evacuation speed and at 5 lx there is a 20% speed reduction of 50–70-year-olds, falling to a 12% speed reduction in younger people.

103. Frantzich [125] suggests that when designing an emergency lighting system the sources of illumination should not dazzle occupants and high reflectivity surfaces in the escape route will spread the light. Lyons [126] notes that should occupants in an emergency become anxious the additional rush of adrenaline will cause dilation of the pupils of their eyes. This dilation will make the person more susceptible to glare.

104. Lyons [126] states that the commonly held position has been that the illuminant colour of emergency lighting has little importance although he quotes work that does not necessarily support this notion.

105. Frantzich [125] reports work by Jensen that has shown that the level of lighting has no effect on visibility when the density of smoke is high, suggesting that emergency lighting would have little benefit on evacuation in such circumstances. In other work by Jensen [127], he states "*Normal and emergency lighting systems are easily blocked by smoke and may create total darkness or very dense fog like atmosphere reducing visibility to less than 2 m*"*.*

106. In the work reported by Wright et al. [128] it has been noted that in smoky conditions people walked significantly more slowly under traditional overhead emergency lighting conditions when compared to a range of safety way guidance systems (see Section A1-B.2.4). They further noted that "*Simply increasing the illuminance of an overhead lighting system does not radically increase the speed that people are prepared to walk at*".

A1-B.1.7 Suppression

- **Search term:** "fire suppression" (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 6 470

107. As defined in PD 7974-1 [129], suppression typically refers to a system or process which can affect the growth of a fire, reduce the rate of heat release or initiate a period of decay that can also result in eventual extinction of the fire.

108. In most cases, water is used as the main suppression agent for buildings due to its relative abundance and lack of cost [130], as well as its useful fire extinguishing characteristics such as high specific heat and high latent heat of vaporisation [131]. Water sprays from sprinklers extinguish a fire by directly wetting and cooling the combusting surface, cooling the air by vaporisation (energy absorption) and diluting the air with water vapour [132]. In contrast, watermist relies on the cooling and dilution mechanisms with less support from surface wetting [132]. Other suppression agents, such as dry and wet chemicals and foams, generally operate on the principle of blanketing the fire with the agent [132].

109. Fleming [131] proposes that, for most applications, *"sprinkler systems are considered to be the most effective and economical way to apply water to control, suppress, or extinguish a fire"*. Fleming refers to four main types of sprinkler system:

- Wet pipe systems, which consists of a network of pipes containing water under pressure. The sprinklers are activated by a heat responsive element (sprinkler head) connected to the pipes, allowing the water to discharge.
- Dry pipe systems, which are similar to wet pipe systems but with the water held back by dry pipe valves (kept close by air or nitrogen pressure). When the heat responsive element activates, the gas escapes and the dry valve operates, permitting the water to flow.

- Deluge systems, which rely on open sprinklers rather than automatic sprinkler heads. A deluge valve holds back the water supply from the pipes and is activated by a separate fire detection system. Once activated, water flows from all sprinklers comprising the system.
- Pre-action systems, which are like deluge systems but include automatic sprinkler heads. Therefore, when the deluge valve is activated by the fire detection system, water is admitted to the piping network but is only discharged from activated sprinkler heads.

Dry pipe, deluge and pre-action systems are rarely (if ever) found in residential applications.

110. Another relatively common type of automatic water fire suppression system is watermist. Mawhinney and Back [133] describe watermist as fire suppression systems that discharge fine water sprays with drops no larger than 1 mm. Watermist nozzles therefore produce sprays that have a higher fraction of very fine droplets when compared to a standard sprinkler spray.

111. Till and Coon [134] indicate that the *“purpose of a sprinkler system is twofold: detection and extinguishment”*. It is suggested that detection is accomplished when a sprinkler head activates and water flows in the system, operating a water flow detection device which can subsequently activate an alarm system. Further discussion on the use of sprinklers for detection can be found in Section A1-B.1.1. It is arguable whether the water of a sprinkler system is intended to outright extinguish a fire but instead is predominantly intended suppress / control it to an extent that its growth is limited or reduced, as expressed in the previous PD 7974-1 [129] definition.

112. Suppression benefits occupant escape by limiting fire growth and spread, which in turn affects the severity of conditions occupants may face. For escape within apartments, the work of Fraser-Mitchell and Williams [135] highlights the benefits of sprinklers in improving tenability and facilitating occupant escape. This work, and the general impact of fire safety provisions on internal dwelling design and occupant safety, is discussed further in Section A1-B.3.1.

113. Similar to the work of Fraser-Mitchell and Williams [135], when modelling dwelling fires development and occupancy escape using Bayesian networks, Matellini et al. [136] indicate that sprinklers can be effective in reducing the probabilities of death or remaining trapped in a fire, *“considerably more so than a smoke alarm”* due to their benefit as a means of detection / alarm, suppression and assisting firefighting operations.

114. A key consideration in automatic suppression systems is the thermal sensitivity of the head or nozzle element. For sprinklers, this is usually considered with respect to the ‘response time index’ (RTI) and ‘conductivity factor’ (C factor). The RTI represents a thermal time constant for the heat-responsive element of a sprinkler head in relation to velocity and convective heat transfer and the C factor characterises the heat loss to the sprinkler housing due to conduction [137].

115. Hopkin and Spearpoint [137] discuss the regular use of concealed sprinkler heads in residential buildings, often included due to their aesthetic benefits. However, a

consequence of this sprinkler head design, when compared to exposed pendent heads, is that the thermal response of the sprinkler is delayed. Hopkin and Spearpoint [137], Yu [138], and Annable [139] have all undertaken studies which demonstrate that thermal sensitivity parameters are substantially altered by concealing the sprinkler head. A consequence of this is that the time of sprinkler activation is delayed, both impacting its effectiveness as a detection element and increasing the time before fire suppression occurs.

116. Nolan [130] states that *“the effectiveness of all fire-extinguishing measures can be determined by the rate of flow of the extinguishing medium and the method or arrangement of delivery”*. With respect to sprinklers, Evans [140] proposed a suppression algorithm, estimated from experimental data, as a means of quantifying the impact of sprinkler spray on the heat release rate of a fire, where the rate of decay post-activation was shown to be proportional to the water spray density.

117. With respect to system reliability, a literature review by Koffel [141] concluded that *“when combining the operational effectiveness and performance effectiveness data as published in the August 2005 NFPA report, the overall reliability of automatic sprinkler systems is 91%”*. PD 7974-7 [142] provides indicative probabilities of sprinkler reliability based on US data, indicating a 93% *“reliability where the equipment operated”*, 96% *“effective of those that operated”* and 89% *“where operated effectively”*.

118. Estimates of operation reliability by Bukowski et al. [143] suggest that there is limited information on the reliability of modern-day residential sprinkler systems. Bukowski et al. also note that residential systems are generally less likely to be maintained properly and a decrease in operational reliability may be expected. In the context of UK design, systems designed to the domestic standard, such as BS 9251 [144], may not offer the same level of resilience as commercial systems, such as those designed to BS EN 12845 [145].

119. In addition to the data mentioned previously, PD 7974-7 [142] provides a range of values for sprinkler ‘effectiveness’ (a combination of availability, reliability and efficacy) from New Zealand data, with the effectiveness of residential systems ranging from a lower bound of 46% to an upper bound of 99%, with the expected values ranging from 90% to 96% depending on the type of water supply (mains supply, diesel pump, and dual supply). The bounds and expected values were derived from fault tree analyses which accounted for a variation in failure probabilities of the different system components, and hence a wide range between the upper and lower bound is estimated.

120. Discussion on manual suppression by use of fire extinguishers and blankets is included in Section A1-B.1.5.

A1-B.1.8 Smoke control

- **Search term:** ("smoke control" | “smoke ventilation”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 1 680

121. When discussing smoke control, Klote [146] refers to the terminology of NFPA 92 [147], which describes a smoke control system as *“an engineered system that includes all methods that can be used singly or in combination to modify smoke movement”*. UK fire safety guidance, such as BS 9999 [148], differentiates the terms ‘smoke control’ and ‘smoke clearance’. For smoke control, BS 9999 suggests smoke control is *“a technique used to control the movement of smoky gases within a building in order to protect the structure, the contents, the means of escape, or to assist fire-fighting operations”*. This distinction does not appear to be internationally recognised but has been adopted for the purposes of this report. Smoke clearance is discussed later in Section A1-B.5.3.

122. Klote [146] notes that approaches to smoke control consist of using provisions to either prevent occupants encountering smoke or evaluating the effects of some smoke interaction while intending to still provide tenable conditions for occupants to escape. In addition to supporting occupant escape, smoke control may also be used to assist in firefighting operations, such as by maintaining temperatures below tenability thresholds or protecting specific building areas, such as common stairs [149].

123. Smoke control can either be mechanically induced (mechanical ventilation) or can rely on natural effects and the buoyancy of smoke for exhaust (natural ventilation). Mechanical ventilation typically comes in the form of pressurisation, depressurisation, or smoke exhaust ventilation (‘venting’) or ‘throughflow’ systems [150], whereas natural ventilation almost exclusively operates as a means of smoke exhaust ventilation.

124. Morgan et al. [150] refer to pressurisation as the process of introducing air *“into an escape route (usually a stairway) at a rate sufficient to hold back any smoke trying to pass onto that route. The pressure differences across any small opening onto the route must be large enough to offset adverse pressures caused by wind, building stack effect and fire buoyancy. It must also be low enough to allow the escape doors to open with relative ease”*. Conversely, depressurisation is described as *“where gases are removed from the smoke-affected space in a way that maintained the desired pressure differences and / or air speeds across leakage openings between that space and adjacent spaces”*. Morgan et al. also refers to ‘throughflow ventilation’ or ‘smoke exhaust ventilation’. This type of system does not rely on maintaining specific pressure differentials / velocities, but instead the intention is to *“keep the smoke in the upper regions of the building leaving clear air near the floor to allow people to move freely”*, such as by providing high level exhaust ventilation and low-level inlet ventilation.

125. The performance of any system will be dependent on its specification. For natural systems, this will be influenced by the size, location and operation of smoke vents or shafts. For mechanical systems, the performance will be affected by velocities and flow rates achieved by fans along with any associated ductwork and dampers.

126. For standard mechanical smoke exhaust systems, the volumetric flow rate of the system is fixed and defined / commissioned at an ambient (i.e., non-fire-affected) temperature. However, Wegrzynski et al. [151] proposed a “*smart smoke control (SSC)*” system where the “*momentary volumetric capacity*” of the system is dependent on the density of the removed gas (i.e., a mixture of gas and smoke) so that the mass flow is

constant with time. Wegrzynski et al. found that this adaptive performance approach could be beneficial in small spaces with a restricted smoke reservoir area and limited air supply, where standard fixed flow / ambient systems could be infeasible from a design perspective.

127. For residential design, a particular focus is placed on the ventilation of common escape routes, including corridors and stairs. Although not an exhaustive list, the following represent some common provisions which may be observed in the ventilation of escape routes in residential design:

- Openable vents (OVs) are a form of natural smoke control where natural openings are used to exhaust smoke directly to outside [152]. Depending on the application, they can be placed in the vertical (e.g., wall) or horizontal (e.g., roof) orientation. Their operation can be automatic (AOVs), such as by opening upon local smoke detection, or they can be manually operated, such as activated by a switch provided for the fire and rescue service. These differing means of operation are applicable for all ventilation systems described in this section.
- Natural smoke exhaust shafts connect a space to outside by protruding through the height of the building and exhausting smoke at high level [152]. The design of these shafts relies on ‘stack effect’, where the temperatures and buoyant forces generated by smoke cause it to rise within the shaft and generate a pressure difference [146].
- Mechanical exhaust shafts operate in a similar fashion to natural shafts but, instead of relying on natural effects, flow is induced using fans (usually located at the top of the shaft). These systems may be supplemented by additional inlet air provision in the enclosure of interest, e.g., in a corridor, and this is discussed later.
- The principles of pressurisation systems have been discussed previously. For residential design guidance in the UK, these typically take the form of stair, lobby and / or lift shaft pressurisation systems [153].

128. With respect to the above residential smoke control provisions, SCA guidance [149] suggests *“a system* […] *should open on the initial fire floor only and all other floors shall remain closed”* and *“the vents on all other storeys should remain closed even if smoke is subsequently detected on floor other than the fire floor”*. The implication, as discussed by Klote and Milke [154], is that the smoke control system is designed only to address smoke within a specific zone and *“often, the smoke zone is one floor of the building…”*, although Klote and Milke go on to state *“the smoke zone can consist of a number of floors. A common approach is to make the smoke zone be the fire floor plus the floor directly above and below the fire floor”*, inferring that the fire will be restricted to a single floor. This approach places an expectation on the compartmentation and / or other provisions to limit the spread of fire and smoke between floors. However, this observation is not unique to smoke control, and could be extended to other fire safety measures, such as fire mains and sprinkler systems (depending on the extent of fire spread and the area of operation which has been designed for).

129. External factors such as outside temperatures and wind conditions can have a prominent impact on the performance of natural ventilation systems [155]. Marchant [156] notes that many problems for natural vents may arise due to wind, such as the onset of positive pressures reducing efficiency or stopping the flow of smoke. Marchant [156] also

suggests *“the use of vertical shafts and flues for smoke control seems to be a natural technique because of their similarity to chimneys. Unfortunately they are not too successful and part of the reason may be the difficulty of driving the ambient air from the shaft before smoke can flow upwards. The use of fans to begin the extraction process has been suggested for shafts for smoke venting in 2-storey shopping malls”*. Numerical studies by Wegryzynski and Krajewski [157] highlights the impact of wind on the performance of natural vents as well as the importance of vent orientation, indicating that wall mounted vents show significantly worse performance than roof mounted vents.

130. With respect to ventilating common corridors and stair protection in residential buildings, BRE undertook a computational fluid dynamics (CFD) based fire and smoke modelling assessment of different ventilation provisions. The studies, referred to hereafter as BD 2410 [158], considered the steady state performance of different common corridor ventilation design options in their capability to protect stairs from smoke ingress during both means of escape and firefighting operations. The provisions considered in the study included: AOVs, natural exhaust shafts, and mechanical exhaust shafts. As summarised by Hopkin et al. [159], the BD 2410 studies highlighted that both natural smoke shafts and mechanical smoke shafts were more resilient than AOVs for the objective of protecting the stair from smoke ingress. In these specific studies, natural and mechanical smoke shafts were shown to protect the stair for apartment fires with a range of heat release rates up to 2.5 MW.

131. In the UK, mechanical smoke control is often used to support the design of single stair buildings where travel distances are within standard guidance and those which include ‘extended’ travel distances within common corridors, i.e., when the corridor travel distances are greater than the maximum bounds recommended in guidance [152]. In extended travel distance circumstances, BS 9991 [160] notes that the primary objective of the system is to *“return the extended corridor and the associated corridor to tenable conditions for means of escape and rescue purposes”*. Hopkin et al. [161] provides an example of a corridor clearance system and associated modelling processes, where the corridor incorporates mechanical extract at one end of the corridor and a source of inlet at the other. By providing ventilation in this arrangement, the system can facilitate the clearing of the corridor after it has become compromised with smoke.

132. A key element of smoke control system performance is its effectiveness or reliability. That is, the contribution of smoke control to fire safety performance is only valuable if the system operates as intended, or even operates at all. Data from the New Zealand Fire Service [162], reproduced in PD 7974-7 [142], suggests that stairwell pressurisation systems achieve an effectiveness in the range of 47 to 52%, where this effectiveness is a function of:

- Availability – whether the system is on-line when called upon.
- Reliability – the ability of the system to operated when called upon.
- Efficacy – whether the system meets the performance required when operational.

133. The New Zealand Fire Service report [162] states that *“stairwell pressurisation system reliability is low”* and *“this is due to the overall system complexity as well as industry opinion on the prevalence of faults on installed systems”* although the uncertainty around the data

and assumptions is acknowledged. While the reliability data refers specifically to pressurisation systems, many of the observed issues would be transferable to other ventilation types, including faults with dampers, wiring / cabling, the blocking of vents or relief paths etc.

134. Klote and Milke [154] provide system reliability estimates for five different system designs, where they indicate that the reliability of the system decreases significantly as the number of components increases (Table A1-B5), with a system incorporating three fans and nine components having a reliability prior to commissioning of 56% and a 14 month mean life of the commissioned system. In the worst case, a system with five fans and 54 components was estimated to achieve a mean commissioned life of three months. However, it is important to note that the analyses conservatively assume that the failure of any one component would result in complete system failure. Comparable event / fault tree analyses by Zhao [163] estimates a “likely reliable” range of 52% to 62% for smoke control and stair pressurisation (and depressurisation) systems for 5 to 20 storey buildings.

Table A1-B5 Estimated system reliability for new smoke management systems that have not been commissioned, reproduced from Klote and Milke [154]

System	No. of HVAC system fans	No. of other components	Reliability of new system before commissioning	Mean life of commissioned system (months)
1	3	0	97%	116
2	0	3	83%	46
3	3	9	56%	14
4	5	18	31%	8
5	5	54	3%	3

135. Harrison and Spearpoint [164] discuss smoke control system reliability, suggesting *“smoke management systems can be complex and involve the operation of many interfacing components, including detection systems, exhaust fans, natural ventilators, automatic smoke curtains, dampers, fresh air intakes, etc. Experience of actual installed systems in real buildings has led to concerns on the efficacy of some smoke management systems, especially over the lifetime of a building”*. Harrison and Spearpoint go on to discuss the work of others, including surveys of smoke ventilation systems in shopping centres in Brisbane, where it is indicated that 5 out of 15 centres reported problems with system operation.

136. Similarly, Lay [165] suggests that, while pressurisation systems are a *“standard feature of high rise building codes from the USA, UK, Australasia, China, India, the UAE and many other locations”*, their use can come with a number of design, installation and operational challenges. Based on anecdotal experience, Lay notes that these can include difficulties in commissioning where the system *“refuses to perform as intended”* and the effect the system may have on door opening forces, which may subsequently restrict occupant escape. Experimental studies by Svensson [166] also indicate that while functioning positive pressure differential systems are beneficial for firefighters, it may detrimentally impact conditions for occupants located in a fire-affected apartment.

A1-B.2 Passive measures

A1-B.2.1 Fire separation

- **Search term:** ("fire separation" | “compartmentation”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 1 580

137. Fire separation, sometimes used interchangeably with the term ‘compartmentation’, refers to physical construction, such as walls, floors, and doors [167] which has been determined to achieve some form of ‘fire resistance’ performance.

138. Fire resistance is usually considered from the perspective of stability / loadbearing capacity, integrity, and insulation performance. As summarised in BS 9999 [148]: loadbearing capacity refers to the ability of a fire-rated element to withstand the effects of fire without the loss of loadbearing performance; integrity refers to the ability of a fire-rated element to limit the passage of flames and hot gases; and insulation refers to the ability of a fire-rated element to limit the transmission of heat from an exposed face to an unexposed face. Depending on the design intent of fire separation, it may not be expected to achieve fire resistance performance in all three of these measures.

139. In discussions on smoke control, Klote [146] states that *“compartmentation has been recognized as a way of controlling the spread of fire and smoke. When a person closes the door to a burning room, smoke flow from the room decreases considerably. Also, the amount of air available to the fire drops off. Today this passive smoke protection is recognized in many buildings and fire codes even without a design analysis.”* Similarly, Shorter [168] says *“a fire protection feature, which is one of the most important in limiting the spread of fire, is compartmentation. To form an effective compartment the construction separations should have the necessary fire endurance.”* Jacoby et al. [169] suggest *“architectural and fire separation features may need to be coordinated with expected egress paths.”*

140. In 1962, McGuire [170] described the *“use of fire-resistant construction to separate a building into fire-resistant compartments”* as *“the single design feature that will contribute most to [the] reduction of [fire] risk”*.

141. McGuire [170] goes on to suggest that the most important issue which requires consideration is the size and nature of compartments in which a building is divided. The choice of this will *“depend on considerations of life and property risks, which in turn will be influenced by such factors as the probability of an outbreak of fire in various locations throughout the building and the proportions to which such a fire can be allowed to develop”*. Certain areas may be identified as ‘special compartments’ which have a unique nature or may be categorised as more ‘important’. McGuire provides stairs as one example, as they form a key part of the occupant escape route.

142. McGuire [170] refers to practices where larger compartments may be considered acceptable if sprinkler protection is provided, as *“sprinkler protection reduces the probability*

of the development of a substantial fire". Suppression is discussed further in Section A1-B.1.7.

143. An important consideration in fire separation is how occupants will travel through it if needed, e.g., from one fire resistant compartment to another. For this, fire doors are typically included. Fire doors are a type of door that, together with their frame and furniture, are intended (when closed) to resist the spread of fire and / or smoke [148].

144. McGuire [170] notes that it is fundamental that doors located in fire separation / compartment walls should never be wedged open and proposes automatic door-closing mechanisms or electro-magnetic door catches released upon fire detection can be effective. Frank et al. [171] used logging devices to monitor the real-time position of doors in managed accommodation buildings including hotels, apartments, dormitories, and rest homes. Frank et al. identified that there was a 10% mean probability that a door with a self-closing device could be found open at a given time, either due to being propped open or due to disabling the self-closing mechanism. Internal doors being propped open within apartments is discussed later in Section A1-B.3.1.

145. To reduce the likelihood that fire doors are wedged open, Purser [172] indicates *"in many buildings, and as recommended in most current guidance, it is normal to avoid this wedging issue by fitting cross-corridor fire doors with hold-open devices, automatically released to allow the doors to close in the event of a fire detection."*

146. Frank et al. [171] discuss reliability data on fire doors and compartmentation, noting that there was very little data regarding the performance of individual passive elements. The text in the following paragraphs details the reliability data which is available and has been reproduced from the work of Frank et al.

147. Bukowski et al. [143] refer to two sets of expert surveys cited that indicate probabilities that an opening will be fixed open. The Warrington Delphi UK study, which estimated the probability that an opening will be fixed open as 29%. With respect to compartmentation more generally, the Warrington Delphi study indicated a reliability for masonry construction of 81% and 69% for gypsum partitions, but concrete was not considered. The Australian Fire Engineering Guidelines estimated that the reliability of a passive element (such as a wall) should be reduced from 95% to 90% if an opening with an automatic closer is present. This 95% reliability for passive elements aligns with the recommendations of DD 240-1 [173], which indicates a 5% likelihood of failure for a compartment wall or floor.

148. PD 7974-7:2003 [174] indicates that up to 23% of fire doors are held open by some means that will not release in case of a fire, and of the hinged fire doors that are not blocked open, 20% may fail to close correctly. Frank et al. refer to work by Yashiro et al., which reported estimates of the reliability of fire doors with automatic closers and interlock devices, as well as fire shutters using Tokyo Fire Department data. Fire doors with automatic closers were estimated to be 97% reliable, 91% reliable when interlock devices were used, and fire shutters were also estimated to be 91% reliable. Fernandez [175] noted that nuclear facility inspectors found fire doors propped open, however no quantitative data was reported. Testing conducted by Factory Mutual in the early 1990s indicated that the

failure rate of fire doors including horizontal sliding doors on inclined tracks, horizontal sliding doors with counterweight closures, horizontal sliding doors with spring closures, vertical sliding doors, and swinging doors in Maximum Foreseeable Loss walls was 15% [176].

149. Ramachandran [177] discussed the status of fire doors in 28 buildings reported to be equipped with fire doors where large fires occurred during 1965 and 1966 in the UK. While door position data at the time of fire was only available for 19 of the fires, it was found that fire doors were open in 5 fires, or 26% of the fires with known door positions. Frank et al. [171] refer to a 1970 study by Langdon Thomas and Ramachandran which looked at data on fire doors propped open provided from fire brigade inspection visits in the UK (for a total of 91 909 doors observed), with the percentage likelihood of being propped open ranging from 5% for assembly buildings to 39% for institutional buildings. Dwellings were shown to have a percentage propped open for 17%.

150. For escape in residential buildings, Ronchi and Nilsson [15] indicate that *“information spread is slower due to compartmentation and social links can delay movement”*.

151. With reference to other hazards from fire-resisting elements, Kodur et al. [178] note that “…*no consideration is provided to the adverse effect of performance specific problems of new constituent materials (for e.g. spalling in high strength concrete), toxicity, and degradation in their corresponding material properties at elevated temperatures in fire resistance prediction*s.” See Section A1-B.2.2 for discussion on the performance of construction materials.

152. Work quoted by Bukowski et al. [143] suggests that without an opening the operational reliability of masonry construction is between 81% and 95%, and is between 69% and 95% for gypsum partitions.

A1-B.2.2 Construction materials

- **Search term**: "construction materials" (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 10 700

153. Heat and smoke generated by a fire may affect the ability of occupants to escape. Severe thermal radiation may cause burns to the skin, but occupants may otherwise avoid going too close to a fire which could prevent occupants from escaping or require they find an alternative route. The convective flow of heat may impede escape and may require occupants to find an alternative route or to take preventative action such as crawling under a hot gas layer, thus slowing their escape. Smoke generated by a fire may affect visibility and/or the ability of occupants to breathe for sufficiently long durations to make their escape. A reduction in visibility will likely reduce occupant movement speed and lead to less effective decision-making when selecting routes etc. [179]. The effects of heat and smoke on people is a highly complex topic and is not covered in detail herein and readers are directed to the chapter in the SFPE Handbook by Purser and McAllister [121] for more information.

154. Although it is more likely that the contents of a space will form the major contribution to a fire hazard, it is possible that the construction materials could also play a part. The potential fire hazard from construction materials involves their propensity to ignite, contribute to fire development, and generate heat and smoke. Clearly materials that are easier to ignite, burn more readily and/or generate greater quantities of soot and toxic gases are more likely to affect the ability of occupants to escape.

155. Where necessary the hazard from construction materials is addressed by controlling their reaction-to-fire properties, typically ignitability and/or combustibility. The potential for the generation of toxic products is not normally addressed for buildings but is considered in transportation systems etc. There are arguments put forward by some parties, for example Hull et al. [180], that the potential toxicity contribution of construction materials should be controlled. Separate projects on behalf of MHCLG on the fire smoke and toxicity of construction materials and the fire performance of external wall systems are ongoing and so further details are not elaborated in this report.

156. The other sections in this review suggest that often the most direct approach to address the hazards posed by smoke and heat is by providing separation between the fire products and occupants (see Section A1-B.2.1) or through the application of smoke control measures (see Section A1-B.1.8). The materials of construction should provide adequate separation where it is required to affect evacuation, and this is discussed in Section A1-B.2.1.

A1-B.2.3 Structural design

- **Search term:** ("structural design” | “structural fire resistance”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 5 820

157. In this document, ‘structural design’ refers to structural elements and materials that assist in maintaining the stability of a building, with particular consideration of its performance when subject to fire conditions.

158. As with fire separation, the fire performance of structural elements can be considered from the perspective of stability / loadbearing capacity, integrity, and insulation performance. This is discussed in Section A1-B.2.1.

159. Structural failure could come in the form of collapse or deformation without collapse. The latter may detrimentally affect fire separation and facilitate fire or smoke spread. For example, the deflection of structural beams could damage a plasterboard partition.

160. Hopkin et al. [181] suggest that the structural fire performance objectives can be observed from two perspectives: provision of adequate time; or an adequate likelihood of surviving burnout. This would depend on the consequence of structural failure and the type of building being considered, including their height and evacuation strategy. For example, with respect to a stay put evacuation strategy, the objective would be expected to focus on surviving burnout.

161. Law and Bisby [182] refer to statements by Smith in which *“one would expect fire resistance to increase with building height in order to ensure the stability of the framework for people escaping, or for those who might remain in a building designed with phased evacuation”*. The implication is that structural collapse could have a direct consequence on the building occupant’s opportunity and ability to escape.

162. McGuire [170] suggests that an alternative approach to structural fire resistance could be considered where *“complete destruction of the property is tolerable”* as long as evacuation of the building was achieved prior to this point. However, it was noted that *“such an approach must be given the most careful thought”* and *“it can only be valid where adequate warning can be expected from detection and alarm systems, and where it is known that the response to an alarm will be the complete evacuation of the building”*.

163. Most modern high-rise building structures are composed of concrete, steel or a composite of the two materials, with codes and standards focussing on these structural materials [183]. Barber [184] notes that, in more recent years, interest has been growing in the construction of tall timber buildings.

164. In some cases, the structural elements can contribute as a source of fuel, changing the fire dynamics within the building. An example of this is for mass timber buildings, including cross-laminated timber (CLT). Hopkin et al. [181] and Law and Hadden [185] suggest that the fire dynamics implications of such materials can *“undermine assumptions underpinning fire resistance paradigms for cases where the structure must survive burn-out and the structure is not prevented from contributing as a source of fuel”.*

A1-B.2.4 Signage and wall plans

- **Search term:** ("signage” | “wall plan” | “wall plans”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 9 790

165. Signage systems are widely used in the built environment to aid occupant wayfinding during both circulation and evacuation [186]. These include non-emergency signs, intended to assist in routine navigation and emergency signs intended to assist evacuees locate an exit in emergency situations. These signs are particularly important where there is no direct visual access for the occupant to a potential target (exit) and orientation becomes difficult due to the lack of reference points [187], [188]. The information conveyed by signage systems is intended to compensate for the complexity of an enclosure (i.e. where the spatial design does not suggest how it should be used) and/or where exits are not sufficiently apparent, thereby improving wayfinding efficiency.

166. BS EN 16069 ‘Graphical symbols — Safety signs — Safety way guidance systems (SWGS)’ defines a SWGS as a “*system to provide conspicuous and unambiguous information and sufficient visual cues to enable people to evacuate an occupied area in an emergency along a specified escape route by using a comprehensive arrangement of visual components, signs and markings*”.

167. Given the importance of providing information through signage systems to facilitate occupant wayfinding, there is little regard of the effectiveness of occupant utilisation of this information.

168. Complex building designs need mechanisms to aid navigation during routine circulation. In emergency situations, the ability to navigate efficiently assumes even greater importance given reduced time and the risk of harm [188]. Evacuation from large and complex public or residential spaces can be hindered by a lack of detailed knowledge of the internal connectivity of the building space, especially when lifts are the normal mode of movement. In such premises, occupants are usually unaware of the most suitable means of escape.

169. This is a well-known problem [189] with building occupants usually electing to make use of familiar exits, typically the exit with which they entered the building, with emergency exits or exits not used for normal circulation often being ignored. In fire situations, where smoke may also obscure vision, the problem is often fatally compounded. Large-scale fires involving fatalities, such as Dusseldorf Airport, Stardust Disco, Beverly Hills Supper Club, Summerland, and the Station Night Club are examples of situations where the inability to locate efficient means of escape contributed to loss of life, [190]–[194].

170. The effectiveness of wayfinding systems is reflected in the likelihood that the occupants use an emergency exit; i.e. to locate and make use of an exit that is not normally used [195], [196]. Different systems have been recommended to direct evacuating people for both smoke-filled environments [197], [198] and clear conditions [199], [200]. Among them, the use of flashing lights has been reported as a possible solution to encourage emergency exit usage, discussed below.

171. The number of visual stimuli received from the environment, other occupants, the location, and the given the attentiveness of the occupants involved, all influence wayfinding. The presence of signage within an enclosure can aid and reduce the amount of time spent wayfinding (i.e. building a mental map of the space and selecting a route) – particularly crucial during emergencies. Signage can provide the occupants with options, suggestions, and the opportunity to decide on the best possible route for evacuating an enclosure.

172. Emergency signage is designed to help evacuees identify the existence of key egress components (e.g. emergency exits or stairs) and to provide a path to such components (e.g. primary and secondary signs forming a chain that eventually connects corridors, stairs and a final exit point). The directional indication of the sign should be consistent with the intended escape route.

173. The effectiveness of a sign is reliant upon the resident population perceiving the sign, paying attention to it, understanding the content (i.e. it is both legible and comprehensible) and then make use of this content (e.g. to follow the sign to reach an exit). It is immediately apparent that those with sight loss would not have access to signage and therefore do not receive the same benefits [188], [201], [202].

174. The effectiveness of a sign is affected by its design, but also in the context in which it is viewed. For instance, the ambient lighting levels (see section on emergency lighting), the

contrast between the sign and the wall behind it, the existence of other signs/visual noise in and around the sign, the air quality (e.g. whether there is smoke), physical obscuration (e.g., the presence of obstacles) – much of which falls outside of the design of the sign itself. It may be possible for too much information in the environment, overloading the evacuee or crowding out the emergency message being provided.

175. The effectiveness of the sign will be influenced by several design factors [203], [204], [205]:

- Sign dimension (height is particularly important in establishing viewing distance).
- Location (in respect to the target object, such as an emergency exit).
- Positioning (flat against the wall or at an angle to the moving flow).
- Sign background colour (typically green given the visibility of green in smoke, or occasionally red).
- Sign text / graphic / pictogram colour (typically white on green for contrast).
- Content of the sign (i.e., the message being conveyed).
- Whether there is lighting built into the sign (e.g., luminance levels generated).
- The symbols used in the sign and any associated text (particularly important where multiple languages are used).
- The size of the content (affecting the distance from which the message might be understood).
- The font used (affecting the distance from which the message might be understood).
- The intended distance from which the sign should be viewed (and the angle from which the sign is viewed).
- Whether the sign is static or dynamic (i.e., changes in response to a change in the conditions faced).

176. Each of these elements is prescribed in various national and international codes (e.g., NFPA 101, BS 5499, ISO 3684/6309/7010). The prescriptions allow for each individual element to be defined and how various elements are used in conjunction with each other. These regulatory provisions address the visibility of the sign in normal conditions. Typically, the emergency sign consists of three parts: display surface, light source, and driver circuit. Before the year 2000, most exit signs used fluorescent lamps. More recently, various light sources, such as LEDs and photoluminescent materials, have been developed and applied to exit signs, and their evacuation efficiency has been studied [206].

Figure A1-B3 Using ISO 3864 to combine graphic and text, from [205]

177. The most obvious confounding factor to the effectiveness of signage is the presence of smoke. Jin conducted seminal research on the capacity of participants to read signs through smoke of different obscuration and irritancy. Jin found that as the smoke increased in optical density (extinction coefficient) so sign visibility reduced. This reduction was all the

more significant when the smoke was irritant. Over several decades, research have established that the brightness, size, and distance of exit signs influence their visibility, Jeon et al. [207]. Jin et al. [196], [197] examined the impact of smoke on the visibility of signs, while Collins et al. [208] and Wong and Lo [209] noted that the shape, colour, luminance contrast, directional markings, and surroundings of exit signs influence their visibility, along with numerous others who furthered the analysis into the relationship between signage, visibility and movement in smoke [210], [211], [212], [213], [199], [214], [196], [197].

178. Galea et al.'s [186] experimental work shows that only 38% of people ‘see’ conventional static emergency signage in presumed emergency situations in an unfamiliar built environment, even if the sign is in front of them and their vision is unobstructed. However, people who see the sign follow the sign. These results suggest that current emergency guidance signs are less effective as an aid to wayfinding than they might be and that signs are likely to become more effective if their detectability can be improved. Galea et al tested the use of a dynamic signage system on wayfinding and found that 77% saw the sign and that, once seen, all of them made use of the sign.

179. Ronchi and Nilsson [215] investigated the impact of flashing lights on route selection in an experimental setting. They examined the following attributes:

- The colour of the light,
- The flashing rate,
- The type of light source, and
- The number and the layout of the lights.

They found the following: 1) Flashing lights should be present in the emergency exit portal design; 2) Recommended colours of flashing lights are either green or white; blue lights are not recommended, 3) The flashing rate should be between 1 Hz and 4 Hz. Flashing rates lower than 1 Hz are not recommended. Flashing rates higher than 4 Hz have not been investigated; 4) The type of light source should be LED, while single and double strobe lights are not recommended; 5) The layout and position of the lights can be either with 1 or 3 lights or 2 bars on the side of the door.

180. As mentioned, where visibility is limited (either through hearing issues or environmental conditions), the benefits of visual signs decline. Directional signage has been developed to help guide individuals to particular locations, using a swooping broadband sounds that aid navigation in certain environments [197], [216], [217]; [218]; [219]. Although not in wide use, there are several technologies available that have been specifically designed to aid emergency evacuation, for example using mobile smart devices [220], [221]. These may be examined at a later stage.

A1-B.3 Horizontal egress

A1-B.3.1 Internal dwelling arrangements

- **Search term:** ("internal arrangement" | “internal dwelling”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 895

181. Hopkin et al. [222] undertook a review of fire safety design of apartments in England and the UK more generally, where the most common approaches to the internal arrangement of flats have been discussed.

182. A common approach to internal dwelling arrangements is to restrict the distance occupants may have to travel in the dwelling before reaching a separate compartment or place of relative safety [222]. As discussed by Ronchi et al. [223], the main purpose of limiting the travel distance is to minimise the distance occupants may need to travel in a fire or smoke affected environment, therefore minimising the time that they may be subject to untenable / toxic conditions. The distance that occupants are comfortable travelling in a fire-affected environment will be influenced by their familiarity with the environment and the severity of the conditions [224]. Purser and McAllister [225] suggest *“it may be possible to set less stringent tenability criteria if occupants are familiar with the building”*, e.g., with a minimum visibility limit in the region of 5 m for domestic enclosures.

183. An apartment may be provided with a ‘protected entrance hall’, which refers to a fire-rated enclosure (i.e., fire-rated walls and doors) which separates the ‘access room’ from the rest of the rooms in the apartment. Historically, this approach has been adopted in the UK to minimise fire and smoke to spread throughout the apartment and reduce the likelihood that the final escape route of the apartment is impeded [226].

184. The adoption of protected entrance halls uses compartmentation to enclose the most probable fire rooms and separate them from the escape route. In their review of dwelling fires data across multiple regions and countries, Spearpoint and Hopkin [227] identified that the majority of dwelling fires occur in the kitchen (53-55%), while fires in hallways / corridors / open plan areas only account for in the region of 4-5% of incidents.

185. The approach of using internal compartmentation within the apartments is somewhat reliant on the fire doors being kept closed by the occupants, and in some cases self-closing devices may be provided for the doors. However, previous studies by Andrew Irving Associates [228], [229] and Colwell [230] identified that a significant proportion of occupants either propped open, disabled or tampered with self-closing devices for a variety of reasons. It was concluded that *“there [is a] consensus that self-closing devices could be a nuisance…”*, it was *“fairly common practice to wedge doors open more or less permanently”* [228] and *“for the majority of those properties where self-closing devices are provided, users are likely to disable them to meet family needs”* [230]. Subsequent work by McDermott et al. [231], which described 40 interviews with occupants inhabiting new homes, concluded that in all private dwellings with self-closing fire doors, the occupants

reported interfering with the self-closing mechanism. Similarly, Hopkin et al. [232] and Leathley and Gibson [233] have both identified that it is likely for occupants to keep internal dwelling doors open throughout the day, with this likelihood of doors being kept open ranging from 27% to 73%, depending on the connecting room and whether occupants are awake or sleeping. Ultimately, Hopkin et al. [232] concluded that there is *"potential for daily household activities to take priority over the safety benefits which internal doors can provide"*. Hopkin et al. [222] noted that the recommendation of providing self-closers for fire doors internal to dwellings was omitted in the 2006 version of AD B, due to these closers *"commonly [being] tampered with or propped open"*.

186. In some instances, apartments may be afforded multiple exit routes / doors. This is done to provide occupants with multiple choices of escape in the event of a fire. For example, in a situation where one exit is compromised by fire or smoke, then occupants may be able to escape using the alternative exit.

187. As summarised by Hopkin et al. [222], *"open plan apartments [or 'open plan flats'] refer to situations where there are 'inner rooms' connected to an 'access room' which forms the only escape route"*. For example, a building situation where the apartment access room also includes the living area and / or kitchen area would be referred to as an open plan apartment, with the omission of a protected entrance hall and fire separation for the internal escape route. For open plan apartment design, Fraser-Mitchell and Williams [135] quantitatively assessed the risk from fires in these apartment types using probabilistic fire and evacuation models. In their assessment, Fraser-Mitchell and Williams identified that, when compared to apartments provided with protected entrance halls, open plan apartments could achieve a relative level of safety with the inclusion of sprinkler protection and automatic detection and alarm in every habitable room. The premise was therefore that open plan design could be accommodated with other enhanced fire safety measures which alerted occupants more quickly and reduced the severity of fire conditions.

188. As discussed previously, kitchens represent the most probable room of fire origin in a dwelling [227]. Therefore, the work of Fraser-Mitchell and Williams [135] mostly considered situations where the kitchen remains enclosed and only the living area was open to the access room. In subsequent work documented by Davis et al. [234], the modelling of Fraser-Mitchell and Williams was revisited to assess situations where the kitchen was unenclosed. It was found that the risk to occupants where the kitchen was not enclosed was comparatively lower than in the case for an enclosed kitchen. According to Davis et al. [234], this was attributed to providing early smoke detection and quicker occupant evacuation times.

189. In apartments which are open plan and do not enclose the kitchen in fire-resistant construction, the location of cooking facilities can have a direct impact on occupant escape. Spearpoint et al. [235] note that *"kitchen hob (stovetop) fires may pose a threat to occupants, particularly in open-plan dwellings in which the cooking arrangement is in proximity to an escape path"*. In these instances, Spearpoint et al. [235] suggest that an assessment may be undertaken which considers the impact of radiation and convection from a cooking fire on escaping occupants.

190. Certain types of apartments can incorporate multiple storeys, such as duplexes and triplexes. These multiple-storey apartments could include an exit on each storey or, alternatively, occupants may have to descend / ascend an internal stair to reach the final apartment exit. Fraser-Mitchell and Williams [135] provide example arrangements that have been used to support multiple-storey apartments, such as designing flats in an 'upside down' arrangement so that the bedrooms and the apartment exit are located on the lower level, where *"it can be argued that the occupants of the bedrooms do not have to escape through the living space and the natural buoyancy of smoke offers a degree of protection"* [135]. However, Fraser-Mitchell and Williams did not investigate the effects of open plan design in multi-level apartments and indicated that *"more work is needed if conclusions about comparisons of risks of death and injuries can be drawn…"* [135].

A1-B.3.2 Corridors

- **Search term:** corridor* (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 51 900

191. Corridors form one of the key escape route elements for occupants to be able reach a place of safety. For residential design, corridors are often used to form a protected escape route and connect dwellings to escape stairs, and to subsequently connect escape stairs to the outside.

192. Over the last 30 years, a great deal of data has been collected to describe horizontal flow rates and movement speeds. These evacuation parameters are sensitive to:

- Individual characteristics (e.g., age, weight, movement impairment, encumbrance, etc.).
- Corridor dimensions.
- Underfoot conditions.
- Proximity to surrounding population (i.e., occupant density).
- Lighting levels.
- Visibility.
- Social groupings (e.g., whether people are moving at their own maximum speed or reduce this speed to ensure that group coherence is maintained).
- Distance to be travelled.

193. An important aspect of escape through corridors is occupants' horizontal movement / walking speed. PD 7974-6 [2] provides an equation for estimating the horizontal movement speed of occupants as follows:

$$S = k - akD$$

where S is horizontal movement speed (m/s) and D is occupant density (pers/m^2), with empirical constant values of of k = 1.4 and a = 0.266 recommended for horizontal travel. This therefore indicates that higher occupant densities will produce slower movement speeds.

194. Thompson and Marchant [236] suggest that “interference threshold” is when the separation distance between individuals is 1.6 m or greater, as it is at this distance that occupant walking speed is unaffected by others around them.

195.The data shown in Table A1-B6 reflects movement of mixed capability populations, where those with impairments are in a significant minority [237]. The compiled datasets were collected in different ways and reflect different situations (e.g., different densities, underfoot conditions, etc.). However, provide a sense of the average movement speeds that are achieved during evacuation.

196.Table A1-B6 presents a summary of the averages generated in the 47 datasets examined. This therefore excludes the significant variation present in those datasets and should only be considered indicative.

Table A1-B6 Average horizontal movement speed data (in m/s), according to UK and non-UK scenarios, summarised from Gwynne and Boyce [237]

Parameter	Non-UK	UK
Horizontal movement speed (m/s)	1.2 [0.6-2.2]	1.4 [1.2-1.6]
Dataset count	39	8

197. Bosina and Weidmann [238] collated a large dataset (from 223 other datasets) of walking speeds from existing literature. Bosina and Weidmann considered the impact of several factors on walking speed, including the occupant density, age, and body weight.

198. For low occupant densities, Bosina and Weidmann [238] observed that *“speed varies greatly”* and that the range of speeds reduces as the density increases. Generally, as the occupant density increases, the occupants’ horizontal movement speed reduces. This relationship can be observed in Figure A1-B4. The impact of occupant density on flow through bottlenecks is discussed in Section A1-B.3.3.

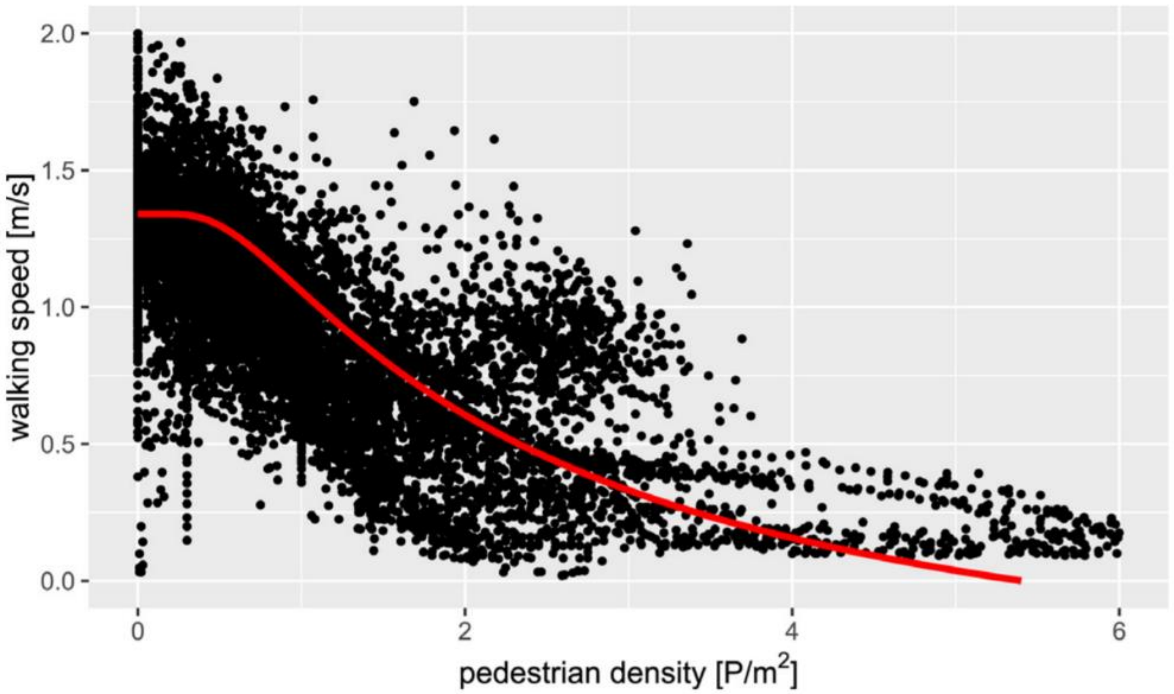


Figure A1-B4 Relationship between horizontal movement speed and occupant density, reproduced from Bosina and Weidmann [238]

199. Age has been shown to have a significant impact on walking speed, as presented in Figure A1-B5. Generally speaking, Bosina and Weidmann [238] suggest that *“the walking speed is considered to increase until the age of about 20 and then decrease similar to the physical abilities”*.

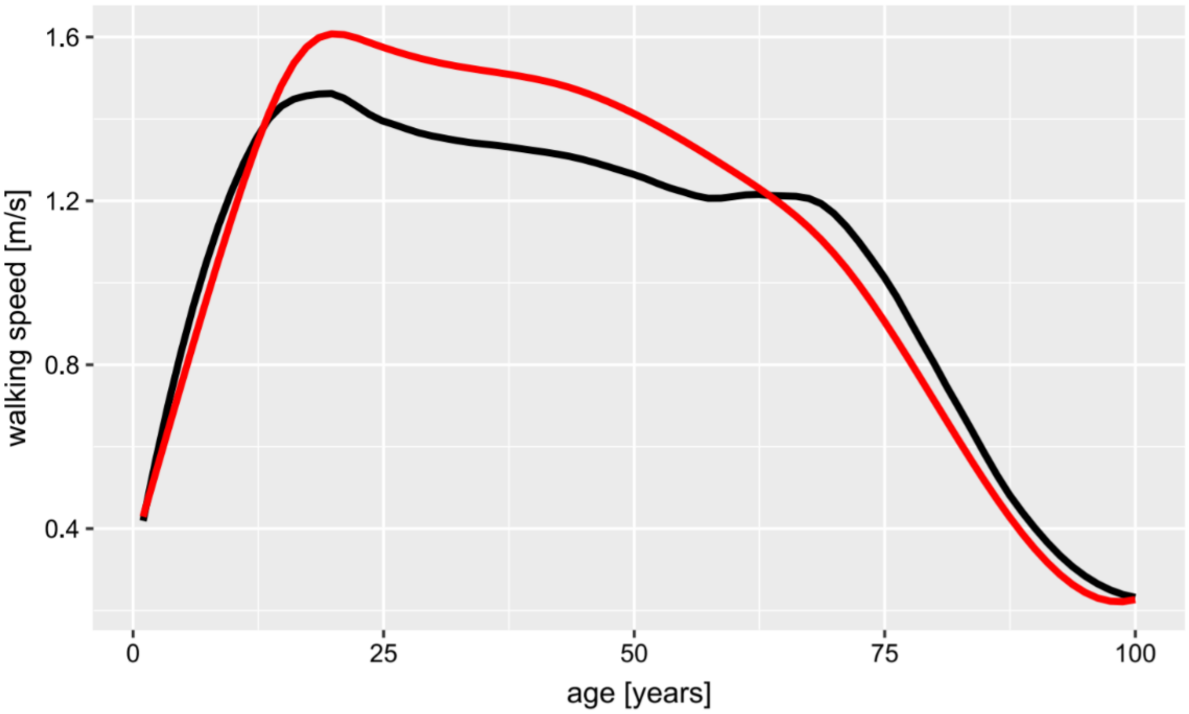


Figure A1-B5 Relationship between horizontal movement speed and age, reproduced from Bosina and Weidmann [238]. Black refers to Bosina and Weidmann’s ‘new data’ and red refers to old data from Weidmann (not available in English).

200. Figure A1-B6 presents a relationship between horizontal movement speed and body weight, as identified by Bosina and Weidmann [238]. The figure indicates a slight (but not significant) decrease in walking speed with increasing weight. However, the figure does not indicate the relationship between weight and height of occupants, e.g., body mass index (BMI). Therefore, it is not clear to what extent obesity may impact movement speed.

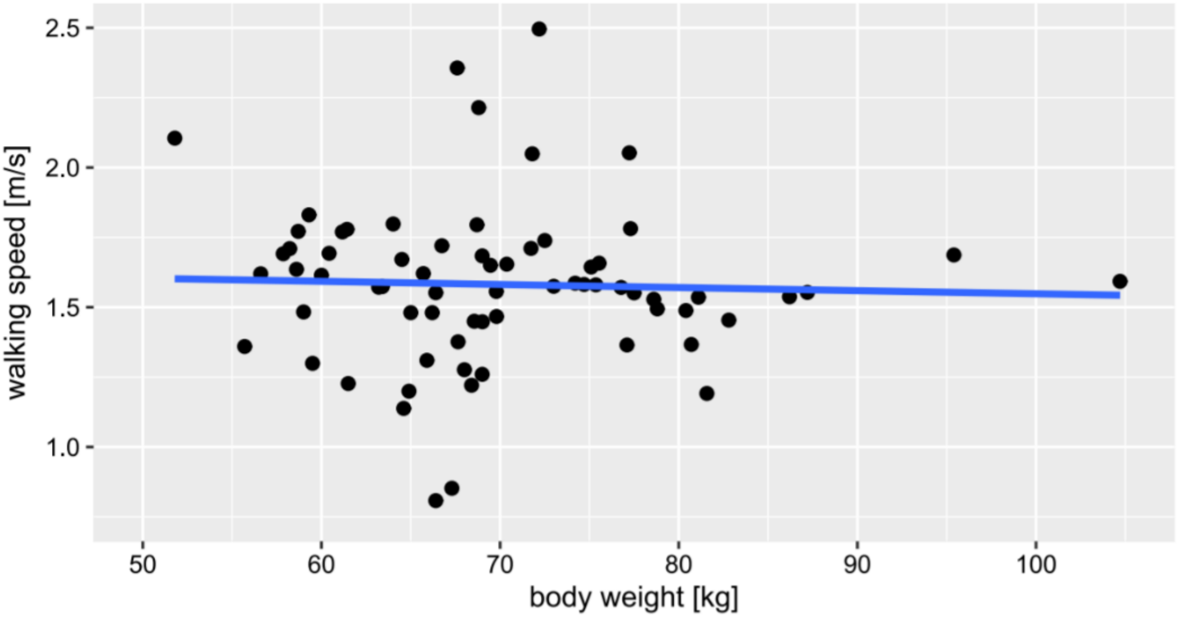
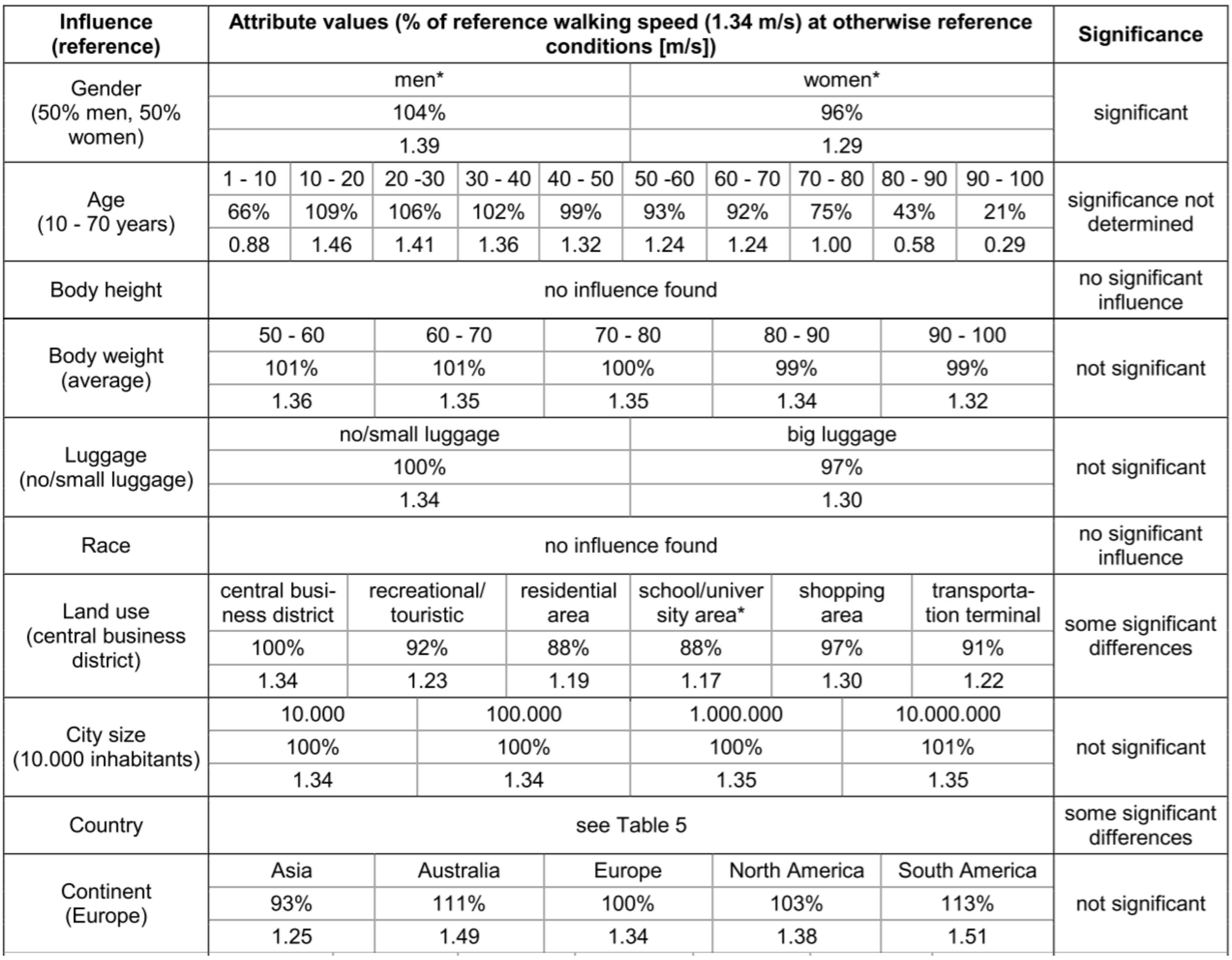


Figure A1-B6 Relationship between horizontal movement speed and body weight, reproduced from Bosina and Weidmann [238]

201. Bosina and Weidmann [238] summarise the impact of various attributes on movement (see Figure A1-B7). There are two points of note: (1) the average rates produced are comparable to those shown in Table A1-B6 previously; and (2) evacuation performance in residential settings is typically shown to be lower relative to other occupancy types.



Influence (reference)	Attribute values (% of reference walking speed (1.34 m/s) at otherwise reference conditions [m/s])										Significance
Gender (50% men, 50% women)	men*	women*									significant
	104%	96%									
	1.39	1.29									
Age (10 - 70 years)	1 - 10	10 - 20	20 -30	30 - 40	40 - 50	50 -60	60 - 70	70 - 80	80 - 90	90 - 100	significance not determined
	66%	109%	106%	102%	99%	93%	92%	75%	43%	21%	
	0.88	1.46	1.41	1.36	1.32	1.24	1.24	1.00	0.58	0.29	
Body height	no influence found										no significant influence
Body weight (average)	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100						not significant
	101%	101%	100%	99%	99%						
	1.36	1.35	1.35	1.34	1.32						
Luggage (no/small luggage)	no/small luggage	big luggage									not significant
	100%	97%									
	1.34	1.30									
Race	no influence found										no significant influence
Land use (central business district)	central business district	recreational/ touristic	residential area	school/university area*	shopping area	transportation terminal					some significant differences
	100%	92%	88%	88%	97%	91%					
	1.34	1.23	1.19	1.17	1.30	1.22					
City size (10.000 inhabitants)	10.000	100.000	1.000.000	10.000.000							not significant
	100%	100%	100%	101%							
	1.34	1.34	1.35	1.35							
Country	see Table 5										some significant differences
Continent (Europe)	Asia	Australia	Europe	North America	South America						not significant
	93%	111%	100%	103%	113%						
	1.25	1.49	1.34	1.38	1.51						

Figure A1-B7 Summary impact of factors on movement performance, reproduced from Bosina and Weidmann [238]

202. The flow through bottlenecks and doors is discussed in Section A1-B.3.3, where it is identified that wider ‘bottlenecks’ (which would include corridors) produces faster flow times, dependent on the occupant density.

203. Reviewing data between 1985 to 2015, Gwynne and Boyce [237] found average horizontal flow rates of 0.66 pers/m/s (ranging from 0.6 – 1.25 pers/m/s) across eight datasets. However, this excluded much of the ‘standard’ data typically used in fire safety engineering. Bosina and Weidmann [238] reviewed a much wider range of data, going back considerably further and including a wider range of pedestrian scenarios, and generated an average of 1.4 pers/m/s (ranging from 0.87 – 2.07 pers/m/s) across 55 datasets. In both cases, these figures only represent the average of each dataset and so do not reflect the variability that might normally be expected. In comparison assumes a horizontal flow rate for design of 1.33 pers/m/s [2].

204. The effective width of corridors and flow through corridors will be affected by the ‘boundary layers’, a concept which refers to the need for exit routes to maintain sufficient width to accommodate occupants’ lateral body sway and balance [2]. The effective width of a corridor (or door) is therefore the clear width less any boundary layers. Example boundary layer values are given in Table A1-B7 from PD 7974-6 [2], where corridors are suggested to

have a boundary layer of 200 mm (on each side), which is greater than the presented values for stairs, doors, railings and handrails.

Table A1-B7 Boundary layer widths for different exit route elements, reproduced from PD 7974-6 [2]

Exit route element	Boundary layer [mm]
Theatre chairs, stadium benches	0
Railings, handrails	90
Obstacles	100
Stairways, doors, archways	150
Corridor, ramp walls	200
Wide concourses, passageways	460

205. As discussed in Section A1-B.3.1, it is common in design to restrict the distance occupants may have to travel. With respect to corridors, the distance may be limited to minimise the time it takes for occupants to reach a place of relative safety, such as a stair. This perspective is supported by Hagiwara and Tanaka [239], who suggest *"provisions for adequate arrangements of means of escape of maximum travel distance, common path of travel, length of dead-end corridor and distance between two exits."*

206. Veeraswamy et al. [240] undertook an assessment of wayfinding criteria from a building evacuation perspective, considering how occupants select their escape path. The assessment suggested that handedness and the side of the road occupants drive on exert a significant influence on path choice. Another important factor was the length of the first 'leg' of an escape route, where occupants are more likely to choose an escape route of its first leg is comparatively shorter.

207. PD 7974-6 [2] suggests that building complexity will affect both pre-evacuation time and the time required when wayfinding. The arrangement of corridors will subsequently affect the wayfinding complexity. Major et al. [241] highlight a case study example where a university building is referred to as *"notorious for way-finding difficulties"* due to *"repetitive similarity of individual parts in its modular design"*.

208. In addition to the physical impact of the corridor on occupant movement, the corridor's appearance can also affect its use. Gibson [242] developed the notion of affordances, which refers to what an object offers to people in relation to their objective. In this instance, the affordance is the degree to which a corridor facilitates escape through its appearance. For instance:

- Does the condition of the corridor suggest that it is in use?
- Does the lighting level enable the corridor to be seen?
- Is there a visible exit at the end of the corridor?
- Does the corridor look in good repair?
- Is the corridor blocked in any way? etc.

All the above elements may factor into an occupant's decision to use a corridor as a means of escape and they may also affect the movement speed that might be maintained along that corridor during escape. This aspect of fire safety design is currently quite difficult to quantify and might interact with other key influences over route selection, such as spatial familiarity [243].

209. Spatial familiarity has been shown to have an impact on the exit which occupants select when escaping. Heliövaara et al. [244] suggest that *"people tend to prefer familiar exit routes"* and *"people choose to follow others"* when they are evacuating. Kinateder et al. [245] verified the concept of 'movement to the familiar' using virtual reality experiments, where it was highlighted that participants of the experiment were *"significantly more likely to exit through a familiar door than through a second available exit. This effect was greater when virtual neighbors also left by the familiar door…"*.

210. An experimental study by Heliövaara et al. [244] for exit selection in evacuation of a corridor suggests that when occupants are faced with a 'non-trivial' decision on exit choice, *"members of an evacuating crowd may not be able to make optimal decisions when assessing the fastest exit to evacuate"*.

A1-B.3.3 Doors

- **Search term:** door* (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 273 000

211. Doors provide a means of access to a space and a means to control the environmental conditions within a space (e.g. reduce draughts, retain heat, attenuate noise, etc.). Doors have various opening / closing mechanisms and may have some means to prevent their use such as locks or security gates. The expected normal function of a door may conflict with their performance in a fire safety situation.

212.This section discusses doors in relation to their physical impact on occupant wayfinding and physical travel. Doors as a fire separation / compartmentation provision is discussed in Section A1-B.2.1.

213. The New Zealand verification method C/VM2 [246] proposes a calculation to estimate the flow rate through a door or horizontal opening:

$$F_c = (1 - aD)kDW_e$$

where F_c is the calculated flow (persons/s), D is the occupant density near the door (C/VM2 recommends using 1.9 persons/m^2), W_e is the effective width of the door and k and a are factors which vary depending on whether travel is horizontal or vertical (by accounting for stair riser / tread dimensions), with values of k = 1.4 and a = 0.266 recommended in C/VM2 for horizontal travel. This calculation method and the associated parameters are also consistent with the recommendations of PD 7974-6:2019 [2]. The implication of this calculation is that flow rate can be considered linearly proportional to the effective width of the door. The concept of boundary layers and their impact on the effective width of an opening is discussed in Section A1-B.3.2.

214. Nelson and Mowrer [247] and Predtechenskii and Milinskii [248] indicate that flow through a door increases as a function of density up to a given threshold. Beyond this threshold, the flow rate is estimated to decrease as densities become unfavourable and restrict occupant movement. This relationship is presented in Figure A1-B8, as reproduced from Seyfried et al. [249].

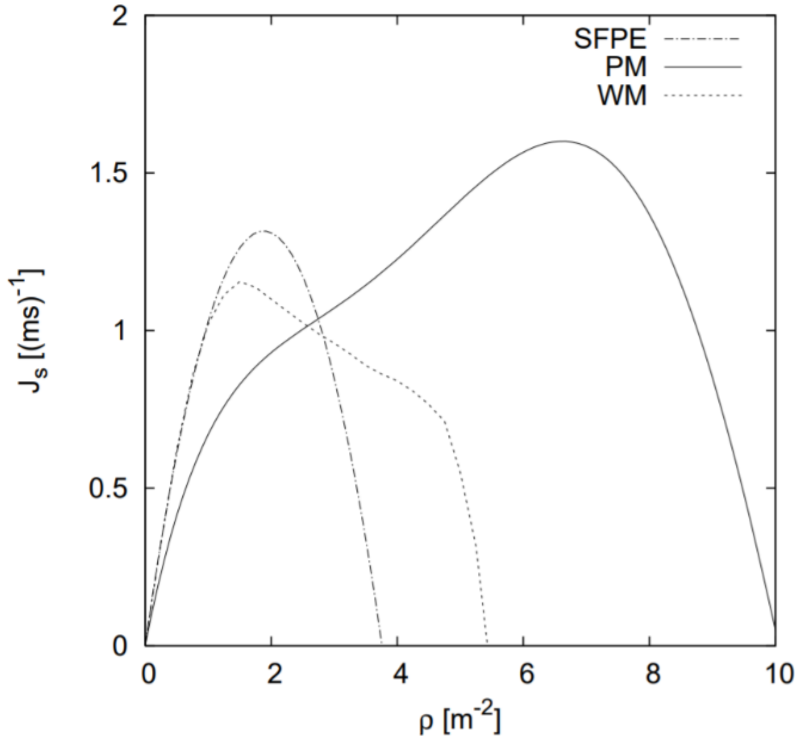


Figure A1-B8 Door flow rate (pers/m/s) as a function of occupant density (pers/m^2), reproduced from Seyfried et al. [249]. SFPE = Nelson and Mowrer [247], PM = Predtechenskii and Milinskii [248], WM = Weidmann (not available in English)

215. As mentioned above, common relationships around exit flow capacity assume a linear relationship as a function of the exit width. In contrast, Hoogendoorn et al. [250] suggest that flow increases in a stepwise manner, through lane formations. This is sometimes referred to as the ‘zipper effect’, which is a self-organisation behaviour influenced by the available space and movement speed. Due to this effect, it is suggested that additional flow capacity is only achieved when an additional ‘lane’ is able to develop. However, work by Seyfried et al. [249] appears to indicate that assuming a linear increase in flow as a function of width is reasonable once the exit width exceeds approximately 0.7 m.

216. Gwynne and Boyce [237] discuss a number of empirical studies on occupant flow rates through doors and the impact on horizontal movement, several of which are discussed herein.

217. Daamen and Hoogendoorn [251] undertook a series of experiments considering door width, and population type and composition. The impact of the population type on door ‘capacity’ (i.e. the flow rate per unit width) is presented in Figure A1-B9. The populations

with a greater quantity of children were shown to achieve the highest flow rate. Daamen and Hoogendoorn hypothesise that *“this is not only due to the large enthusiasm of the children, but also the smaller physical size off children compared to adults…”*. The lowest flow time was found to be for populations containing participants who were mobility impaired, which included three participants who were blindfolded and three who were in a wheelchair.

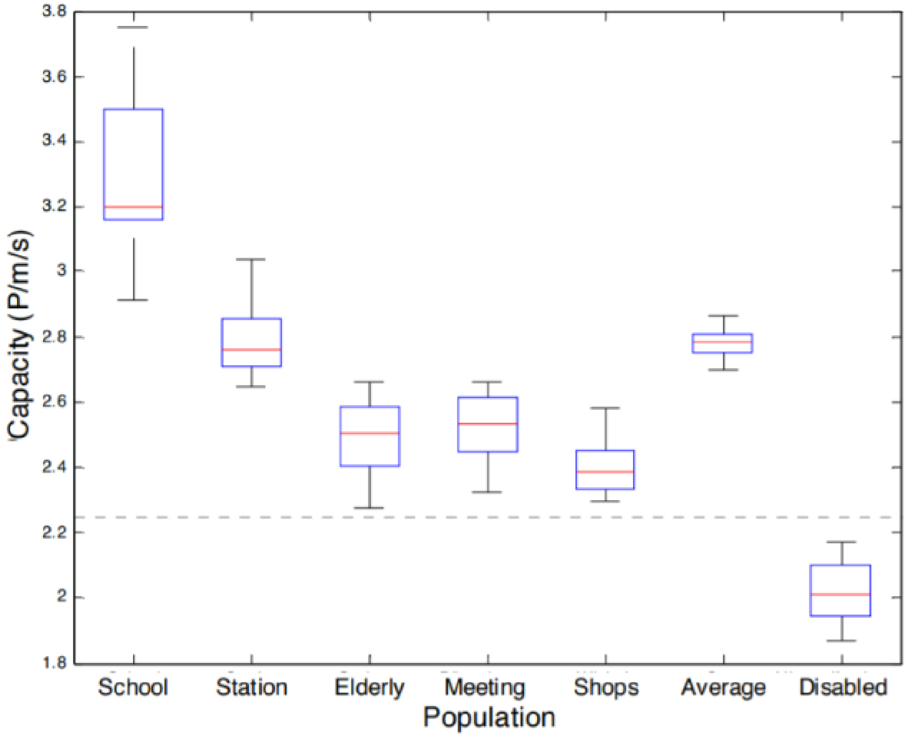


Figure A1-B9 Box plot of door capacity considering population type, for a 0.85 m wide door, reproduced from Daamen and Hoogendoorn [251])

218. Daamen and Hoogendoorn [251] also considered whether the presence of a physical door opened at 90° (in the direction of escape), instead of an equivalent opening with no door, impacted the occupant flow. They found that this resulted in a flow rate capacity reduction due to the impact on walking trajectories ‘downstream’, reducing the flow rate to approximately 80% when compared to an opening with no door.

219. Seyfried et al. [249] collated experimental data for flows through ‘bottlenecks’, where a bottleneck refers to some form of narrowing along an escape route, e.g. in a corridor or by the introduction of a door. Seyfried et al. observed “*significant differences*” based on the geometry of the bottleneck, i.e., its length and position with respect to incoming flow, and the initial conditions, i.e., initial density values and the initial distance between participants and the bottleneck. The data is presented in Figure A1-B10, presenting a relationship between the bottleneck / exit width and the achieved flow rate.

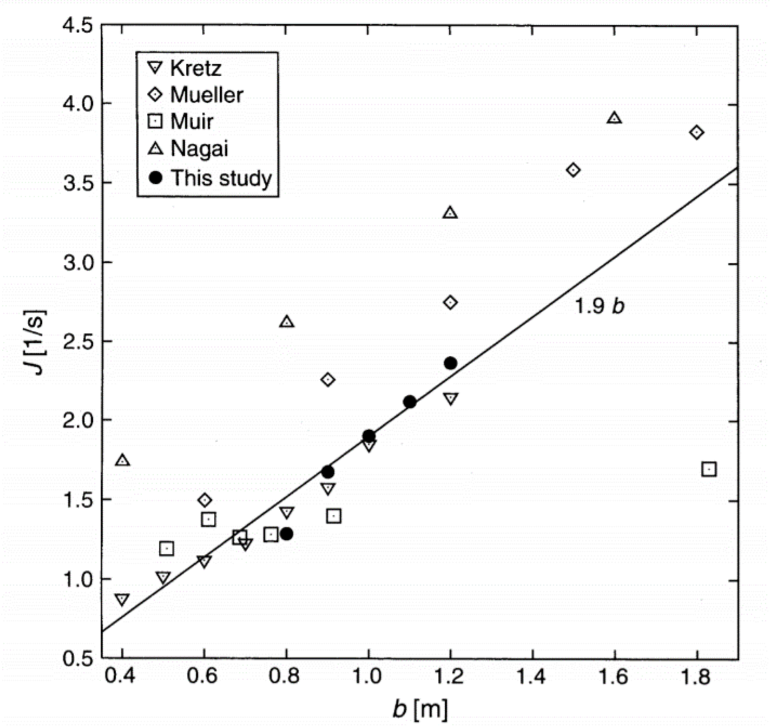


Figure A1-B10 Data relating to door flow, J is the flow rate (pers/s), and b is the ‘bottleneck’ width (m), reproduced from Seyfried et al. [249]

220. Rinne et al. [252] performed evacuation trials and monitored the flow through 32 exits to estimate the flow rate. The data for these evacuation trials is presented in Figure A1-B11, where a loose trend can be observed in relation to wider exits producing a faster flow rate.

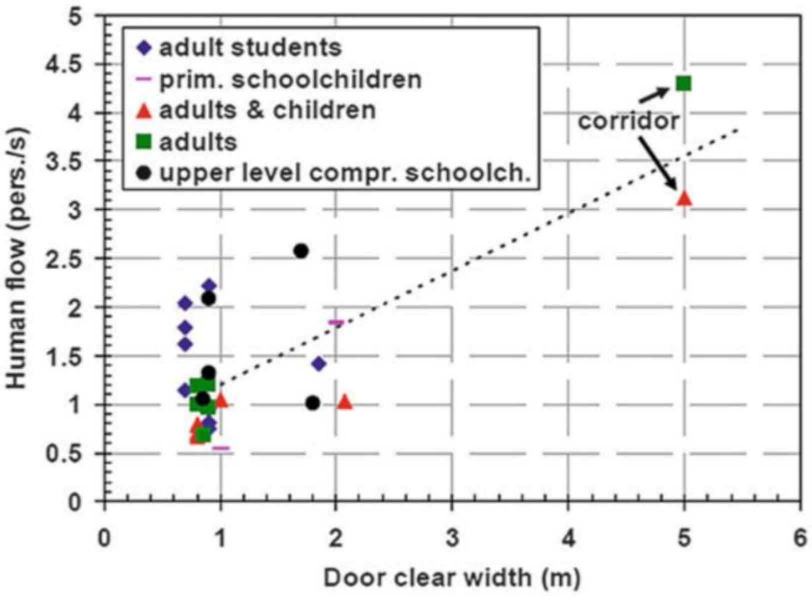
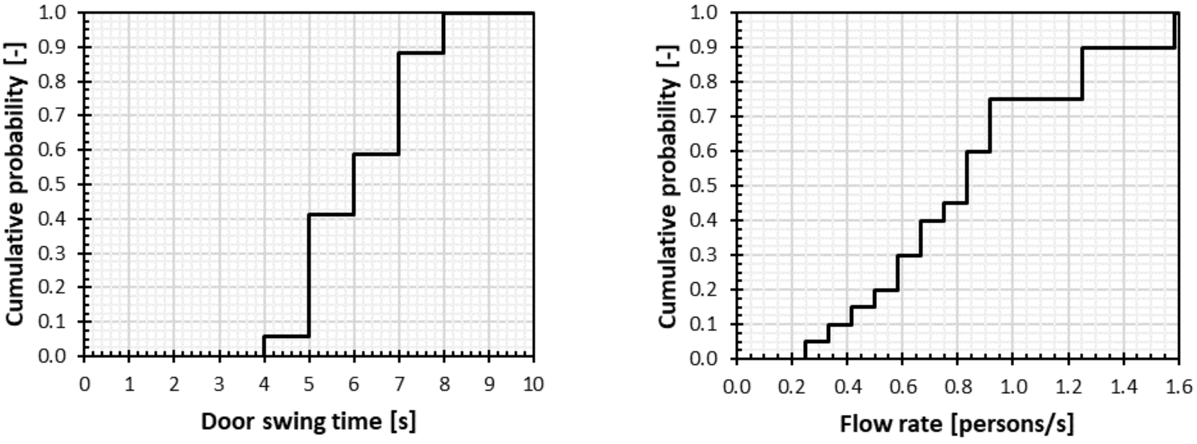


Figure A1-B11 Data relating to door flow, reproduced from Rinne et al. [252]

221. During trial evacuations of university buildings, Frank [253] undertook an evaluation of the door swing times. The doors included a range of widths, leaf configurations and locations. The operation of the doors was observed using a combination of video recording and logging devices that measured the door angle as a function of time. As part of the process, Frank assessed what he referred to as the ‘door negotiation time’, described as *“the time between the door states of being completely closed”*, i.e., the time from the

occupant initially opening the door to it closing behind them after they had passed through. For the evacuation trials of the university buildings discussed previously, Frank [253] identified instances where more than two occupants evacuated in a continuous stream, with a maximum of up to 37 occupants in one single stream. From this, the average door swing time per occupant was determined. Hopkin et al. [152] interpreted this data to produce cumulative density functions (CDFs) for the door swing time (for a single evacuating occupant) and occupant flow rate (for multiple occupants), as presented in Figure A1-B12.



(a) (b)

Figure A1-B12 CDFs for door swing time and door flow rate, adapted from Frank [253] and reproduced from Hopkin et al. [152]

222. Hopkin et al. [152] used probabilistic calculations and experimental data to estimate door open times for occupants escaping from apartments, as this could have an impact on both the escape time and the extent of smoke spread from the apartment in the event of a fire. The door open time was estimated as a function of the door swing time, the door flow rate, and the number of occupants located in the apartment. The number of occupants varied depending on the size of the apartment / number of bedrooms, using occupant density distributions from Hopkin et al. [254]. The estimation of the door open time, for different apartment sizes, is presented in Figure A1-B13 in the form of a CDF. This calculation assumes that all apartment occupants evacuate simultaneously. The paper was concerned with the length of time that the door was physically open and therefore the distributions that are presented do not capture the time for the door to be unlocked, etc.

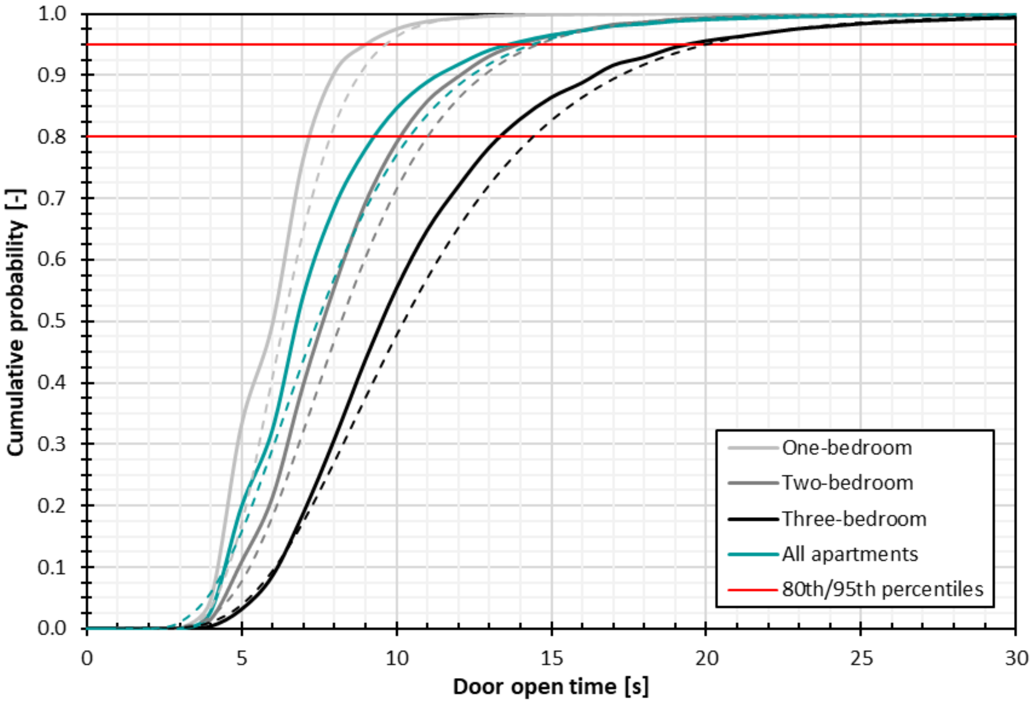


Figure A1-B13 Apartment door open time distribution for different sized apartments, from Hopkin et al. [152]

223. Son et al. [255] assessed the impact of door opening direction, door handle type, and visibility conditions on occupant movement (for single occupants). Push and pull doors were considered alongside different handle types of doorknob, door lever and 'panic' bar. Movement times were found to be fastest when the door opening direction was push, irrespective of the type of door handle. For handle types, movement times were shortest for a panic bar handle and longest for a doorknob, but differences were not shown to have a statistically significant difference. From the experimental times, the door opening 'delay' time ranged from 1.96 to 2.88 s for push and 3.91 to 4.43 s for pull under normal visibility conditions, and this increased to 7.38 to 12.56 s for push and 12.88 to 16.35 s for pull under limited visibility conditions. It is important to note, however, that the assessment only included participants between the ages of 20 and 40 and did not include any individuals with a mobility impairment.

224. Self-closing devices on doors are discussed in Section A1-B.2.1 and occupant habits with respect to propping and keeping doors open are discussed in Section A1-B.3.1. In some cases, doors can be provided automatic openers or 'fail-safe' actuation release mechanisms which means that the door opens upon smoke detection, removing the need for occupants to operate the door. These mechanisms are discussed in BS 7273-4 [256]. Door actuation release mechanisms can be adopted for sliding doors or rotating doors, which in their standard configuration are usually recommended to be excluded when assessing building designs for escape purposes [257].

A1-B.3.4 Balconies

- **Search term**: balcony (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 21 400

- **Search term**: balconies (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 19 400

225. Multiple storey buildings may include balconies (and terraces) as part of the design of the structure. BS 8579 [258] provides guidance on the design of balconies and terraces, and the general term ‘balcony’ is used in this report. Balconies may be private to a single occupancy, shared by several occupants or be accessible to the public.

226. The construction of a balcony may include combustible elements and/or balconies may be used as a place to store combustible items. Therefore, balconies may be a location of fire ignition and may contribute to fire spread along with the generation of smoke and toxic products. Further investigation of these aspects is ongoing through a separate research project on behalf of MHCLG.

227. Balconies that are publicly accessible will generally form part of the building circulation routes. Access balconies can be used to connect a circulation route to a separate ‘stair tower’.

228. Modern balconies that are accessed by the public should be designed to accommodate the movement of wheelchairs, allow people to move to a place of safety etc. [258]. These design requirements can assist in the evacuation of a building during an emergency.

229. Balconies specifically and solely designed as a means of escape from fire were common on buildings in the US around the turn of the 20th century. These ‘skeleton’ fire escapes, external to the building, consisted of iron balconies and ladders (see Section A1-B.4.4.2). Such means of escape had a number of problems that included maintenance, being kept clear of snow and ice, would be used for the storage of items, the need to position a section of ladder to reach the ground etc. This report does not discuss these means of escape and further information can be found in the work of Wermiel [259].

230. A balcony may provide a place to escape from heat or smoke; an opportunity to get information about an incident [260] that may aid with subsequent occupant decision-making on their need to evacuate from a building. This would be the case even where the balcony does not form part of the circulation route.

231. In some jurisdictions such as Japan, the local authorities recommend that a balcony be provided as an emergency exit from hotel guest rooms [261].

232. In the study of Proulx et al. [262] it is recommended that whether a balcony forms an emergency exit must be clearly stated as part of the fire strategy. They comment that

"*balconies can be used as a place of refuge, unless the person is in the apartment of fire*". Refuges are further discussed in Section A1-B.3.5. Proulx et al. [262] also noted that for the building they were studying that the "…*manual given to residents stated that, in the case of a fire not in their own unit, occupants are to evacuate onto their balconies and wait until the situation is under control*."

233. Occupant movement along balconies can likely be treated similar to corridors (see Section A1-B.3.5) although balconies will generally have a balustrade rather than a wall long one edge, thus affecting the effective width. Weather conditions such as wind, rain, snow and ice etc. may have an effect on movement. For that reason, local ordinances may require that balconies be kept free of obstructions including ice and snow.

234. Gatfield [263] noted that buildings in the UK used to have a feature in which a stairway and lift discharged to an open balcony as an alternative to an internal lobby. However, this approach fell out of favour as the result of an apartment block fire somewhere around 1991 or earlier in which combustible cladding had a major impact on fire and rescue operations. Gatfield suggests this fire occurred in London although the report authors have not been able to verify which incident this was.

A1-B.3.5 Refuge points

- **Search term**: (refuge* | "refuge point" | "refuge points") (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 99 200

235. Refuges might be used in conjunction with the evacuation procedure in place, or because individuals involved in the evacuation are not able to reach a place of safety. For instance, when the population requires it (e.g. when there a large number of people involved in progressive evacuation procedure or when the population includes people in wheelchairs having to get to a place of relative safety.

236. Dedicated refuges are used most commonly used for non-fire emergencies (e.g. tornadoes in the USA) or for fire emergencies outside of Europe (e.g. in Hong Kong and Singapore). However, refuges are defined in BS 9999:2008 'Code of Practice for Fire Safety in the Design, Management and Use of Buildings' as "*an area that is both separated from a fire by fire-resisting construction and provided with a safe route to a storey exit, thus constituting a temporarily safe space*" [92].

237. The US Federal Emergency Management Agency issues guidance on the design, development and maintenance of refuges and safe rooms to provide shelter for victims subjected to extreme weather conditions such as hurricanes and tornadoes [264]. The guidance identifies several design issues that may be relevant here, including:

- The required capacity of the refuge facility given the estimated population size with and without impairments (i.e. the number of people in wheelchairs that can be accommodated).
- The ability of occupants to enter and leave the space before, during and after the scenario has developed.

- The time for people to reach the space and then access it.
- The projected time that people will remain in the space (especially if there is limited access to information).
- The need for signage indicating the location of, entrance to, and purpose of the refuge space (e.g. tornado room, etc.). Depending on the type of facility, signage might need to be provided in several languages.
- The presence of ventilation and heating to support occupation.
- The need for sanitation facilities, especially for protracted incidents.
- Emergency and non-emergency lighting/power requirements.
- Whether the space is single-use or multi-use. For instance, does it have routine uses, is it used in response to several emergency incident scenarios, etc.
- The emergency plan associated with the use of the space during an incident.
- The performance of drills and provision of staff training. Those using the facility should at least be familiar with the warning signals used, the existence and purpose of the refuges, the routes to them, the location of the doors, etc.
- The provision of food, water, medical kit, communications equipment and emergency supplies.
- The importance of monitoring occupant arrivals and departures at a refuge to simplify search and rescue efforts conducted by emergency responders.

238. These factors indicate the array of issues that might be generated by a refuge and they ways of alleviating these issues. It should be noted that most UK refuges typically have fire protection to ensure the safety of the occupants for a period of time, but few of the other systems implied by the list above. Indeed, most UK refuges are dual purpose (e.g. a landing in a stairwell, etc.).

239. Proulx examined the benefits of employing a defend-in-place strategy [265]. A similar type of strategy (in terms of the experiences of the population) would be required when using a refuge. She focused on high-rise applications. Proulx referenced the work of MacDonald [266], noting that evacuees may increase their exposure to the fire conditions by leaving (the relative safety) of their protected apartments. For instance, MacDonald examined 20 fires and found that 82% of fatalities had succumbed while evacuating. This led MacDonald to conclude that unless the fire was in an occupant’s apartment, it was probably better for them to remain in place. Similarly, in the 1995 North York fire, six previously fit and unimpaired casualties aged between 16-35 years were found in stairwells. An evacuating population may increase the chance of exposing itself to fire conditions as the distance required to reach safety increases, for instance, where occupants must travel up multiple floors to reach safety. In addition, the act of vertical evacuation – especially when using stairs to traverse numerous floors – will produce fatigue. This may reduce speed and increase the likelihood of trips and falls. It may also exacerbate existing mobility impairments in the population. However, it should be noted that Proulx’s analysis was conducted pre-911 (and by implication pre-Grenfell Tower). Public perceptions on remaining in place may well have been influenced by these events – both in terms of building collapse and compromised compartmentation. However, the long-term impact on public perception is not well understood [267].

240. McConnell and Boyce [268] surveyed 300 occupants with multiple sclerosis to determine their perceptions of refuge areas within a building. This sample population was relevant as individuals with movement impairments are expected to use refuge areas during an evacuation from fire – assuming that evacuation is impossible in the time available and that they would need shelter until rescue. The researchers found that many respondents did not know how to use a refuge, did not feel comfortable using it, and did not feel as safe as those who did not need to use the refuge (e.g. the ambulant). Nearly 80% of their sample population was concerned about being forgotten, 65% were concerned about being left alone, 50% had little or no knowledge of the refuge areas, 35% said that they would not use a refuge, and 60% indicated that they would not remain in the refuge for longer than 10 minutes. This would have posed several challenges to a procedure based on the use of a refuge – both for the intended users and the impact that they might have on other egress routes should they choose not to use the refuge. In addition, the population suggested that seating was vital in the refuge area and 65% highlighted the need for information while in the refuge area. This work indicates some of the perceptions that need to be addressed when proposing refuge use. However, it should be remembered that this population (those with an impairment) would have had to use a refuge while others evacuated to a place of safety. This may have influenced their perception of a refuge and resentment at remaining behind.

241. The installation of a refuge would need to consider the elements detailed in Table A1-B8.

Table A1-B8 Elements to be considered in the installation of refuges

Emergency plan	• How can the emergency plan ensure that the use of the refuges is as intuitive to unfamiliar and untrained passengers as possible? • How can occupants be engaged in the development of the emergency plan to help ensure intuitive design and buy in? • Will all residents have equal access to the refuge or will their use be prioritised? • Who is expected to respond to the refuges to provide onward assistance to those using them?
Routine movement / facilities	• How can routine movement around the building and facilities be located to increase awareness and familiarity of the refuge? • Should the refuge have a use during routine, non-emergency operations? Does the routine use of this space increase the chances of the fire incident originating in the refuge? • Does the routine use of the refuge encourage maintenance of the space and associated systems?

Location of refuges	• Where should refuges be located both to ensure performance and encourage use? • How can refuges be positioned to reduce the distances required to reach them? • How many refuges are required to ensure access and capacity? • Are there sufficient refuges or separate/protected routes to the refuge to ensure that floor populations can access the refuge irrespective of the location of the fire?
Refuge design	• What should the capacity of each refuge be? Will the refuge be large enough to contain residents from multiple floors? • How will the conditions in the refuge be maintained to ensure comfort and safety; e.g. issues of ventilation, protection from fire effluent (from external sources or from the construction of the refuge), heating, lighting and power? How will these be maintained during nonemergency and emergency scenarios? • What sanitation facilities will be provided? • How will access to the refuge be maintained during the incident, whilst preventing any fire effluent entering the space? Will arrivals always be allowed to enter the refuge? • Given that the space will likely be used by ambulant and non-ambulant individuals, what seating arrangements and wheelchair spaces should be provided to ensure comfort? • Will access to the refuge be suitable for those with mobility impairments? How can this be achieved? How can the refuge be designed to suit the needs of and encourage confidence in the entire population? • What emergency power and lighting systems will be in place to ensure independent operation during an emergency? • How will potable water supplies be maintained? • How will station staff, responders and refuge occupants communicate? How will this communication address issues of sensory impairment (e.g. deaf/blind passengers)? • How will information on the conditions around the station be provided to those in the refuge? • How long are people expected to be in the refuge during the incident? Is the refuge a transient safe zone (place of relative safety) or a final destination? Is the refuge connected to grade level? • How many access points will each refuge have? • What medical facilities will be in the refuge? • Will the refuge appear to be a safe and robust structure? • Will those outside of the structure be able to clearly see that the internal conditions are tenable?

Fire protection measures	• What fire protection and suppression systems will be available in the refuge and the surrounding areas? • How can residents access the refuge without compromising the fire protection of the space? • What is the fire rating of the refuge (i.e. how long will it afford a protection to an occupant)?
Resident outreach	• What education and outreach can be developed to make residents aware of the • use of the refuge? • How can residents be convinced that the refuge concept is safe, and safer than other approaches available?
Staff training	• Will refuge be staffed? • If so, what training will be offered to staff to ensure familiarity with the use of • refuges?
Routine signage	• How will the routes to the refuge be signed during routine operation? • How will the location of the refuge be signed during routine operation? • How will this signage address the potential dual role of the refuge (in routine/emergency scenarios)?

A1-B.4 Vertical egress

242. We address a range of vertical movement measures that might be employed, the assumptions on which they are based and their respective strengths and weaknesses. Here, movement measures refer to those parts of a procedure that address the physical movement of the occupant population and their target destination. It is apparent that the effectiveness of these measures is driven by a number of variables: occupant familiarity, the deployment of human/technological/procedural resources, the inclusivity of the measure, the physical implications of employing the measure, the individual experience, and the number of people that can be handled (i.e. the capacity) of the measure in question (see Table A1-B9).

Table A1-B9 Applicability of egress route selection based on underlying conditions.

Provision	Strengths	Weaknesses
Stair	• Assumes population is safer outside of the building. • Concept is familiar to occupants. • Likely already in place. • No training required regarding use. • Allows individual a sense of agency over their movement to safety. • A sense of movement towards a place of safety.	• Not accessible to entire population. Those with mobility impairments, the elderly, those with health/fitness issues or small children and those who are encumbered may not be able to use stairs - especially for long periods. Evacuation devices might be required to compensate, allowing vertical movement of those with movement impairments. However, will require considerable effort from those involved. • Requires route integrity. However, if not protected stairs can become blocked by smoke. Alternative routes would then be required. However, these may not be familiar to population. • Ascending extended distances may be fatiguing, may be beyond unfit, and may take too long. • Although stair use is familiar, ascending to reach safety may not be. • Performance of evacuating population can be affected by slower moving social groups or individuals, depending on the width of the stair. • May require responders to use same egress routes to access space. Responders may also be required to search for evacuees who may have got into difficulty during their evacuation. Responders may also be needed to provide assistance. • Stairs may become congested if use is imbalanced. May be alleviated through phased approach. • Potential exposure to environmental conditions unless stairwells are protected.

Provision	Strengths	Weaknesses
Lift / Elevator	• Assumes that occupant population is safer outside of the building. • Existence of component known to occupant. • May already be in place. • Accessible to population including those in wheelchairs. • May be used to complement stairs and escalators. • A sense of movement towards a place of safety.	• Use of component during an emergency unfamiliar to most people. • If not already present, may require significant. • development/construction. • Must be supported by emergency power supply. • Will require fire protection to prevent effluent affecting the lobby and the elevator shaft. Detection required to assure viability. • Would need protected lobby to allow for evacuee queuing as they wait to board. • Would require occupants to wait in elevator lobbies. They may not be content to do so, if waiting times are protracted. • May not be suitable for all scenarios. For instance, • structural damage, power cuts, etc. Therefore, other procedures would be required. • May not provide sufficient capacity to evacuate entire population in a timely manner (e.g., in 4-6 minutes). • Education required to ensure the public is aware of emergency elevator, that they perceive it as a safe option and that they know when it should be used. • May need to be staffed to ensure that it is used in accordance with the emergency procedure. Additional staff training would then be required to ensure elevator movement is managed (where it stops, etc.) and evacuee prioritization is followed (e.g. if the mobility impaired board first, etc.). • Signage required indicating which of the elevators can be used as part of an emergency evacuation and their capacity. • Real-time information required for those occupying the elevator and waiting for the arrival of the elevator. This should reflect the expected elevator arrival time (countdown to elevator arrival), and the expected time for it to reach safety.

Provision	Strengths	Weaknesses
Refuge	• Assumes that occupant population is safer in a protected location while the incident is addressed. • Sufficient protection in accessible refuge area. • Sufficient capacity to house evacuating population. • Accessible to population, including those in wheelchairs (assuming on horizontal access is required). • Reduce exposure of population during movement phase.	• Component not familiar to population. • Population may be reluctant to remain in place. Perception may be that refuge is not capable of providing sufficient protection. • A sub-population might be reluctant to remain in place, if the rest of the population is evacuating to the surface [268]. • Needs management to ensure balanced use - if there are several refuges available to prevent overloading. • Placement of refuge(s) would need to ensure access irrespective of the location of the incident. • It would need sufficient capacity for the entire target population. • Its existence, use and access would need to be signed. • The use of a refuge would eventually require a safe egress route to be produced by emergency responders to allow occupants to evacuate.

243. These approaches may be included as part of a procedure. In addition, their relative robustness when employed against credible fire situations should also be examined. A number of factors influence fire scenarios – the materials involved, fire size, speed of development, location, etc. To demonstrate this type of qualitative analysis, only the location of the incident is examined here (see Table A1-B10). The performance of each movement measure is examined according to the relative vertical position of the population to the fire incident.

Table A1-B10 Applicability of egress route in relation to location of population

Provision	Location of population		
	Above fire	Same level	Below fire
Stair	Slow movement/ congestion may block those below. Potential for fatigue/trips over longer distances. Some mobility impaired remains in place. May feel discomfort given that other population is evacuating.	Potential exposure to fire effluent if congestion develops. Potential for fatigue / trips over longer distances. Some mobility impaired remains in place. May feel discomfort given that other population is evacuating.	Waiting required until incident controlled above them. Otherwise, population may be forced to move towards fire. Potential for fatigue/ trips over longer distances. Some mobility impaired remains in place. May feel discomfort given that other population is evacuating.
Lift / elevator	Congestion may develop in elevator lobby. Especially if priority given to those below and those with movement impairments.	Waiting in lobby may increase anxiety and increase exposure to incident. Challenge in managing access to elevator where access prioritization is in place and where incident is nearby.	Will require evacuating population being transported through incident floor. Waiting in lobby may increase (given prioritization, etc.) and then increase anxiety.
Refuge	Horizontal access. Should not affect other ascending evacuees on other levels.	Horizontal access. Congestion levels at refuge determined by distance to be covered to reach refuge, capacity of refuge access points and size of population using the refuge.	Horizontal access. Should not affect other ascending evacuees on other levels.

A1-B.4.1 Stairs

- **Search term**: stair* (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 51 700

244. Movement on a stair is more complex than that on the horizontal given the additional dimension of the movement involved, the potential for merging flows that approach from

multiple directions and the increased complexity of gait and motion on the stair itself [269]. As such, not only does the stair present a challenge as a means of egress, but it also increases the probability of trips and falls in comparison to movement on the flat [270].

245. The effectiveness of the stair is reliant on the way in which they are used. This initially relates to selection and use of the stair as a means of egress (influenced by the stair's affordance and familiarity with the route), the movement rates on the stair, the capacity of the stair to accommodate the evacuation demand placed on it, and the behaviours exhibited on the stair itself (e.g. spacing behaviour, overtaking, counter-flow, resting, lane formations, social/group behaviour, falls, handrail presence/use, etc.).

246. The traditional method to evacuate mid- to high-rise buildings is the use of stairs. The design of stairs may be based on different concepts [15]. Stair width may be designed in order to provide an adequate capacity in relation to the largest occupant load floor, or to accommodate the simultaneous evacuation of a given number of floors, e.g. 2–3 floors, given the case of a phased strategy. Different factors have been investigated, such as the design of the stairs in general, e.g., number of the stairs, stair width, staircase length, location in the building, etc. or their specific features, e.g., the slope of the stairs [271], the values for capacity on stairs [272], [273], the impact of occupancy levels on stairs [274], etc. It should be noted that the capacity of the stair is a combination of its physical design, the evacuation procedures and the behaviour/performance exhibited by evacuees when using them.

247. Stair design in relation to evacuation are reflected in building codes, e.g., Approved Document B, NFPA 101, International Building Code. Once met, the interaction between the evacuees and the physical stair design drive performance during the evacuation; e.g. ergonomics, motivation levels (and associated speeds), evacuee behaviour, etc. [272]. Role may also influence evacuation performance from a behavioural perspective. For example, the experiments carried out by Boyce et al.[275] showed that deference behaviours may arise during the evacuation process in stairs (e.g. male groups giving priority to women or groups with children, staff guiding other occupants, etc.), along with differences in movement rates along demographic lines (e.g. age, gender, etc.). It is expected that the impact of gender is linked to role and so as the gender / role alignment becomes reduces, so gender will become less of a behavioural predictor. The impact of gender on travel speed going forward is less clear.

248. Merging streams of evacuees in the floor-stair interface introduces an additional complexity. Flows may interact on the same level or join from different levels, making the negotiation of such interactions more challenging. The impact of merging behaviours can dictate the rate at which individuals join the stair, and the number of people on the stair at any one time. As such, it consequently affects the total evacuation time, who is in the queue waiting to join the stair, and where that queue is located. Galea et al. [276] suggested that in high-rise buildings, floors should be linked to the landing on the opposite side to the incoming stair to increase the efficiency of the flows. Boyce et al. discussed merging ratios (i.e. the proportion of people gaining precedence when two or more flows meet). Boyce et al. [275] performed experiments that show the merging ratio was approximately 50:50, irrespective of door configuration.

249. Stair evacuation can involve prolonged exertion. This becomes more of an issue with reduced fitness or deteriorating health. Fatigue is a factor that needs to be considered [277]. Investigations of actual accidents, [278], showed that evacuees may need to interrupt their journey due to fatigue, causing an additional delay in the evacuation process. This problem will become more evident over the years since the physical abilities of occupants is gradually reducing (due to changing demographics) [279]. This poses issues of individuals delaying movement due to the need to rest and the potential for them delaying the movement of others should this rest block their movement (should rest locations not be provided).

250. Stair evacuations present significant issues regarding people with health conditions or impairments – especially those using wheelchairs. Different evacuation problems have been analysed in the literature such as the ability of the occupants to use stairs with or without movement aids [280] the impact on evacuation of the formation of groups with their assistors or others [272], [281], the use of dedicated stair devices [282], [283], etc. (refer to Section A1-B.4.3 on movement devices). The range of impairments causes significant variation in the performance and behaviours of evacuees using a stair. The Americans with Disabilities Act (ADA) in buildings (ADA 2010) highlights the need for an adequate design taking into considerations all these issues which shall be an integral part of the safety design. Again, it should be noted that the ability of an individual to evacuate along a stair is not typically in isolation of other evacuees. Therefore, enhancing evacuation performance of individuals with impairments may have secondary benefits to those with them and those around them.

251. Stairs may be subject to counter-flows for various reasons (e.g. firefighter access, people returning to their flats, etc.) as noted by Kratchman [284], as evidenced in the evacuation of the World Trade Center [285].

252. The nature of the impact of stair design is most obviously apparent in the travel speeds that can be maintained. The SFPE Handbook presents a set of datasets collected to describe the travel speeds collected across different domains. These are not categorised by occupancy type given that stair designs are typically not driven by occupancy type – rather by expected demand. Undoubtedly, these are collected in different ways and reflect different situations. To give a sense of the impact stair use has on maintained travel speeds the compiled datasets are shown in Table A1-B11. These reflect the set of average indicators for each dataset examined (either the mean or median). This does not represent the full range of values in each case.

253. According to the data, there is a slight reduction in the travel speeds maintained while climbing the stairs (dropping from 0.64 m/s to 0.57 m/s). This should be compared against the travel speeds maintained on the horizontal (i.e. in a corridor).

Table A1-B11 Stair travel speeds by direction of movement

Parameter	Up	Down
Diagonal speed (m/s)	0.57 [0.3-0.83] n=22	0.64 [0.1-1.1] n=57

254. Bosina and Weidmann [238] compiled data from across a range of different sources to develop a relationship between various factors and achievable walking speed on stairs. In Figure A1-B14, the impact of increasing population density on walking speed can be seen, with increasing density levels reducing travel speed once a population density of 1 p/m^2 has been reached.

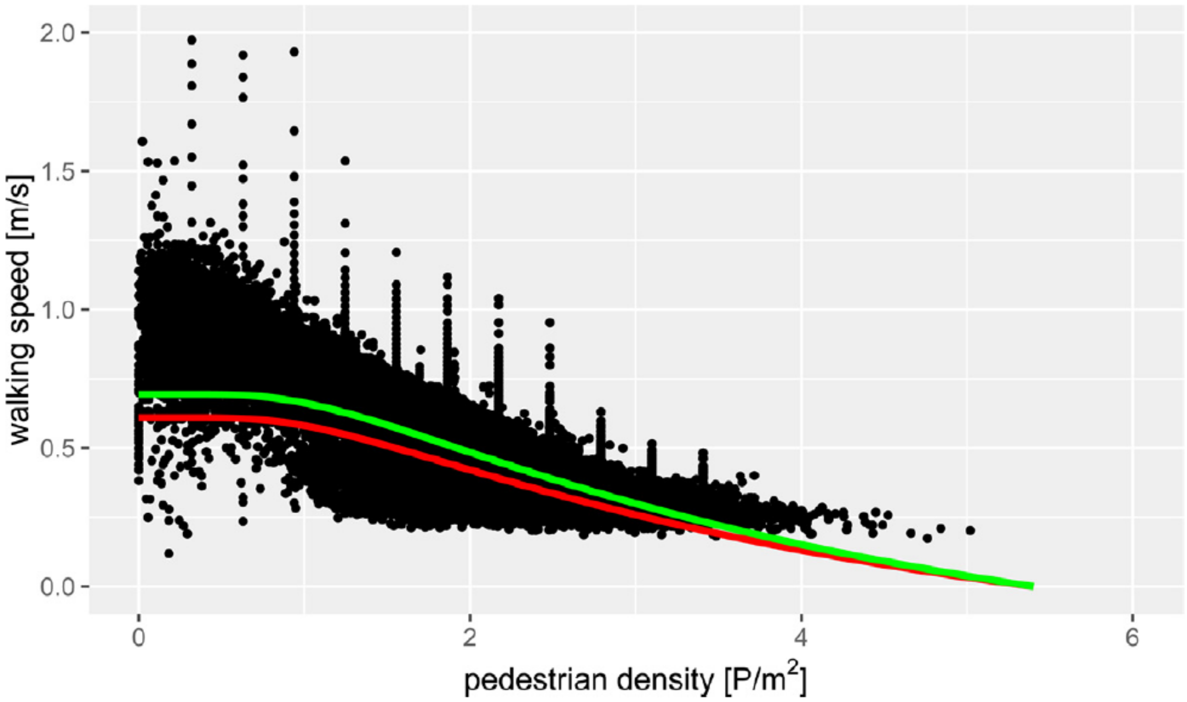


Figure A1-B14 Relationship between stair speed, population density and direction of movement, reproduced from Bosina and Weidmann [238] (green – down, red- up)

255. Similarly, Bosina and Weidmann [238] examined the impact of include on the achievable travel speeds (see Figure A1-B15). It is apparent that whether the individual is ascending or descending, travel speed reduces as the gradient of the inclination becomes more severe.

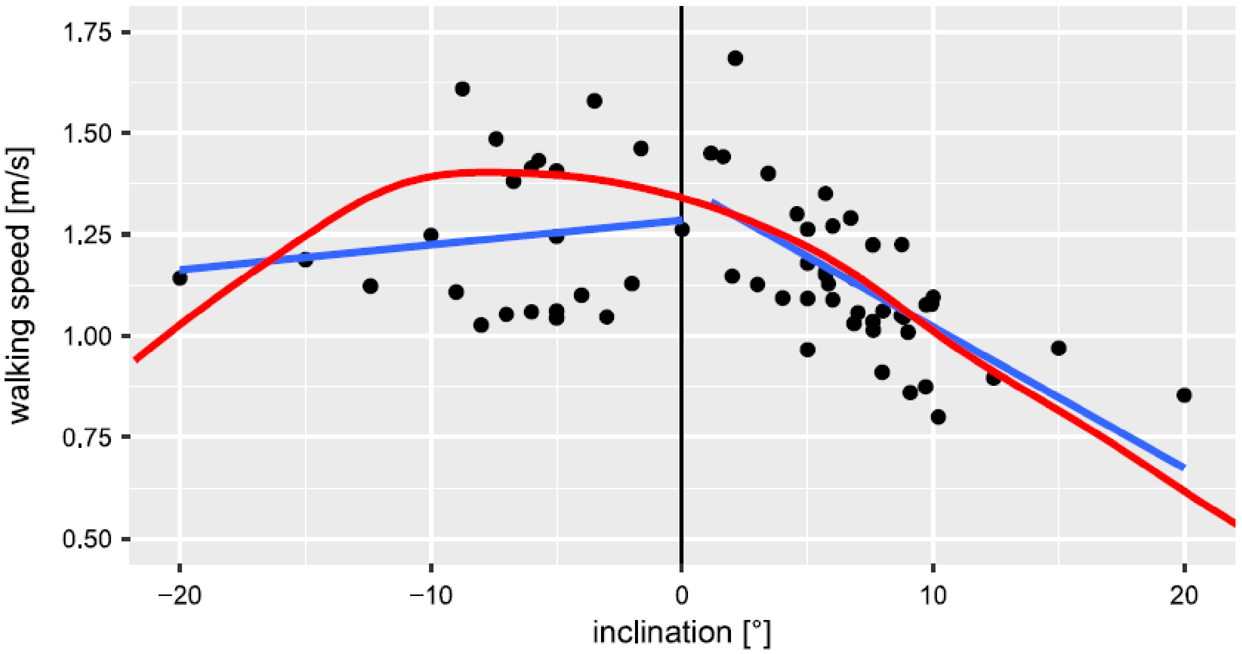


Figure A1-B15 Relationship between inclination and direction speed, reproduced from Bosina and Weidmann [238] (blue is new data, while red is existing data)

A1-B.4.2 Evacuation lifts

- **Search term**: ("evacuation lift" | "evacuation lifts" | "evacuation elevator" | "evacuation elevators") (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 193

256. Elevators move passengers between floors. In doing so, elevator performance is affected by a number of elements, passenger boarding, lift capacity, door opening/closing time, door width, the distance between floors / the number of floors, the number of lifts in operation, the lift speed / acceleration / deceleration, the dwell time (i.e. the default stationary time), and the procedure employed for it to move between the floors. The operation of the lift is also affected by population attributes beyond the lift manufacturer's/operators control (e.g. walking speeds, person footprint, arrival rates, population size, number of people in wheelchairs, level at which people join lift, number of people with luggage/objects, destination floors, etc.). Their use during an emergency will be reliant on them to withstand the fire conditions produced, the water produced in addressing the fire, the capacity to reconfigure use of the lift (either automatically or by a local member of staff inside the lift) and a protected power supply to support its use in emergency scenarios [15], [16], [286].

257. Depending on the environment, passenger, freight and emergency access lifts might be in operation. In specialist environments (e.g. hospitals), relatively complex elevator strategies might be employed ensure segregation due to contagious or vulnerable populations.

258. Elevators/lifts are not traditionally employed for emergency movement. The public has been advised through guidance and signage to avoid using lifts during fires. This history will

need to be addressed in any preparation or procedure to ensure that a resident population has sufficient confidence in their use during an emergency. However, with more effective protection and system design and an increased propensity of people in wheelchairs, emergency lifts become an alternative means of egress to stairs, assuming that the evacuation has some vertical component.

259. Tubbs commented: “*The use of elevators has historically been prohibited during fire emergencies. However, this philosophy is increasingly being reconsidered… [where] stairs may not be the best evacuation option for occupants with disabilities or debilitating health problems such as asthma or arthritis. Combined with post-9/11 concerns, the unique characteristics of such buildings has shifted the focus solely from phased and partial evacuation to the capability of full building evacuation, making elevators a critical part of the overall emergency egress system. With elevator-assisted evacuation now being allowed in several countries around the world, the subject bears a closer look*.” [287]

260. Zmud of NuStats produced a report (after the World Trade Centre 911 attacks) to investigate the level of fire safety knowledge of high-rise building occupants in the US [288]. 73% of residential participants and 80% of commercial participants thought that the use of lifts during an evacuation was never safe. In residential buildings on average 2% of participants thought that lifts were "usually safe" and 3% of participants thought lifts were "*as safe as using the exit stairs*" during an evacuation.

261. However, even where it was not intended where stair capacity is compromised they elevators might be used [286]. 250 occupants of the Cook County Administration Building (Chicago, US) were evacuated from a fire on the 36th floor. There were 16 lifts and two stairwells which spanned the entire building. The fire was on the 12th floor. Some occupants evacuated via elevators before the call had been announced as they had seen the fire. The call to evacuate went out eight minutes after discovery via a public address system that advised occupants to evacuate via stair and not elevator. Smoke entered the stairwells, blocking access for some evacuees. Six people died on the 20th–24th floors and in a stairwell. 54% of the respondents to the post-incident survey conducted by Proulx et al stated that they used elevators to evacuate despite warnings and previous training telling them otherwise.

262. Similarly, the Forest Laneway Fire (Ontario, 1995) occurred in a 30-floor apartment block containing 365 apartments, two stairwells and four elevators, occupied by an estimated 545 people. The fire started on floor 5 around 05:00 within an apartment living room. There were six fatalities. 219 survivors were surveyed. 162 (74%) respondents used elevators to evacuate with 157 doing so with rescue personnel. There were several unsuccessful attempts to use elevator to evacuate (prevented by smoke spread). The majority appeared to know that they should not use a lift during fire evacuations.

263. Fahy and Proulx [74] state that out of the 202 occupants that they interviewed initially in WTC1 who stated their means of egress, 3 used lifts at some point during their evacuation (excluding 22 occupants that were trapped inside lifts). Whilst discrepancies between the exact number of lift users in WTC1 exist it is evident that a small number of occupants used lifts during the evacuation. Other occupants decided that they knew they

should not use lifts during an evacuation but due to the long travel distance decided it was acceptable:

- “We got to the 78th floor and Judy said, “*Let’s see if the elevators are working. I’m thinking I shouldn’t be taking an elevator, but I* guess *the thought of walking down 78th floors in my high heels was not exactly something I wanted to do*.”

264. Such reports suggest that even though building occupants are aware of the common practice to not use lifts during evacuations, there are circumstances where they will use their own judgement to decide whether to use lifts or not [286].

265. The design of an egress strategy based on lift use should take into account not only the design challenges but also the behavioural factors and their impact on the effectiveness of evacuation strategies. For instance, the willingness of the occupants to use lifts instead of the stairs in relation to the floor where occupants are located when the evacuation starts [286], [289], [290].

266. Occupant perception an issue in lift use during an emergency given longstanding guidance not to use them. Levin and Groner [291] found that perceptions of lift reliability impacted individuals’ likelihood of using them during emergency situations. This is likely due to historical advice, but also in the perceived frequency of them malfunctioning (suggesting better and more visible routine maintenance). Findings indicate a linear relationship between floor level and willingness to use lift during evacuation between 5 and 60 floors. Findings indicate over 50% of occupants above the 40th floor are willing to use the lift to evacuate.

267. The provision of communication systems within the lift may enhance confidence – the capacity to quickly communicate with personal on the ground or responding [289]. It is speculated that either these systems are not typically in place or that residents are not familiar with their functionality. In addition, signage would need to accompany emergency lifts, especially where guidance had previously precluded their use. It would also need to inform / remind passengers of the use of the lift and procedural priorities; e.g. where those in wheelchairs are given priority within the emergency procedure, etc.

268. Kinsey et al. [292] examined the impact of varying stair/elevator egress on a 50-storey structure occupied with 7840 occupants, with strategies reflecting elevator availability (0-32 elevators), stair availability (0-4 stairwells), route selection (nearest, pre-determined). The most effective strategy was a combination of elevators and stairs (with suitable lift procedures) – 50% faster than stairs alone.

269. London Plan Guidance [293] suggests that evacuation lifts within residential buildings can be operated using three methods: driver assisted (evacuation under the control of an assistant who controls the lift from the car operating panel); automatic evacuation (the lift serves registered landing calls and automatically transfers occupants to the main evacuation exit floor); or remote assisted evacuation (driver assisted from a remote location). The guidance goes on to note that, in the absence of a competent person for driver assisted evacuation, an alternative method should be considered.

A1-B.4.3 Movement devices

- **Search term**: (“movement device” | “movement devices”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 44

270. The need for movement devices is reliant on the population demographics present in the property, the egress routes that must be traversed and the egress options available (i.e. those in the building and those available given the progress of the fire). As the UK’s population ages, has increased obesity issues and community medicine enables those with medical conditions and impairments to live in the wider community, so the likelihood for movement devices being needed and being employed during an evacuation will increase. Although not part of the building as such, they are indirectly required given the routes available in the building (e.g. stairs) and the alternatives that may be absent (e.g. refuge areas on the same floor emergency elevators, etc.).

271. A range of different devices are available, some of which are employed in multiple occupancy types (typically owned by the individual aided by the device, e.g. a walking stick). Others are fixtures of the building to aid emergency evacuation (e.g. evacuation chair located in a stairwell/refuge), while others are typically only used in facilities where large proportions of severely impaired (e.g. stretchers and mattresses in hospitals or care facilities). Given that larger numbers of people requiring movement assistance may live in residential blocks, these devices may appear and are therefore briefly discussed. It should also be noted that where devices are damaged, then other available devices (e.g. sheets/mattresses) available in a flat might be employed.

272. Movement devices can directly affect the movement rates achieved, egress routes used and (indirectly) the decision-making process as people will be aware of the effectiveness of the device and its influence on performance. Movement devices might be required for egress movement including horizontal and vertical components. The dimensions of the device may become important on (a) their access to certain routes (e.g. motorized wheelchairs and staircases), (b) the number of such devices that might occupy a refuge location, (c) the effort required to manoeuvre them around corners or through doors, and (d) their effect on movement along a route (e.g. can people overtake on a stair or corridor).

273. Those devices associated with an individual are most likely to appear in residential properties. These include walking sticks, crutches, walking frames, electric wheelchairs, manual wheelchairs, and rollators. In the most authoritative analysis of these devices, Boyce et al. conducted experiments on horizontal movement and on vertical movement of those with different types of devices. Average horizontal and vertical movement rates (from the work of Boyce [280], Sano [294] Jiang [295], Shields et al. [296], Lavender [297], [298], Adams [282] and Kuligowksi [105] are shown in Table A1-B12 and Table A1-B13.

Table A1-B12 Average horizontal movement speeds

Movement device	Unassisted speed (m/s)	Assisted speed (m/s)
Crutch	0.87 [Jiang]	
Crutches	0.94[Boyce] 0.78 [Jiang]	
Walking stick	0.81 [Boyce]	
Walking frame	0.57 [Boyce]	
Wheelchair	0.69 [Boyce] 1.35 [Brand] 0.72 [Shields]	1.30 [Boyce] 1.1 [Shields]
Electric wheelchair	0.89 [Boyce] 1.85 [Brand]	1.5 [Boyce]

274.It is apparent that different devices produce different travel speeds across horizontal and vertical movement. This relationship is complex such that some devices benefit from or require operators, while others produce significantly different performance on the flat and stair. This latter point might be due to the complexity of stair movement in conjunction with the range of impairments that require assistance. It should also be noted that some of these devices if stored in public spaces will take up floorspace and may limit capacity (e.g. wheelchairs).

Table A1-B13 Average vertical movement speeds

Movement device	Unassisted speed (m/s)	Assisted speed (m/s)
Crutch	0.22[Boyce] 0.43 [Jiang]	
Crutches	0.33 [Jiang]	
Walking stick	0.32 [Boyce] 0.23 [Kuligowski]	
Walking frame	0.16 [Boyce]	
Wheelchair		0.13 [Boyce] 0.25 [Kuligowski] 0.32[Shields]

Movement device	Unassisted speed (m/s)	Assisted speed (m/s)
Evacuation chair		0.81 [Adams] 0.86 [Lavender] 0.66 [Lavender] 0.69 [Lavender] 0.82 [Lavender] 0.26-1.11 [Sano] 0.21 [Kuligowski] 0.83 [Hunt]
Carry chair		0.57 [Adams] 0.34 [Lavender] 0.75 [Lavender] 0.58 [Hunt]
Drag sheet		0.62 [Adams] 0.67 [Hunt]
Fabric seat		0.45 [Lavender]

275.Hunt et al. reviewed data on performance rates produced by devices less-commonly used in residential properties or were operated in accordance with hospital requirements [299] (see Table A1-B14).

Table A1-B14 Average performance elements associated with hospital movement devices. All activities require assistance, reproduced from Hunt [299], Alonso [300] and Adams and Galea [282]

Movement device	Horizontal speed (m/s)	Vertical speed (m/s)	Preparation time (s)
Stretcher	1.1 [Adams] 1.0 [Hunt]	0.55 [Adams] 0.5 [Hunt]	78 [Hunt]
Drag sheet	0.9 [Adams] 0.89 [Hunt]	0.62 [Adams] 0.67 [Hunt]	65
Bed	0.40 [Alonso]		
Evac chair	1.46 [Hunt]	0.83 [Hunt]	33 [Hunt]
Carry chair	1.50 [Hunt]	0.58 [Hunt]	42 [Hunt]

276. Such devices also require a different number of (likely skilled) operators to assist in their use and movement. For instance, for stair movement stretchers require four two operators, evacuation char requires one operator, carry chair requires 2-4 operators (depending on the staff involved), and rescue sheets require two operators [299]. This requirement of staff to operate such devices may preclude their use in residential buildings.

A1-B.4.4 Other means of vertical escape (escape windows, ladders etc.)

277.As discussed below, there have been and continue to be a wide range of means to provide vertical escape [301]. Several of these methods date back to the inception of taller buildings in the 19th century with some modern updates being proposed. Whether such devices have any practical merit over the use of stairs and lifts is a matter of debate that began almost as soon as they were implemented [17]. This report briefly mentions some of these alternatives but not to a high level of detail.

A1-B.4.4.1 Roof hatch

- **Search term**: (scuttle | "roof hatch") (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 3 490

278. A roof hatch or ‘scuttle’ was one of the earliest alternative means of escape required by building codes. For example, in 1852 in Brooklyn all buildings had to have “*a scuttle or place of egress in the roof*” [302]. The scuttle was not to be less than three feet by two feet (0.91 m by 0.61 m).

279. Other than references mentioning the provision of roof hatches in buildings there appears to be no further information on their impact on evacuation.

A1-B.4.4.2 Ladders

- **Search term**: ladder (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits**: 52 100

280. When conducting the literature search many of the references identified work on the use of ladders by the fire and rescue services. This report does not specifically this aspect as such ladders are not be part of the physical measures within a building that affect evacuation.

281. The use of external ladders fixed to a wall of a building as a means of escape from taller buildings became prevalent in the US during the latter part of the 19th century [259]. However, the practicality of using these measures was questioned by some observers especially given the manner in which they were installed and the expectations of people to be able to use them.

282. Straight or angled ladders were used in conjunction with balconies to provide an external escape route. These were said to have been common in New York before 1900 but criticism was levelled that “*women, children, the aged, and the disabled could not use them*” [259] and could potentially expose evacuees to the fire as they tried to escape. As an example, the types of garments worn by women at the time made escape by such means a difficult prospect. Further discussion on balconies is given in Section A1-B.3.4.

283. In the 1881 report of the Franklin Institute in Philadelphia [17] following fires in mills they noted that stairways should be the preferred means of escape from a building as it

"…*is usually broader and easier to descend than any special contrivance such as a ladder, probably ten times as many persons can escape*…". The report goes on further to discuss the merits (and lack of) various ladder arrangements.

A1-B.4.4.3 Windows

- **Search term:** window* (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 148 000

284. Under certain circumstances windows can be used as an alternative means of escape to internal evacuation routes [303]. Typically, only windows on the ground or first floor of buildings provide a viable means of escape. The distance of the window ledge above the ground presents a fall hazard to occupants [304], and even relatively fit occupants using a ground floor window can end up falling as they negotiate a window-type opening [125].

285. The ability of occupants to use a window will depend on a number of factors including the dimensions of the window, the height of the sill above the floor and the physical capabilities of the occupants. In the work by Frantzich [125] he measured the number of people (in this case students) passing per second through windows of various heights and widths (Table A1-B15). In each case the window ledge was 1.2 m above the ground.

Table A1-B15 Number of persons per second passing through windows, from Frantzich [125]

Window height (cm)	Window width (cm)				
	50	60	70	80	90
90	0.37	0.47	0.51	0.56	0.42
80	0.28	0.33	0.40	0.47	0.47
70			0.27	0.34	0.42
60		0.17	0.20	0.24	0.34

286. Jones et al. [305] describe their work on teaching children emergency fire escape procedures which included having participants climb onto a table close to a 91.4 cm x 105.7 cm window from which they could escape. It appears the work did not consider whether the safety of using a window was viable in terms of the potential fall hazard.

287. As noted by Wermiel [259], windows have been used as a means to access ladders, external balconies, ropes and chutes.

A1-B.4.4.4 Escape chutes

- **Search term:** chute* (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 10 300

288. The concept of using a chute for means of escape from tall buildings is not a new idea and have been in existence since before the 1880s. Recommendations by The Franklin

Institute in Philadelphia [17] states "*The objection to the chute form of apparatus is that it is an unusual means of egress in which terrified people could place no confidence*".

289. Proposals for escape chutes, slides and similar occur in the literature in which more modern rigid or flexible materials are suggested [306] over the traditional cloth designs used in the 19th century. Zhang [307] suggests that using slides would result in a much faster vertical evacuation time than would be achieved using stairs. Whether such devices would be practical for high-rise residential buildings and the range of occupants that would be expected to live is such buildings would seem to be debatable [306].

A1-B.4.4.5 Ropes etc.

- **Search term:** rope* (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 56 300

290. Similar to ladders and chutes, the idea to install ropes or other similar devices as a means of escape from a building were proposed in the 19th century, with similar concerns expressed at the time [259]. Ropes might be in the form of a single coil with knots in it through to rope ladders.

291. More recently there have been proposals to install controlled descent devices that allow individuals to abseil down the outside of a building [306]. Clearly such devices impose certain expectations on the user that might not be appropriate for a broad range of building occupants.

A1-B.5 Firefighting

A1-B.5.1 Fire mains and hydrants

- **Search term:** ("fire main" | "fire mains") (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 366

- **Search term:** ("fire hydrant" OR "fire hydrants") (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 4 760

292. Fire mains are located within the building and provide a means for the fire and rescue service to connect hoses for water supply. Typically, they are provided either in the form of 'dry' or 'wet' mains. A dry fire mains is usually kept empty and supplied through a hose via a fire and rescue service pumping appliance, whereas wet fire mains are kept full of water and supplied by dedicated pumps and tanks in the building development [308]. Wet mains are more commonly considered in 'tall' buildings, to help provide adequate water pressure at higher storeys [309].

293. Hydrants are generally located externally to the building and can be used to either assist the fire and rescue service in attacking the fire directly from the appliance, or they

can be used to direct water supply to the building fire mains (e.g., a dry riser). As noted in PD 7974-5 [310], *“water supplies for manual firefighting are usually provided from hydrants, either those of the water authority fitted on street mains, or private hydrants installed by the building owner or developer”*.

294. The provision of fire mains and hydrants assists the fire and rescue service in attacking a fire in the building. The subsequent impact of this is that fire growth and spread can be limited, or the fire is extinguished entirely. Therefore, for any occupants located within the building as the fire and rescue service attack the fire, this provision of hydrants / fire mains could indirectly support their evacuation. Occupant evacuation could require direct assistance from the fire and rescue service, as observed in the work of Kuligowski et al. [105], and thus conditions within the building, along with fire and rescue service availability, will influence this process.

295. PD 7974-5 [310] notes that fire and rescue services might have different preferences for fire mains locations, e.g., whether they are located within the stair or within a protected lobby or corridor. PD 7974-5 goes on to suggest *“according to an on-scene risk assessment, this [lobby / corridor mains] could enable firefighters to lay initial attack hose-lines from the fire floor itself, reducing the likelihood of smoke infiltrating into the firefighting stairwell”*. The location of fire mains can therefore impact on tenability conditions within the building, which may subsequently affect occupant escape.

296. The water flow density available to firefighters will have a direct consequence on their ability to adequately attack a fire. Grimwood and Sanderson [311] note a direct correlation between the amount of water deployed during early fire development and the resultant building damage. The implication is therefore that insufficient water supply in the early stages of a fire could result in a greater extent of fire spread, potentially impacting the evacuation of building occupants later.

A1-B.5.2 Firefighting lifts

- **Search term:** ("firefighting lift" | “firefighting lifts” | “fire-fighting lift” | “fire-fighting lifts” | “fire fighting lift” | “fire fighting lifts”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 28

- **Search term:** ("firefighting elevator" | “firefighting elevators” | “fire-fighting elevator” | “fire-fighting elevators” | “fire fighting elevator” | “fire fighting elevators”) (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 24

297. Many of the benefits, attributes and variants associated with firefighting lifts overlap with those of evacuation lifts, discussed in Section A1-B.4.2. However, unlike evacuation lifts, firefighting lifts are not primarily intended to assist with the means of escape of occupants.

298. The main purpose of a firefighting lift is to provide firefighters with quicker (and less physically intensive) access to floors throughout a building, without requiring usage of the stairs. Mellor [312] notes that *“as early as 1930, it was recognised that firefighters should be provided with a means of swift access to the upper floor of large buildings”*. Mellor goes on to note that *“modern firefighting techniques involves the use of equipment that needs to be moved by means of lifts”*. This is supported by Kuligowski [313], whose building-specific case study indicates that firefighting lifts have the potential to reduce the time for firefighters to ascend to the 33rd floor of a building by 15 to 30 min.

299. Despite their use not being dedicated to means of escape of occupants (unlike evacuation lifts), firefighting lifts may be used by the fire and rescue service to undertake rescue operations and assist occupant escape. For example, PD 7974-5 [310] notes that *“different fire and rescue services have different operational procedures regarding the use of fire-fighting lifts for disabled evacuation”*.

300. Firefighting lifts may automatically ground upon some form of smoke or heat detection [314], or they may be provided with an ‘override’ or ‘priority’ switch, to recall the lift and initiate firefighter service [263]. In this case, once this switch is operated, the lift is effectively eliminated for general building use.

301. Depending on the jurisdiction and operational procedures, the firefighting lift can be in a dedicated lift (or stair) lobby or, alternatively, could be in a common corridor or stair [312]. However, there have been some suggestions that lifts could be included externally to the building, to reduce the possibility that they become compromised by smoke or heat [315]. An alternative means of protecting the lift from smoke ingress is to consider lift shaft and / or lobby pressurisation through the use of mechanical ventilation [314].

A1-B.5.3 Smoke clearance

- **Search term:** "smoke clearance" (fire* | smoke) (house* | dwelling* | flat* | apartment* | residential | domestic) (egress | escape | evacuation) -wild*
- **Google Scholar hits:** 83

302. In BS 9999 [148], smoke clearance is separated from smoke control in that smoke clearance is specifically “designed *to remove the products of combustion following a fire and used at the discretion of the fire and rescue service to assist fire-fighting operations”*. BS 7346-4 [316] refers to smoke clearance as *“where smoke is exhausted from a building after the fire has been supressed”*. Therefore, this section refers exclusively to these types of systems, differentiating them from smoke control systems discussed in Section A1-B.1.8. Despite this, most of the content described for smoke control will overlap with that of smoke clearance.

303. Unlike smoke control, smoke clearance does not necessarily provide a direct benefit to building occupants during means of escape. One reason for this is that it is often manually operated, for example by the fire and rescue service after the fire has been extinguished (as acknowledged in BS 9999 [148]). However, this activation can still support escape to

some extent by clearing the affected spaces of smoke after the fire, particularly if the building continues to be evacuated following fire extinguishment.

304. As with smoke control, smoke clearance can be provided in the form of natural vents or some form of mechanical alternative. In some cases, day-to-day ventilation (i.e., systems not designed specifically for fire) can be used to assist in smoke clearance. Short et al. [317] propose that *“as a general observation, if natural ventilation is viable when dealing with day-to-day heat gains and fresh air requirements, it is likely that such a system will operate effectively in exhausting heat and smoke from a fire.”*

305. The principles in the design of many smoke clearance provisions can be consistent with smoke control. However, there are certain provisions that may be better suited to clearing smoke following a fire than limiting smoke spread during a fire. One example of this is jet fans, where jet fans are used to mix or dilute contaminated air and / or direct this air towards extract points [318]. Enright [319] suggests *“Outside of tunnel applications jet fans are considered to have limitations as a means of smoke control. This is because their effectiveness is limited without side walls and they de-stratify the smoke layer. Jet fans can however, aid post-event in smoke clearance under the control of the attending fire brigade.”* However, in a modelling case study of a car park, Enright indicates that jet fans are not necessarily detrimental to conditions during means of escape. Merci and Shipp [320] suggest that jet fans *“can be useful to ‘wash out’ difficult zones (e.g., stagnation zones)”*.