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Research and analysis

Evacuation from fire in high-rise residential buildings: a rapid evidence review

Published 24 November 2022

Applies to England

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This publication is available at https://www.gov.uk/government/publications/evacuation-from-fire-in-high-rise-residential-buildings-a-rapid-evidence-review/evacuation-from-fire-in-high-rise-residential-buildings-a-rapid-evidence-review

Acknowledgements

The authors (Nathan Hudson, Mehul Kotecha, Alison Beck and Georgia Lucey of NatCen) and the Home Office Research team would like to express thanks to Professor Steve Gwynne and Dr Lynn Hulse for peer reviewing the report. We would also like to thank members of the means of escape in blocks of flats technical steering group, which is led jointly by the Home Office and the Ministry of Housing, Communities and Local Government (MHCLG) (now called Department for Levelling Up, Housing and Communities), for their input into the study.

Executive summary

Background

Following the Grenfell Tower fire on 14 June 2017 an independent review of building regulations and fire safety was published (MHCLG, 2018). This was followed by Phase 1 of a public inquiry, which was published in October 2019 (Grenfell Tower Inquiry, 2019). These reports outlined several recommendations, including that the Government develop national guidelines for carrying out partial or total evacuations of high-rise residential buildings.

In March 2020, the Home Office commissioned the National Centre for Social Research (NatCen) to produce a synthesis of existing academic evidence regarding fire evacuation in high-rise residential buildings. The findings of this review will contribute to the ongoing work to develop national guidance for evacuation strategies.

Aims and objectives

The review aimed to summarise the existing academic evidence on evacuations from high-rise residential buildings in the UK and assess the strength of the evidence. It also sought to identify any weaknesses and gaps in the current

evidence base and answer the following research questions:

- what are the most effective methods of evacuation from fires in high-rise residential buildings
- how do occupants make decisions about fire evacuation from high-rise residential buildings
- how do firefighters make decisions about evacuating occupants from high-rise residential buildings

Method

This review was undertaken using a rapid evidence assessment (REA) design. The REA comprised three key stages:

Literature searching stage to identify the nature, availability and range of evidence relevant to the research questions.

Critical evaluation stage to evaluate the quality of evidence.

Extraction and synthesis stage to extract and summarise data thematically.

During the critical evaluation stage, studies were scored using a weight of evidence tool developed by NatCen to assess relevance to the research question and quality of research. Once scored, approximately 60 studies were prioritised for full review by a panel of researchers based on the weight of evidence score and contribution to the evidence base.

Scope of the review

The Home Office is responsible for fire and rescue services in England, but relevant evidence from the UK and other international evidence was included in this review. The review focused on peer reviewed academic research published since 1985, to ensure identified UK research was published in line with the building regulations brought into law that year, through to July 2020 when the review took place. Given the anticipated limited UK-specific academic evidence base the review includes non-UK research, and some research relevant to non-high rise and non-residential settings.

While the international evidence promotes learning from other fire evacuation scenarios, the transferability of international and non-residential evidence must be considered particularly in relation to differences in the design and layout of UK high-rise residential buildings and the impact this may have on fire evacuations.

This rapid evidence review does not consider operational guidance and it acknowledges that the transferability of findings from the academic research may be limited due to a range of factors such as differences in building design, building maintenance and regulations.

The review did not cover guidance from fire and rescue services or any other organisation on fire evacuations from high-rise residential buildings in the UK, including the use of a ‘stay put’ strategy and lifts during evacuations. It is important to note that National Fire Chiefs Council (NFCC) and stakeholder led simultaneous evacuation guidance was issued in October 2020 and has subsequently been updated.

Key Findings

Limitations of the evidence base

Overall, the review found that there is limited evidence focused specifically on fire evacuation in UK high-rise residential settings. The vast majority of available academic research is international, with only a handful of studies providing UK-based evidence. Furthermore, while few studies provided information to assess transferability of findings to UK high-rise residential settings, the limited UK-specific evidence did corroborate international findings, suggesting a certain degree of transferability. However, most evidence identified in this review offers insight into different elements of evacuation strategies, rather than a comprehensive assessment of evacuation strategies from high-rise residential settings.

It should be noted that no studies identified mention a ‘stay put’ strategy. While some inference can be taken from North American studies that mentioned ‘defend in place’ (sometimes referred to as ‘stay-in-place’) this is a different evacuation strategy that places different expectations on residents. Findings should also be considered with this in mind.

What are the most effective methods of evacuation from fires in high-rise residential buildings?

The review found the availability of evidence on effective methods of fire evacuation in high-rise residential buildings is significantly limited. However, the body of evidence suggested that when evacuation is necessary no single strategy is universally appropriate for high-rise residential buildings. Instead, every high-rise residential building should have a fire evacuation plan individual to each building, developed in full consideration of the building design, taking into account the composition of occupants and, crucially, the presence, or indeed absence, of effective compartmentation.

Considering the limited evidence base, the findings of this review tentatively suggest that, when evacuation is necessary and effective fire safety arrangements such as compartmentation are in place, phased and partial evacuation strategies (such as ‘defend-in-place’ and ‘delayed evacuation’) are safer than simultaneous evacuation (the studies did not consider differences in when simultaneous evacuation could take place) within high-rise residential settings.

The evidence also identified the importance of delayed evacuation for those unable to evacuate unassisted, and the need to ensure exit routes and refuge areas are safe and effective. The success of phased, partial and delayed evacuation strategies, however, depends on effective compartmentation and other building design features, as well as good communication systems to provide occupants with sufficient and ongoing information.

International modelling and simulation studies (no UK studies were identified) suggested the use of fire-safe lifts can reduce overall evacuation time in high-rise buildings, depending upon the number of floors, and the number and composition of occupants. However, the extent to which these findings apply to real-fire scenarios, and indeed specifically to UK high-rise residential settings is unclear.

Most of the available evidence that addressed the effective evacuation of vulnerable groups, focused on older residents and residents with limited mobility and visual impairment.

How do occupants make decisions about fire evacuation from high-rise residential buildings?

Due to a lack of robust evidence, a limited amount of specific evidence covers occupant decision-making during high-rise residential fires. While the study of occupant decision-making during high-rise residential fires is well established, much is based on small-scale survey and qualitative studies. Caution must therefore be taken when considering the findings, particularly if seeking to generalise to wider populations or to other high-rise residential buildings.

Collectively, UK and international evidence suggested occupants do not immediately evacuate upon recognising fire cues. Both UK and international studies also suggested occupants of high-rise residential settings are reluctant to use lifts during fire evacuation. In a UK context, this chimes with the NFCC 'stay put' position statement (https://www.nationalfirechiefs.org.uk/Stay-Put-position) which generally states that stairs should be used instead of lifts if occupants need to evacuate (NFCC 2020).

How do firefighters make decisions about evacuating occupants from high-rise residential buildings?

There is a significant lack of published academic peer reviewed evidence on how firefighters make decisions on evacuating occupants from high-rise residential buildings in the event of a fire. Of the limited evidence available, most is international and focused on the decision-making of firefighters in general, rather than specifically in high-rise residential settings.

Future research and evidence gaps

While the findings from this review provide some insight into fire evacuation in high-rise residential buildings, the ability to identify the most effective methods of evacuation is limited by a paucity of high-quality research and an evidence base largely developed in non-UK settings. An important contribution of this review is therefore the identification of significant and wide-ranging evidence gaps, which would need to be addressed in order to improve the peer reviewed academic evidence base.

These include:

- research that directly compares the effectiveness of different evacuation strategies in UK high-rise residential settings
- research on the effectiveness of lifts for fire evacuation within UK high-rise residential settings
- research on UK high-rise residents' willingness to use lifts during fire evacuation upon instruction
- research on the effective evacuation of vulnerable groups from UK high-rise, residential settings. This includes residents with reduced cognition, residents with small children, residents with English as an additional language, and residents' potentially limited knowledge of evacuation procedures, such as those who are short-term, un-tenured or guests
- research on firefighters' decision-making regarding the evacuation of

occupants within UK high-rise residential settings

1. Introduction and methodology

1.1 Background

Following the Grenfell Tower fire on 14 June 2017 an independent review of building regulations and fire safety was published (MHCLG, 2018). This was followed by Phase 1 of a public inquiry, which was published in October 2019 (Grenfell Tower Inquiry, 2019). These reports outlined several recommendations, including that the Government develop national guidelines for carrying out partial or total evacuations of high-rise residential buildings.

In March 2020, the Home Office commissioned the National Centre for Social Research (NatCen) to provide a synthesis of existing academic evidence regarding fire evacuation in high-rise residential buildings. The findings of this review will contribute to the ongoing work to develop national guidance for evacuation strategies.

1.2 Aims and objectives

The review aimed to summarise the existing academic evidence on evacuations from high-rise residential buildings in the UK and assess the strength of the evidence. It also sought to identify any weaknesses and gaps in the current evidence base and answer the following research questions:

- what are the most effective methods of evacuation from fires in high-rise residential buildings
- how do occupants make decisions about fire evacuation from high-rise residential buildings
- how do firefighters make decisions about evacuating occupants from high-rise residential buildings

This review also sought to identify evidence relating to the evacuation of

residents with individual and situational vulnerabilities in the event of a fire. This included residents with reduced mobility or cognition, older residents, residents with small children, residents with English as an additional language, and short-term / un-tenured / guests of residents with potentially limited knowledge of evacuation procedures.

All other aspects and circumstances around fire evacuation should be considered outside the scope of this review for example evidence regarding the technical specification of high-rise buildings, or the use of fire-resistant building materials.

1.3 Method

This review was undertaken using a rapid evidence assessment (REA) design (Government Social Research Service, 2014). The primary purpose of a REA is to provide a robust, systematic synthesis of available evidence, within a limited timeframe. REAs achieve this by undertaking most of the steps of a full systematic review; however, these steps are shortened, simplified or omitted, and require a strict scope definition for inclusion or exclusion of evidence.

This REA comprised three key stages:

- **literature searching stage** to identify the nature, availability and range of evidence relevant to the research questions
- **critical evaluation stage** to evaluate the quality of evidence
- **extraction and synthesis stage** to extract and summarise data thematically

1.3.1 Stage 1: literature searching stage

The first stage sought to identify existing evidence to address the research questions in line with the broad inclusion criteria. Due to suspected low volume of evidence, this string was designed to be both broad and inclusive in order to identify as many potentially relevant studies as possible. An example of the string search applied is outlined below.

> **Example search string**
>
> (TITLE-ABS-KEY (fire OR fires OR flames OR conflagration OR fireball*

> OR blaz* OR)) AND (TITLE-ABS-KEY (evacuat OR exit* OR leav* OR escap* OR quit* OR flee* OR decamp* OR depart*) W/3 (building* OR apartment* OR flat OR flats OR hous* OR “tower block” OR high-rise OR “high-rise” OR skyscraper OR tenement* OR residence* OR residential OR accommodation OR dwelling* OR habitation)) AND PUBYEAR > 1984 AND (LIMIT-TO (LANGUAGE , “English”))

1.3.2 Stage 2: critical evaluation

Having completed the literature searching stage all identified pieces of evidence were screened and assessed to determine relevance and quality. This was done in two phases: title and abstract screening, followed by the screening of full-text.

Title and abstract screening

Abstrakr software was used to read titles and abstracts or executive summaries in order to rapidly identify potentially relevant items of evidence. Again, due to suspected low volume of relevant evidence, this stage was broad and inclusive in order to identify as many potentially relevant studies as possible. Duplicates were then removed and full documents were retrieved for all those available.

Full-text screening and evidence assessment

Full-text screening was undertaken to assess and score each document for relevance (out of 7) and robustness (out of 2) in accordance with a weight of evidence tool. The research team developed this tool according to a prioritisation heuristic, which gave higher scores to studies if they: (1) presented UK data; (2) focused specifically on high-rise and/ or residential settings; and (3) provided insight into vulnerable groups. Evidence was also rated for methodological robustness, as described in Table 1.

Table 1: Weight of Evidence Tool

Relevance (Total out of 7)	Robustness (Total out of 2)
High-rise: **Score 2** - the evidence specifically relates to high-rise buildings (≥6 storey or ≥18m) **Score 1** - the evidence is	**Score 2** - Research design is explicit and considered, including: · Clear, explicit statements and rationale behind sampling, data collection, assumptions, study comparison, modelling approach (+1) · Methods are considered, both appropriate

Relevance (Total out of 7)	Robustness (Total out of 2)
unclear but, relates to buildings of any type, in general **Score 0** - the evidence does not relate to high-rise buildings	and reliable (+0.75) · No obvious bias that is likely to influence research objectivity and/or study findings (+0.25)
Residential: **Score 2** - the evidence specifically relates to residential buildings **Score 1** - the evidence is unclear but relates to buildings of any type, in general **Score 0** - the evidence does not relate to residential buildings	**Score 1** - Research design is explicit but less considered, including: · Explicit but incomplete/limited design information, with limited rationale behind sampling, data collection, assumptions, modelling approach (+0.5) · Methods are appropriate and reliable but with concerns over approach (+0.25) · Potential bias (+0.25)
Vulnerable group: **Score 1** - the evidence applies to those with vulnerabilities **Score 0** - the evidence does not apply to those with vulnerabilities	**Score 0.5** · Unclear robustness or uncertainty on how to rate evidence · Evidence reviews (as do not draw on primary evidence)
Country: **Score 2** - the evidence specially relates to buildings in the UK **Score 1** - the evidence is not specific to the UK and relates to international buildings	**Score 0** - Research design is not explicit and/or considered · No discussion of or rationale behind sampling, study comparisons, modelling approach, data collection · Inappropriate methods and significant reliability issues · Clear bias · Thought pieces or editorials

Evidence selection and prioritisation

Due to the relatively fast pace with which a REA is conducted, the maximum number of studies included for synthesis was limited to approximately 60 with the exact figure dependent on screening outcomes. An additional prioritisation process was necessary to ensure all research questions and subjects of

interest were addressed, and to avoid the duplication of evidence. Selection of these studies was undertaken in several iterative stages.

All UK studies were selected to be included in the review. The remaining studies were split by relevance to each of the research questions and ranked according to the weight of evidence score. Studies were then selected from the top of each list and a panel of researchers qualitatively assessed them in terms of contribution to the research questions and findings duplication. This meant that duplicate studies using similar methodologies and with similar findings were excluded, such as multiple papers that covered similar or the same evacuation modelling scenarios.

As some studies covered more than one research question, they will have appeared in multiple lists but at different rank relative to the other studies addressing each respective question. Inclusion of these studies, and the paucity of research available for particular research questions, meant that the number of studies included to address each research question varies considerably.

As a result of this prioritisation, some studies with relatively lower weight of evidence scores are included in this review. This is particularly the case for areas of limited evidence, such as firefighter decision making. All prioritised studies scored at least 4 out of 9.

1.3.3 Stage 3: Data extraction and synthesis

Having identified evidence to be included, the key information from each document was extracted and summarised. This was completed using a data extraction tool based on the NatCen Framework approach for data management, whereby evidence is systematically summarised using analytical matrices (‘charts’) that represent each of the key research questions. Each matrix comprised of rows representing the reviewed evidence, and columns, representing sub-issues within each area. These charts are provided in Appendix 3.

At the literature searching stage 2,008 potentially relevant studies were identified. After title and abstract screening, this reduced to 498 studies. Full texts were not available for some identified studies. This was due to sources of title and abstracts not linking to full text, or a lack of (often commercial) access. Of all the studies not accessible to the research, the vast majority were international in focus and based on modelling and simulation. No studies inaccessible to the research team presented UK data, as indicated by title and abstract.

Duplicates were then removed and full documents were retrieved for all those available. This resulted in 398 studies to be prioritised and assessed for

inclusion. In total, 65 studies were prioritised for synthesis based on the evidence score. Appendix 1 describes the 65 selected studies, outlining their country-focus (where possible), broad methodology, key findings and weight of evidence score. Appendix 2 lists some additional studies that were identified as potentially relevant but were not prioritised for synthesis, based on the selection process.

Of the 65 studies 21 were evidence reviews, 20 of which included evidence from multi-country settings. Of the remaining 44 studies, 17 provided evidence via modelling and simulation and 27 presented evidence from primary research. Of these 27 primary studies, 19 presented data from qualitative and/or small-scale survey research from the UK (3), USA (5), France (1), Canada (2), China (1), Hong Kong (3), Japan (1), Sweden (1), Egypt (1), and 1 across multiple countries (UK, New Zealand and Sweden). Five studies presented data from field research undertaken in Canada. The remaining three studies included multi-country fire evacuation case study research, analyses of data from fire drills in Canada, and content analysis of UK firefighter video footage.

Table 2 gives an overview of the weight of evidence scores for the papers prioritised for review, scoring for ‘effective evacuation’, ‘occupant decision’, ‘firefighter decisions and ‘overall’, with scores of 4 to 9 available. This review synthesises multiple studies from key (co)authors, including Dr Guyléne Proulx, Michael Gerges and Professor Daniel Nilsson.

Table 2: Weight of evidence scores for papers prioritised for review

Score	Overall	Effective evacuation	Occupant decision	Firefighter decision
4 to <5	16	9	6	4
5 to <6	23	17	10	1
6 to <7	13	9	6	1
7 to <8	12 5	9	-	
8	1	1	1	-
9	-	-	-	-

Score	Overall	Effective evacuation	Occupant decision	Firefighter decision
Total papers	**65**	**41**	**32**	**6**

1.3.4 Scope of the review

The Home Office is responsible for fire and rescue services in England, but relevant evidence from the UK and other international evidence was included in this review. The review focused on peer reviewed academic research published since 1985, to ensure identified UK research was published in line with the building regulations brought into law that year, through to July 2020 when the review took place. Given the anticipated limited UK-specific evidence base the review includes non-UK research, and some research relevant to non-high rise and non-residential settings.

While the international evidence promotes learning from other fire evacuation scenarios, the transferability of international and non-residential evidence must be considered particularly in relation to differences in the design and layout of UK high-rise residential buildings and the impact this may have on fire evacuations. This rapid evidence review does not consider operational guidance and it acknowledges that the transferability of findings from the academic research may be limited due to a range of factors such as differences in building design, building maintenance and regulations. A National Fire Chiefs Council (NFCC) led stakeholder group provides simultaneous evacuation guidance in instances of fires in high-rise residential buildings.

1.4 Structure of the review

The findings of this review are presented in four chapters as synthesises of evidence related to each research questions:

- Chapter 2: **What are the most effective methods of evacuation from fires in high-rise residential buildings?** This includes evidence on the design and implementation of overarching evacuation strategies, and specific components of evacuation, including processes for alerting residents, wayfinding, and building exit.
- Chapter 3: **How do occupants make decisions about fire evacuation from high-rise residential buildings?**

- **Chapter 4: How do firefighters make decisions about evacuating occupants from high-rise residential buildings?**
- Chapter 5 discusses the findings and conclusions.

Evidence on the evacuation of vulnerable groups is discussed in relevant parts of the report.

2. What are the most effective methods of evacuation from fires in high-rise residential buildings?

Key findings

- due to a significantly restricted evidence base, the extent to which this review can identify effective methods of fire evacuation in UK high-rise residential settings is limited and the associated research question cannot be comprehensively answered
- however, the body of evidence suggested that when evacuation is necessary no single strategy is universally appropriate for high-rise residential buildings. In general, international evidence suggested, when evacuations are necessary and effective fire safety arrangements such as compartmentation are in place, phased and partial evacuation strategies (as 'defend-in-place' and delayed evacuation) are safer than simultaneous evacuation within high-rise residential settings
- international modelling and simulation studies suggested fire safe lifts can reduce overall evacuation time in high-rise buildings. The extent to which these findings apply to real-fire scenarios, and specifically to UK high-rise, residential settings, however, is unclear
- there are significant evidence gaps regarding the effective evacuation of vulnerable groups. Of that which is available, the majority focus on older residents, and residents with limited mobility and visual impairment
- the evidence strongly states that every high-rise building should have a fire safety plan, available to residents, which describes fire-related building features and the actions expected of occupants in the event of a fire

This chapter synthesises evidence on the first research question: What are the most effective methods of evacuation from fires in high-rise residential buildings? There was not sufficient evidence to answer the research question comprehensively. This chapter provides a synthesis of best available evidence, presenting a predominately descriptive overview of broad evacuation strategies and components relevant to high-rise, residential settings generally. This chapter also briefly discusses planning for evacuation. The extent to which these strategies can be applied to the specific nature and design of high-rise residential buildings in the UK is unclear.

2.1 Evidence quality

Forty-one studies were identified that provide evidence on either evacuation strategies or components of effective evacuation. Based on the weight of evidence tool that assessed relevance and quality of the studies, the majority scored between 4 and 6 out of 9. Fifteen studies scored over 6 out of 9. Many of the studies are based on focussed qualitative studies and small-scale quantitative surveys comprising small base sizes which means findings need to be treated with caution, as does to generalising findings to different situations, building designs or applying them to wider populations.

Of the studies identified, very few explore overarching strategies of evacuation in high-rise residential settings. Studies which explored strategies provided predominately descriptive insight, offering very little comparative evidence of effectiveness. Furthermore, very few studies presented UK evidence, or provided information to assess the transferability of findings to UK settings. For example, findings may not be transferable to typical building designs in UK settings (e.g. implementation of fire-safe lifts and the number of staircases).

Of the available evidence that addresses the effective evacuation of vulnerable groups, most focused on older residents, and residents with limited mobility and visual impairment. Significant evidence gaps therefore exist regarding the effective evacuation of the majority of vulnerable groups including: residents with reduced cognition; residents with small children; residents with English as an additional language; and residents with potentially limited knowledge of evacuation procedures, such as those who are short-term, un-tenured or guests.

2.2 Strategies for fire evacuation in high-rise, residential buildings

Seven studies were identified that provide limited evidence of the effectiveness of fire evacuation strategies for high-rise residential buildings. Most of the evidence identified was provided by four studies, none of which presented UK-specific data. Much of the evidence from this section derives from: a review of evacuation design for high-rise buildings (Lay, 2007); an international evidence review on fire evacuation modelling (Ronchi and Nilsson, 2013); a modelling study focused on occupant decision making during high-rise evacuation (Groner, 2016) and a study of intelligent evacuation systems of high-rise buildings in India (Kulkarni and Agashe, 2016). Based on the weight of evidence tool, the majority (five) of the seven studies included in this section scored between 4.5 and 5.5 in relation to relevance and quality. One study a score of 7 out of a possible 9 (McConnell and Boyce, 2015) reached, and another scored 8 (Proulx, 1999).

Collectively, the evidence identified three overarching strategies relevant to fire evacuation in high-rise residential settings: **simultaneous evacuation, phased evacuation, and partial evacuation**, which includes **'delayed evacuation'** and 'defend in place'. These types of evacuations as defined within these studies are set out in 'Evacuation definitions' below. No study referred to 'stay put' strategy.

> **Evacuation definitions**
>
> - **evacuation:**
>   the direction of people from a dangerous place to somewhere safe
> - **defend-in-place:**
>   (sometimes referred to 'stay-in-place' in North American literature): a strategy which seeks to minimise the number of people evacuating by instructing occupants to remain in their homes, close and seal doors, and do not evacuate unless directed
> - **delayed evacuation:**
>   a process in which occupants who need assistance to evacuate wait to be rescued in designated refuge areas
> - **simultaneous evacuation:**
>   a strategy in which all occupants vacate the building at the same time

regardless of what threat they are exposed to prior to evacuation

- **phased evacuation:**
  a strategy in which only occupants who are at an elevated risk are initially evacuated (such as those in the immediate vicinity of the fire), while others remain in place for later evacuation
- **partial evacuation:**
  a strategy in which only a proportion of occupants are immediately evacuated, while others move to or remain in a place or area of safety
- **stay put:**
  a strategy in which all residents not directly affected by a fire are expected to remain in their flat

2.2.1 Simultaneous evacuation

Simultaneous evacuation is a process in which all occupants vacate the building at the same time, regardless of what threat they are exposed to prior to evacuation. The evidence collectively suggested simultaneous evacuation is not generally a viable strategy in the evacuation of high-rise residential buildings (although the studies did not consider the different scenarios of when simultaneous evacuation may be used in a residential context). This is due to escape provisions being unlikely to accommodate all occupants simultaneously (Lay, 2007). Physically moving occupants during simultaneous evacuation was also considered to take a long time, particularly for occupants of higher floors, and can cause congestion and ‘bottlenecks’ on escape routes (Ronchi and Nilsson, 2013; Groner, 2016, Kulkarni and Agashe, 2016 and Lay, 2007). This is known to potentially increase the risk of occupants encountering dangerous levels of smoke, fire and/or toxic gas (ibid).

2.2.2 Phased evacuation

Phased evacuation is a process in which only occupants who are at an elevated risk are initially evacuated (such as those in the immediate vicinity of the fire), while others remain in place for later evacuation (Lay, 2007). As described by Ronchi and Nilsson (2013), the benefits of a phased evacuation include the ability to optimise the flow of evacuees, and minimise congestion by decreasing queuing time. It is also thought that phased evacuation can enable the prioritisation of most vulnerable and/or at-risk occupants, such as by evacuating those on or near floors where the fire has occurred (Ronchi and Nilsson 2013; Groner 2016; Kulkarni and Agashe, 2016).

Lay (2007) suggested phased evacuation is a common approach applied to tall commercial buildings, through which the fire floor and the floor above (and sometimes also the floor below) are initially evacuated. However, the success of this approach is considered to rely on measures to prevent rapid fire spread, including sprinklers, compartmentation, and a high level of fire safety management (Lay, 2007). Ronchi and Nilsson (2013) supports this view, identifying the importance of pre-planning and assurances that building regulations are upheld to promote compartmentation.

There is some evidence that phased evacuation can reduce overall evacuation time when compared to simultaneous evacuation, predominately through reducing the possibility of congestion in corridor and stair areas. However, in an evidence review of human behaviour in burning buildings, Proulx (2003) suggested occupants are likely to resist to phased evacuation and prefer to evacuate immediately. Lay (2007) identifies occupant reluctance as a key risk of a phased evacuation strategy, suggesting that the approach relies heavily on occupants doing as they are instructed, even if they see smoke. Effective communication systems are therefore considered an important component of phased evacuation, in order to provide ongoing information and reassurance to building occupants (ibid). This is further discussed below.

2.2.3 Partial evacuation, including ‘defend-in-place’ or ‘delayed evacuation’

Partial evacuation is a process in which only a proportion of occupants are immediately evacuated, while others move to or remain in a place or area of safety. The evidence suggested there are two main variants of partial evacuation: ‘defend-in-place’ (sometimes referred to as stay-in-place in North America literature) and ‘delayed evacuation’.

Described as a more detailed variant of phased evacuation and a “cornerstone of residential evacuation” (Lay, 2007: p.493), **defend-in-place (sometimes referred to as stay-in-place in North American literature)** is a process which seeks to minimise the number of people evacuating by instructing occupants to remain in their homes, close and seal doors, and not to evacuate unless directed.

As described by Lay (2007), much of the rationale underpinning ‘defend-in-place’ relies on an understanding of evacuation processes for occupants who are not immediately confronted by evidence of a fire (i.e. hear fire alarms or witness smoke). The author suggested that while occupants in the immediate vicinity of a fire will likely evacuate immediately, others at less immediate risk may take time to gather clothing, possessions and loved ones.

This delay, in combination with other factors, gives the fire opportunity to spread

which could compromise common areas and risking the likelihood of safe evacuation. It is therefore considered safer for occupants not at immediate risk to stay in their apartments, which are intended to act as sealed, ventilated compartments away from the fire.

Having reviewed North American evacuation procedures for high-rise buildings including residential settings, Proulx (2001a) suggested that in certain high-rise conditions ‘defend-in-place’ can be safer than simultaneous and phased evacuation. However, the author, suggested the approach should only be used when:

- a building is at least 6 storeys in height, since evacuation of low-rise buildings is usually faster in terms of travel distance
- occupants are in enclosed compartments, with access to a telephone and a window or balcony to identify their location
- self-closers are installed on all entry doors
- a central alarm system is present to warn occupants of the occurring fire
- a voice communication system is in use to inform occupants of the fire, and provides information on the evolution of the event, giving them tips on protective activities they should carry out

Ronchi and Nilsson (2013), in an evidence review of human behaviour in fires, also stresses the importance of good communication before and during defend-in-place, suggesting the strategy can fail if residents are not provided with regular information and updates that reassure them to remain in their apartments.

Delayed evacuation is a process in which occupants who need help to evacuate wait to be rescued in designated refuge areas (Ronchi and Nilsson, 2013; Kulkarni and Agashe, 2016). The evidence provides little rationale for delayed evacuation, other than suggesting it may promote a more efficient evacuation by allowing those who can vacate without support to do so first. McConnell and Boyce (2015) however, using findings from a survey of 116 disabled people living in Northern Ireland, found there was little awareness of how to use refuge areas in the event of a fire within residential and commercial settings, and concerns around being forgotten and overcrowding. To improve the effectiveness of delayed evacuation McConnell and Boyce (2015) suggested that refuge areas need communication and ongoing reassurance to encourage occupants to await rescue.

Overall, as discussed by Groner et al. (2016), while the broad strategies of full,

phased and partial evacuation provide some categorisation in evacuation approach, they are likely over-simplified in the academic literature. The authors therefore suggested that a combination of strategies should be implemented during high-rise residential fire evacuation, which considers not only building design but also distinct groups of occupants.

2.3 Components of effective evacuation

Besides providing evidence on evacuation strategies, identified studies also explored specific components of evacuation, including processes for alerting residents, wayfinding, and building exit. Including the seven studies mentioned in the previous section, 39 others were identified that also provide evidence of the components of effective evacuation. Based on the weight of evidence tool most studies (25) scored between 4 and 5.5 in relation to relevance and quality, one-third (13) scored between 5.5 and 7, and only one study (Proulx, 1999) scored 8 out of a possible 9.

Alerting and instructing occupants

The evidence suggested fire and/or smoke alarms play an important role in the evacuation of high-rise residential buildings in alerting both those in immediate and peripheral risk of a fire. However, the placement of alarms was an important consideration within high-rise residential settings. Proulx (1996) for example, using evidence from a survey of people living in Canada who had experienced a fire in a residential high-rise building, suggested that when fire alarms are situated in corridors rather than individual apartments, occupants living in corner apartments, and older occupants, were less likely to hear them.

As presented in Table 3, some studies outlined a wide range of factors that can affect the audibility of fire alarms. Much of this research, however, came from field studies undertaken in high-rise residential settings in countries such as Canada and Hong Kong, and provided little detail on the settings in which they were undertaken. The extent to which their findings are directly transferable to a UK high-rise residential context is therefore unclear.

Table 3: Factors identified as affecting alarm audibility

Factor affecting audibility	Details	Evidence
Building layout	Occupants less likely to hear alarms in corridors and more likely hear alarms if they are in apartments.	Proulx (1995) - experiment observing evacuati Canadian apartment buildings during a simulat emergency. Proulx (1996) - postfire survey of occupants th a fire in Canada. Proulx (1994) - experiments involving a fire eva four mid-rise apartments in Canada.
Occupant characteristics and behaviour	The elderly and those with hearing impairments less likely to hear fire alarms and may rely on neighbours to alert them. Occupants tampering with their fire alarm (e.g. covering them up) if they had a lot of false alarms in the past. Occupants wrongly assuming fire alarm is an error or test.	Proulx (1996) - post-fire survey of occupants th survived a fire in Canada. Lo et al (2000) - post-fire survey conducted wit in two high-rise Hong Kong apartments. Wong et al. (2009) - survey of 327 high-rise res building occupants in Hong-Kong.

Factor affecting audibility	Details	Evidence
What occupants are doing at time of fire	Sleeping occupants less likely to hear fire alarms. Occupants that are using drugs or are drunk may not respond to an alarm.	Proulx (2003) - international review on human burning buildings. Proulx (2001a) - North American evidence revi factors impacting on human behaviour in fire.

Using findings from a multi-country evidence review and a field fire drill study on the evacuation of 307 participants from a high-rise public building in Canada, Proulx et al. (2000) and Proulx and Laroche (2003) suggested three temporal fire alarm signal patterns, comprising of a pulsed audio signal repeated after 180 seconds, should promote recognition of fire alarms and action from residents.

However, a lack of UK-specific evidence makes it unclear whether these are a current or possible feature of UK high-rise, residential settings. Further evidence (Chapter 3) suggested that even when fire alarms are audible and recognised by occupants, this may not be enough to ensure appropriate evacuation responses.

Proulx (1999), in an assessment of high-rise residential fires in Canada, suggested voice communication systems providing clear instructions tailored to the fire situations can be valuable in ensuring residents take appropriate action to evacuate high-rise buildings. In an international evidence review on information required to convince people to use a lift during evacuation in high-rise buildings, Nilsson and Jonsson (2011) found that despite voice communication systems being widely proposed, there is very little research to test their effectiveness.

This review reinforces this finding, which did not find any UK or international evidence, within scope, comparing voice communication to non-voice communication systems within high-rise, residential settings.

2.3.1 Occupant wayfinding

Some evidence was identified that explored components that can assist wayfinding during high-rise residential evacuation. Much of this research is international and/or based on modelling and simulation. Therefore, the extent of transferability to real life fire evacuation scenarios in UK high-rise, residential settings is unclear.

Following a field study conducted in a high-rise office building in Canada, Proulx et al. (2000) suggested photoluminescent (light emitting) material can be effective in guiding occupants evacuating via low-lit or dark stairwells. Kinateder, et al. (2019), in a simulated emergency evacuation using virtual reality with 24 people, also found participants consider green as the most appropriate colour for signposting exit routes, when compared to red, yellow, blue, magenta and white. Olander et al. (2017) provided supporting evidence using a small-scale paired comparison questionnaire study of 46 students at a university in Sweden, found that not only should signage be green, but should also have red flashing LED markings for dissuasive signage. This was true for all emergency evacuation scenarios.

The authors also found no notable differences between the written text ‘EXIT’ or a running man pictogram. Similarly, Andrée et al. (2016), in a virtual reality experiment exploring the exit choice of 72 participants in a high-rise, hotel building, found a green flashing light at the emergency exit sign influences exit choice and can increase the proportion of people choosing evacuation lifts as their first evacuation choice. A key limitation of this body of research, however, is that findings are based on simulated evacuation scenarios. The extent to which these findings apply to real-life evacuation of high-rise residential settings in the event of a fire is therefore unclear.

Besides promoting wayfinding through improving effective signage, some studies suggested providing occupants with real-time information about fire conditions can improve evacuation. Through modelling two fire scenarios in a 32-storey building, Kodur et al. (2020) found evacuation time can be reduced by up to 35% when providing occupants with real-time information regarding the fire location, growth and spread, and information regarding available and blocked exits.

Scenario 1 is based on occupants using the nearest egress path to find a stairway is blocked. Scenario 2 is based occupants being equipped with awareness of the blocked stairwell and immediately seeking an alternative route. However, it is unclear the extent to which these findings apply outside of hypothetical modelling scenarios and consider occupant demographics and the practicality of providing situational awareness information to evacuees.

Some studies provided examples of situation awareness alert systems that can be used during high-rise building evacuations. These included: a radio frequency device system with pre-programmed exit routes to track occupants and notify them of the safest evacuation route (Rahmen et al. 2012); and a system that provides occupants with the best evacuation route according to real-time changing fire conditions, the person's location, and their personal characteristics (such as mobility impairments, age) (Atilia et al. 2018).

While testing in a 10-story high-rise building in Turkey, Atilia et al. (2018) found that although evacuation time using their intelligent systems was longer, outcomes were safer through the avoidance of (simulated) toxic gas, heat, and thick smoke. A key limitation of both these systems, however, is the reliance on individual occupants wearing the necessary tracking devices, and a lack of testing in real-life fire scenarios.

2.3.2 Occupant movement

As outlined below, this review identified a significant amount of evidence on the movement of occupants during fire evacuation in high-rise buildings, much of which focused on the use of stairs and / or lifts. The majority also only provided generic descriptions of buildings, such as 'multi-storey', 'high-rise' and 'super tall'. Furthermore, no studies presented UK-specific evidence, limiting the transferability of findings to UK high-rise residential settings.

It is therefore important to note that while these findings have potential relevance for new buildings in the UK, not all current buildings in the UK have lifts and those that do might not be to the standard required for evacuation during fire.

As described by Ronchi and Nilsson (2013), stairs have long been considered the traditional method to evacuate high-rise buildings. International literature, however, suggested that the need for faster and more efficient forms of evacuation has resulted in fire safe lifts being an increasingly viable evacuation option (ibid).

Andrée et al. (2016) suggested several reasons for this, including an international increase in demand and desire for taller buildings, and greater acknowledgement of the difficulties faced by those with limited mobility and other disabilities during the vertical evacuation, and the impact occupant fatigue can have on overall evacuation time. Proulx (2004) also suggested lifts are more likely to be considered for high-rise evacuations in future, due to the predicted increases in older, overweight and disabled populations.

Several studies explored the ability for occupants with reduced mobility to evacuate high-rise buildings using stairs. Following a comparison of fire drill

data covering 22,000 mobility impaired and non-mobility impaired people across a mix of office and residential buildings, Peacock et al. (2016) found stair movement time to be slower in buildings that housed older and mobility-impaired people.

Kuligowski et al. (2015), in an experiment with 45 older and disabled residents living in a 6-storey assisted living facility in the US, also identified the importance of firefighters providing direct assistance to those unable to evacuate independently.

These studies suggested the most efficient means of evacuating occupants with mobility impairments in this scenario was having two firefighters (one in front, and one behind) assisting via a stair-chair. Some evidence (Chapter 3), however, suggested occupants have general low awareness and reluctance to use evacuation equipment.

Further evidence explored visually impaired occupants' use of stairs during evacuation. In an experiment evacuating 40 visually impaired participants from two-and three-story buildings in Sweden, Sørensen and Dederichs (2015) found occupants who were less severely visually impaired could evacuate at a similar speed to those who were not visually impaired if accompanied by others within a crowd.

Evacuee speed was however, slower depending on the severity of visual impairment, and if occupants had a guide dog or a mobility stick. The extent to which these findings apply to UK high-rise residential settings, however, is unclear.

In line with these findings, there is evidence that lifts are essential for occupants of high-rise buildings who cannot evacuate via stairs (Kulkarni and Agashe, 2016). Koo et al. (2013), in a comparative simulation study of evacuation strategies for people with disabilities in a 24-story building, for example, found that when wheelchair users evacuated by lift and non-wheelchair users evacuated via stairs, overall evacuation time decreased by at least 21.5%.

Besides aiding occupants who experience difficulty or cannot evacuate high-rise buildings using stairs, some studies suggested the lifts can greatly increase the speed of vertical evacuation in general. These studies are summarised in Table 5.

Table 4: Key findings of studies which modelled the use of lifts for high-rise evacuation

Study	Method	Key finding
Min and Yu (2013)	Evacuation simulation of 100 people from the 10th floor of a high-rise building.	Overall, using lifts results is overall a faster method of evacuation; however, the speed of evacuation decreases when the number of evacuees increases due to the increased number of round trips and waiting time.
Sharma et al. (2008)	Risk assessment of the use of lifts in emergency fire evacuation using a Multi-Objectives Decision Analysis (MODA) approach.	Combining stair and lift evacuation (75% and 25% respectively) was comparable to 100% lift or 100% stair evacuation in terms of safety and speed.
Kinsey et al. (2012)	Simulations of full building evacuation scenarios based on a hypothetical 50 floor building with four staircases and 7,840 agents.	Combined stair lift evacuation times can be as much as 50% faster than stair only evacuation time.
Wong et al. (2005)	Computational evacuation models simulating the total building evacuation of a ‘super-high- rise’ building.	A combination of stair evacuation and lift evacuation, the total building evacuation time can be reduced significantly.

Siikonen and Hakonen (2002), through comparative modelling of evacuation strategies, provides a rare crucial distinction between high-rise office and residential settings of various height. The findings suggested that the number of floors and occupants, and the proportion of occupants using lifts, are crucial in determining whether lifts can reduce overall evacuation time (ibid). The authors suggested that within ‘typical’ residential buildings (defined as having less than 50 floors and a population of less than 200 per floor), stairs are the fastest means of evacuation.

For example, they suggested that within a residential building with ten floors, evacuation of half of the population using stairs can take between 4 to 17 minutes compared to lifts which takes about 24 minutes. They also suggested lifts can reduce evacuation time in residential settings if used by a small proportion of occupants. This study, however, did not specify the number of staircases used.

Some supporting evidence for Siikonen and Hakonen (2002) was found in Proulx et al. (2009) and Kulkarni and Agashe (2016). The findings of these evidence reviews suggested that, in general, occupants of lower floors in the building will evacuate faster by using the stairs and that occupants on upper floors in tall buildings will evacuate faster using the lifts.

However, despite this body of evidence that overall suggests lifts can decrease evacuation time in high-rise buildings, all were based on modelling and simulation. The extent to which these findings may apply to real-fire scenarios, and specifically to UK high-rise, residential settings, is therefore unknown.

The review did not identify any evidence that specifically explored the use of lifts for fire evacuation in UK high-rise, residential settings. The only UK examples of lifts being used during fire evacuation provided in the evidence was in the BT Tower, the Shard and Canary Wharf (Wood et al. 2005; Proulx et al. 2009), but these examples were only mentioned briefly, with no supporting information.

Despite international evidence suggesting that the use of lifts may reduce evacuation time in certain settings, some studies stated that lifts must only be used during a fire evacuation if they are appropriately protected. This included the use of power feeders, protected lobbies, adjacent stairwells, concrete-filled, permanent steel shutters, advanced control mechanisms, smoke detection/evacuation and sprinkler systems (Lay 2007; Kulkarni and Agashe, 2016).

In line with this, Chen et al. (2011) cited evidence that suggests lifts used during a fire must be designed to prevent smoke inhalation and protected from the water of fire hoses. Ronchi and Nilsson (2013) also identifies the risk of smoke getting into the lift, and suggested measures need to be taken to avoid ‘the piston’ effect (i.e. smoke being forced into the lift as it moves through the shaft). The extent to which these features are currently included, or can be included, in lifts within UK high-rise residential settings, however, is unclear.

Some evidence also identifies the importance of protecting lobbies from smoke in order to safeguard those waiting to make use of lifts, including those in refuge areas. In a risk assessment of the use of lifts in emergency fire evacuation using a MODA approach, Sharma et al., (2008) reported that the risk of using lifts may reduce when lift lobbies are double-protected with fire doors and interim lobbies, due to reducing fire hazard exposure and ensuring the reliability of lift operational mechanisms.

Some studies identified several ways to optimise the use of lifts during fire evacuation in high-rise residential buildings. As discussed by Bärlund et al. (2005), a paper that focuses on the underpinning logic of simultaneous

evacuation, lifts should have pre-programmed ‘emergency modes’ that activate during a fire to maximise traffic handling capacity and avoid reliance on manual dispatching.

More specifically, Proulx (2004) suggested programming lifts to: first dispense occupants to the ground floor, then go to the fire floor and take those people to the ground or sky bridge floor (lift platforms connecting two high-rise buildings). Lifts should then go to the floors adjacent to the fire floor if occupants pressed the call button. Then lifts should visit all other floors above the fire floor (since they are at higher risk than those on floors below the fire).

Bärlund et al. (2005) also suggested buildings should have fire-proof ‘every day-use’ lifts, as opposed to lifts dedicated to evacuation, to ensure occupants are familiar with how to use them. The extent to which these features are present or possible within UK high-rise residential buildings, however, is unclear. Furthermore, some evidence suggests occupants typically avoid using lifts. This is discussed throughout Chapter 3.

2.3.2.1 Refuge areas

Some evidence suggested refuge floors can be a useful tool in fire evacuation in high-rise residential buildings. As described by Williamson and Demirbilek (2010) in an evidence review on the use of lifts and refuge floors during fire evacuations in Australia, this is through supporting the evacuation of people with mobility difficulties and offering a resting place for occupants fatigued from descending flights of stairs. Evidence from Hong Kong describes how refuge floors can also act as a command point for firefighter teams (Wood, 2007), and pick-up floors for evacuation lifts (Wood et al. 2005).

Through a survey of 116 disabled people living in Northern Ireland, McConnell and Boyce (2015) found low awareness of how to use refuge areas in the event of a fire, and occupant concerns around overcrowding and being forgotten. The findings from this study therefore suggested refuge points must be big enough to accommodate wheelchair users, must provide seating for those who are fatigued and/or may have difficulty walking or standing, and must be equipped with a means of providing regular communication and reassurance (ibid). Lay (2007) provides further evidence on the design of refuge spaces, suggesting: not less than 0.5 square metre per person, separation by 120-minute fire resistance from the fire floor; provision of smoke ventilation; communications systems; connection to both evacuation lifts and a stair core; and should be lit to a typical day-to-day standard.

Several studies also suggested that refuge areas should be linked to exit stairs (Kulkarni and Agashe, 2015; Chow et al. 2013), with one study specifying that these should be external to the building (McConnell and Boyce, 2015). No

studies included in this review provided any information to assess the design or use refuge areas specifically within UK high-rise, residential settings. The transferability of these studies' findings is therefore unclear.

2.3.2.2 Self-rescue equipment and sky bridges

A few studies explored the use of self-rescue equipment during fire evacuation in high-rise buildings. Examples include parachutes, slides and zip wires, amongst others. Ronchi and Nilsson (2013) suggested the use of self-rescue during evacuation was met with "almost universal scepticism" suggesting research often lacks technical details on how they could work in practice. This is reinforced by Lay (2007), who suggests these systems were considered unlikely to play a significant role in the evacuation of occupants in real buildings.

In line with this, evidence of the effectiveness of self-rescue equipment is limited. Zhang (2017) proposed using an external spiral slideway in a figure-of-eight shape to evacuate a building from the outside. Simulation tests on humans found participants did not become dizzy, and the authors' theoretical calculations indicated that the device would be a quicker mode of evacuation than descending via stairs.

Using this equipment, however, is reliant on the availability of sufficient outside space. Similarly, Mateev et al. (2018), through modelling use of a range of self-rescue equipment in a high-rise hostel in Russia, found self-rescuer bars and rescue fixed ladders improved evacuation within the first seven minutes. The extent to which these findings apply to real fire evacuation scenarios, and the design of UK high-rise residential settings, however, is unclear.

Some identified evidence suggested using sky bridges to aid fire evacuation in high-rise buildings. Much of this evidence, however, does not specify use in residential settings and was applied to undefined 'super-tall' settings. In a review of evidence exploring evacuation options for tall buildings in high-rise cities in countries like China and Japan, Wood et al. (2005) suggested skybridges are most effective when placed approximately halfway up buildings, in order to minimise vertical travel distances.

Case study research focused on two 57-story buildings, Chow et al. (2013) suggested skybridges can greatly reduce evacuation time when compared to stairs. For example, in a 57-story building with 7,500 occupants, evacuation by stairs can take 43 minutes 13 seconds, compared to 16 minutes 15 seconds using a skybridge, which has less congestion and quicker occupant movement.

The authors also suggested skybridges with stairs and lifts to provide additional evacuation routes for occupants, especially when the fire is on a lower floor, and sky-bridges positioned next to refuge areas to provide mobility-impaired

people with an alternative exit route, rather than waiting for rescue. No identified studies provided any information to assess the transferability of these findings to UK high-rise, residential settings.

2.4 Planning for an evacuation

While the identified evidence points to several strategies and components of evacuation, the overall weight of evidence suggested evacuation plans need to be made, and specifically tailored to: the building design, the composition of residents, and the needs of the specific fire situation (Ronchi and Nilsson 2013; Groner 2016). As such, the evidence strongly stated that every high-rise building should have a bespoke fire safety plan available to residents, describing fire-related building features and the actions expected of occupants in the event of a fire.

This plan should be prominently displayed in buildings, updated regularly, and implemented regularly in fire drills. This is particularly important because the evidence suggested that not only are residents likely to have significantly varied levels of preparedness but may also express reluctance to certain forms and methods of evacuation. This is discussed throughout Chapter 3.

3. How do occupants make decisions about fire evacuation from high-rise residential buildings?

> **Key findings**
>
> - due to a lack of evidence, the extent to which this review can provide specific insight into occupant decision-making during UK high-rise fires is limited
> - the identified evidence largely suggested occupants do not immediately evacuate upon recognising fire cues, but rather first checked to validate risk, gather belongings, and communicate with other residents

- some studies suggested occupants of high-rise residential settings are reluctant to use lifts during fire evacuation. In a UK context, this chimes with the NFCC 'stay put' position statement (https://www.nationalfirechiefs.org.uk/Stay-Put-position) which generally states that stairs should be used instead of lifts if occupants need to evacuate

This chapter synthesises identified evidence relating to the second research question: How do occupants make decisions about fire evacuation from high-rise residential buildings? Due a restricted evidence base, the extent to which this review can provide specific insight into occupant decision-making during UK high-rise residential fires is limited.

This chapter therefore provides a synthesis of largely international evidence into occupant decision-making during the fire evacuation of high-rise, residential buildings, with some specific insight into UK populations. It begins by outlining a framework for understanding occupant decision-making, it then synthesises evidence at two key stages of evacuation: pre-evacuation and during evacuation.

3.1 Evidence quality

Thirty-two studies were identified that provide evidence on occupant decision-making during fires. Based on the weight of evidence tool that assessed relevance and quality of the studies, the majority (22) scored between 4 and 6 out of 9. Ten studies scored over 6 out of 9. The findings of this review suggest that while the study of occupant decision-making during high-rise residential fires is well established, much is based on small-scale qualitative and survey research and is undertaken outside the UK. The limited UK-specific evidence identified, however, corroborates international findings, suggesting some transferability.

3.2 How occupants make decisions

As outlined by Kinsey et al. (2019), in their evidence review on the influence of cognitive biases on resident responses to evacuation, early research focused

on the perception that occupant decisions were often because of irrational 'panic'. Findings from more recent research, however, suggested panic is rarely seen in fires (Fahy and Proulx, 2009), suggesting occupants are instead "adaptive and cooperative decision-makers sensitive to the information available" (Kinsey et al, 2019: p.466).

In line with this, studies largely suggested occupant decision-making is characterised by the consideration of several factors, including occupant characteristics (e.g. their demographics, knowledge and experience, personality etc), building characteristics (including layout and complexity) and the specific fire situation. Proulx (2001b) outlined characteristics in an evidence review on the factors affecting human behaviour in fire, summarised in Table 5.

Table 5: Factors affecting human behaviour in a fire

Occupant characteristics	**Building characteristics**	**Fire characteristics**
Profile	**Type of building**	**Visual cues**
· Gender	· Residential	· Flame
· Age	· Non-residential	· Smoke (colour, thickness)
· Ability		
· Limitations		
Knowledge and experience	**Fire safety features**	**Olfactory cues**
· Familiarity with the building	· Fire alarm signal (type, audibility, location, number of nuisance alarms)	· Smell of burning
· Past fire experience	· Voice communication system	· Acrid smell

Occupant characteristics	**Building characteristics**	**Fire characteristics**
· Fire safety training	· Fire safety plan	
· Other emergency training	· Trained staff	
	· Refuge area	
Condition at time of event	**Architecture**	**Audible cues**
· Alone vs. with others	· Number of floors	· Cracking
· Active vs. passive	· Floor areas	· Broken glass
· Alert	· Exit locations	· Objects falling
· Under influence of substances	· Stairwell locations	
Personality	· Complexity of space/ wayfinding	
· Influenced by others	· Building shape	
· Leadership	· Visual access	
· Negative toward authority		
· Anxious		
Role		**Other cues**
· Resident		· Heat
· Visitor		

(Adapted from Proulx 2001b: p.4)

Fahy and Proulx (2009) supported this in an analysis of residential and non-

residential case studies of different real-life fire incidents in Canada, which found that occupants can take appropriate actions and remove themselves from the fire situation when needed. In line with this, recent social psychology research suggest occupant behaviour is comprised of a blend of rational and non-rational decision-making. For example, Kinsey et al. (2019), signpost the importance of ‘rules of thumb’ (or ‘heuristics’) that people use to process complex information to make decisions quickly during a fire.

These rules of thumb are not rational, thought out processes, but ‘short cuts’ to decision making, often based on previous experiences (e.g. of a fire, fire drill or fire evacuation). Examples include ‘authority biases’ (tendency to do things based on an authority figure), ‘bandwagon biases’ (e.g. the tendency to do things because many others do) and ‘default biases’ (e.g. to follow a default option, such as the route a person entered a building) (ibid).

3.3 Occupant decision-making pre-evacuation

Overall, the studies identified found that the period prior to evacuation, where fire cues (such as alarms and smoke) are received, noticed and understood by occupants, is a crucial stage for occupant decision-making. As described by Kinateder et al. (2015) in an evidence review on risk perception, studies have shown that the pre-evacuation period can be the same as or longer than the actual evacuation movement time and can contribute to substantial increases in overall evacuation time.

As part of a post-fire survey conducted with 45 occupants in two high-rise Hong Kong apartments, Lo et al. (2000) provides a four-phase classification of the pre-evacuation time period: recognition (or noticing the cue); validation (establishing the reality of the cue); definition (defining the seriousness of the threat); and evaluation (evaluating the effect of the threat and deciding the action).

International studies found that upon noticing fire cues, occupants often do not vacate immediately. For example, through survey research with 62 high-rise occupants in Egypt, Gerges et al. (2017) found that upon hearing an alarm, respondents’ most common hypothetical responses included enquiring with neighbours (84%) and ignoring fire alarms completely (74%).

A post-fire survey with 72 occupants in two buildings in Hong Kong, arrived at a similar conclusion, suggesting 80% of occupants would investigate the source of fire alarms rather than evacuate immediately (Liu and Lo, 2011). Lo et al. (2000) reinforced this by suggesting if occupants receive what they perceive to

be ‘ambiguous fire cues’ they would search for more information prior to deciding to evacuate.

Some studies also suggested occupants upon noticing fire cues delay evacuation by getting dressed, spending time gathering belongings (such as coats, purses and other valuables), and organising dependents and pets (Gerges et al. 2017; Proulx, 2003; Fahy and Proulx 2009; Proulx et al. 2000; Ronchi and Nilsson, 2013).

Further research from Canada also found occupants delay evacuation by trying to warn others in the building (Proulx, 2003) and by tackling the fire themselves. Fahy and Proulx (2009), using analysis of case studies of different real-life fires in Canada, suggest occupants who try to tackle fires tend to be men, while women tend to alert others. This evidence does not elaborate on why these gender differences may exist.

Further evidence indicates occupants’ previous experiences may cause them to decide to not vacate immediately upon noticing fire cues. For example, in an analysis of simulated evacuations in four apartment buildings in Canada, Proulx (1995) argued that occupants may not trust fire alarms due to previous false alarms and/or fire drills. Sekizawa et al. (1999), in their post-fire survey and interviews with occupants who survived a fire in a Japanese high-rise building, suggest occupants are unlikely to evacuate if they perceive fires to be low risk, if they doubt the fire will reach their apartment, or where they have previously experienced small-scale fires with no serious consequences.

However, through a survey of 327 high-rise residential building occupants in Hong Kong, however, Wong et al. (2009), presented slightly different findings, suggesting respondents who had experienced a fire before would be more likely to undertake an immediate evacuation response. This compares to respondents who had not experienced a fire, who would be more likely to treat the cue as a false alarm or fire alarm test.

Proulx and Pineau (1996), when comparing evacuation times and occupant movements between Canadian office and apartment buildings, found office workers are less reluctant to evacuate buildings in response to fire cues, compared to apartment occupants, who are engaged in day-to-day activities such as watching television or bathing.

Following seven in-depth qualitative interviews with ‘lay-persons’, facilities managers and individuals who had experienced a fire living in France, Tancogne-Dejean and Laclemence (2016) provide similar findings, suggesting that residents will only immediately evacuate on the orders of firefighters or building staff.

Some evidence indicated that the design of high-rise, residential buildings may contribute to occupants not fully understanding fire threat. In a review of occupant behaviours during fires, Ronchi and Nilsson (2013) noted that the compartmentalised nature of residential buildings may limit the spread of information between residents during a fire. Likewise, Lo et al. (2000) argue that the sight and sound, and so the threat, of a fire may be hidden in complex residential high-rise buildings.

Gerges et al. (2018) provided supporting evidence after surveying 72 occupants of UK multi-storey buildings and interviewing with experts within the field of fire engineering from the UK, New Zealand and Sweden. The research found these occupants may not receive cues such as smell, sight and noise as they generally live in properties that are separate fire compartments.

Only two of the identified studies, Wales and Thompson (2013) and Gerges et al. (2018), provided evidence specifically on the behaviour and decision-making of UK occupants. Generally, these studies corroborate the findings of international research. Through ten interviews with people who had experienced injuries in accidental dwelling fires, Wales and Thompson (2013) found that interviewees typically stated that when they experienced a household fire and recognised fire cues (such as smelling or seeing smoke), they chose to investigate rather than evacuate immediately.

It was also found that interviewees tended to attempt to tackle or otherwise mitigate the fire themselves prior to evacuating and/or calling 999, and spent time ensuring the location and wellbeing of their pets. The study did not identify how many interviewees had experienced a fire while living in a high-rise building.

Gerges et al. (2018) provides more specific evidence on the pre-evacuation behaviour of UK occupants within multi-storey residential settings. Using a small-scale online survey of 72 UK multi-storey occupants (including those involved and not involved in a real-life fire evacuation), it was found that only 21% of respondents stated they would evacuate immediately. This compares to 41% who would wait until they are sure there is a real fire, 26% who would get dressed and gather belongings, and 11% who would communicate to other residents to see what they are doing.

3.4 Occupant decision making during evacuation

The identified evidence suggests several factors impact occupant decision-making during fire evacuation in high-rise residential buildings, including group

dynamics, perceptions of leadership and perceived accessibility of exit route. Limited UK evidence, however, means that the extent to which these findings consistently apply to decisions of UK occupants of high-rise residential buildings is unclear.

3.4.1 Group dynamics and leadership

Analysis of simulated evacuations in four apartment buildings in Canada (estimated to hold an average of 150 occupants) found 62% of occupants moved in small groups of 2-3 people (Proulx, 1995). This herding behaviour was also observed amongst older residents, who formed smaller groups despite initially evacuating alone, and amongst family units. Proulx (1996), in a post-fire survey with 213 high-rise occupants in Canada, also found that groups tended to stay together, unless separated by fire hazards or overtaken by faster members of the group.

A very small virtual reality experiment that focused on the impact of anxiety on the evacuation behaviours of 33 students, explored an occupant's state of mind in accounting for group behaviours, and found high anxiety encourages occupants to herd when selecting evacuation routes (Lu et al, 2017).

Evidence on the effects of occupant herding on evacuation is mixed. Proulx (1995; 1996) argued herding behaviour can slow down evacuation, as occupants tend to adopt the speed of the slowest person within the group. Wei et al. (2019), based on modelling and simulation focused on family evacuation in a 30-storey residential building, supported this view; suggesting family groups can make it difficult for other occupants to evacuate as they can take up space during an evacuation.

A modelling study focused on group evacuation in high-rise environments, however, suggested groups of up to three can speed up evacuation, as occupants benefit from feedback regarding movements and actions (Hu and Liu, 2018). There is also evidence that occupants with visual impairments find it reassuring to be in small crowds during an evacuation.

For example, during an experiment involving 40 visually impaired participants carrying out different evacuation exercises in four different buildings in Denmark, Sørensen and Dederichs (2015) found that the visually impaired people took cues on obstacles and whether to run or walk from the surrounding crowds. This research, however, also found that visually impaired occupants can find it difficult to adjust their evacuation speed in overcrowded situations (ibid).

Some evidence suggested leadership patterns can influence occupant behaviour during fire evacuations. In an assessment of a high-rise residential

fire in Canada, Proulx (1999) found that elderly residents in high-rise buildings tended to follow the instructions given to them over a personal address (PA) system if they trusted the authority of the person making the announcement, or if it was a firefighter. This was also a finding of Liao et al., (2014) which, following interviews with 381 randomly selected participants across two Chinese cities, found that 88% would use a lift if instructed to by a firefighter.

Using a modelling and simulation study on crowd wayfinding behaviour during evacuation, Pelechano and Badler (2006) compared the impact of ‘trained’ (those familiar with a building and its exits) and ‘untrained’ leadership (those that simply took control of a situation and exhibited leadership skills). The conclusion was that trained leaders can speed up evacuation times significantly; although it is not clear how well their simulation of a ‘complex building’ maps onto a residential building setting.

The identified evidence indicated that occupants do help one another during an evacuation. For example, in their analysis of case studies of different real-life fire incidents in Canada, Fahy and Proulx (2009), found that “altruistic” behaviours were common during fires, including among strangers.This included helping others and guiding them away from risk behaviours, such as tackling a fire.

Some evidence, however, also suggested occupants could endanger the safety of others. For example, in a review of appropriate occupant responses to fire alarms, Proulx et al. (2000), identified evidence of occupants not closing fire doors and breaking windows to let out smoke, which could escalate a fire situation.

3.4.2 Exit route and use of lifts

Several identified studies explored occupants’ choice of exit during a fire where multiple options are available. Fahy and Proulx (2009) and Proulx (2001b) suggest occupants often choose the route that is most familiar to them during an evacuation. This is likely to be the point where occupants entered, particularly if they are unfamiliar with a building. These studies suggested occupants choosing a familiar route could hinder evacuation, as they are not using all exit options and the familiar route may not be the fastest or safest (ibid).

The identified evidence indicates lifts are generally not considered an appropriate means of escape by many people living in high-rise residential settings. In an evidence review on the information required to convince people to use a lift during the evacuation of high-rise buildings, Nilsson and Jönsson (2011) suggested this is because people have for most of their life been instructed not to use lifts during emergency situations.

A small-scale online survey of 72 occupants in UK high-rise buildings (including those that had and had not been involved in a real-life fire evacuation) was the only identified study to provide UK-specific data on occupant decision-making (Gerges et al. 2018). It found that during a fire evacuation 67% of respondents stated they would definitely take the stairs, 16% would probably take the stairs, 8% would probably take the lift, and none would definitely take the lift.

This and various international studies, provide a range of reasons for occupant reluctance to use lifts in the event of a fire. This includes occupants having internalised public service message that lifts are not safe to use in a fire; worries about being trapped (including concerns around smoke inhalation and power failure); concerns that there would not be enough space for the family to fit together in a single lift journey; and concerns that lifts will not arrive regularly enough and there will be too many people waiting for them, which could increase evacuation times (Butler et al. 2017; Gerges et al. 2017; Gerges et al. 2018; Nilsson and Jönsson, 2011; Proulx et al. 2009; Andrée et al. 2016).

Citing evidence of an online survey of 468 people from across 23 different countries, Galea (2014) showed that even if occupants were well informed and the lifts were safe to use in a fire situation, only 33% of people would consider using them. Hawkins (2003), cited in Proulx et al. (2009) provided the only example of UK residents being encouraged to use a lift during high-rise evacuation.

This comes from the evacuation of the (non-residential) BT Tower, whereby very forceful fire wardens/ marshals, together with loud attention seeking messages, are described as being required to ensure efficient usage of both lifts and stairs. The extent to which these findings apply to high-rise, residential settings, however, is unclear.

Despite the evidence indicating occupants of high-rise buildings generally avoid the use of lifts for evacuation, some studies suggested occupant willingness may change in certain situations. For example, Proulx (1996), a post-fire survey with 213 high-rise occupants in Canada, found occupants that were closer to a fire (and so aware of the threat and able to evacuate earlier than other occupants) would be more likely to use lifts.

Liao et al. (2014), through interviews with 381 randomly selected participants across two Chinese cities, also found that 88% would use a lift if instructed to by a firefighter. This is reinforced by Kinsey et al. (2019), which suggests residents feel safer using lifts if instructed by firefighters.

As summarised below, there is some evidence that occupants have concerns about using stairwells during fire evacuation.

Occupants' concerns of using stairwells during evacuation

- fire safety - the effects of fire and smoke entering a stairwell
- poor visibility and navigation- smoke or generally poor lighting in stairwells
- safe evacuation for higher floor levels - the number of stairs and impacts on fatigue and evacuation time
- safe evacuation for children and those with mobility issues - evacuation for these groups and those looking after them would be slower
- reliability - concerns that stairwells may be blocked (e.g. by rubbish or stored materials) or that the fire exits that are locked to keep visitors out

Sources: Proulx (1996); Proulx and Pineau (1996); Proulx (1995); Liao et al. (2014); Gerges et al. (2018); Ronchi and Nilsson (2013).

3.4.3 Improving evacuation of residents

Generally, international evidence suggested that in order to improve the decision-making of occupants of high-rise buildings they require more training and education. In a survey of 224 high-rise building residents and 228 high-rise commercial building occupants in the USA, Zmud (2008) found that residents considered fire drills the most valuable tool in improving preparedness for high-rise fire evacuation.

Butler et al. (2017), based on face-to-face interviews with 51 participants with mobility impairments working in buildings across the US, concluded this is particularly pertinent for occupants with limited mobility, who are identified to desire greater consultation, information and attention in the preparation for fire evacuation. The extent to which these findings translate to UK high-rise residents, however, is unclear.

3.4.4 Further research

Overall, as described by Kinsey et al. (2019) in their review of cognitive biases and decision-making during fire evacuations, further research is required to better understand the processes and cognitive biases that underpin occupant decision-making. This is reinforced by Kobes et al. (2010), who suggested more research is required to better understand the interaction between human behaviour, decision-making and how these interact with the characteristics of different buildings, including high-rise.

4. How do firefighters make decisions about evacuating occupants from high-rise buildings?

Key Findings

- there is a significant lack of published peer reviewed evidence regarding UK firefighters' decision-making about evacuating occupants from high-rise residential buildings
- two main factors were suggested to inform firefighter decision-making: pre-determined procedures and previous experience
- the evidence highlighted that firefighters must assess a significant amount of information in their decision-making process including the specific features of high-rise buildings and awareness of occupant vulnerabilities

Limited UK evidence suggested that if firefighters do not have directly relevant experience of and/or sufficient training in evacuation (including in high-rise settings) systematic errors can occur in decision-making. This chapter synthesises identified evidence relating to the third research question: How do firefighters make decisions about evacuating occupants from high-rise residential buildings?

This review identified a significant lack of independent peer reviewed evidence on firefighter decision making about evacuating occupants from high-rise residential buildings. This chapter therefore describes, more generally, how firefighters make decisions, the factors that influence their decision making, and suggestions as to how decision making might be improved using the best evidence available.

4.1 Evidence quality

Six studies were identified that provide evidence on fire fighter decision making. Based on the weight of evidence tool that assessed relevance and quality of the

studies, the majority (five) scored between 4 and 5. One study scored 6 out of 9. The studies were small-scale and largely international, with only one providing UK specific evidence. Most focused on the decision-making of firefighters in general rather than specifically in high-rise residential settings.

4.2 Processes of decision making

Overall, the evidence identified suggested that having arrived at and assessed a fire situation, two main factors inform firefighter decision-making: pre-determined procedures and learning from previous experience. Based on interviews with 26 experienced fire ground commanders (FGCs) from seven fire departments across the United States, Klein et al. (2010), suggests training and pre-determined standard procedures are crucial components in firefighter decision-making, particularly for coordinating and allocating personnel, equipment and selecting entrance routes into buildings.

However, based on an analysis of video footage from 33 incidents attended by six UK fire and rescue services, Cohen-Hatton et al. (2015), suggested that while firefighters follow established protocol and training, decision-making often occurs in situ and is informed by reflective and reflexive processes.

There is some evidence that these reflective and reflexive processes are often informed by directly relevant previous experiences. This presents obvious challenges to firefighter training, as it requires multiple incidents of the same severity to occur and the goal is to avoid the need for evacuation. Klein et al. (2010), for example, suggests decision-making is a process of recognitional and perceptual matching whereby firefighters rapidly examine available options and, based on their experience, accept or reject forms of action.

Similarly, Kinsey et al. (2019) in their review of cognitive biases and decision-making suggested firefighters use heuristics or ‘rules of thumb’ when making rapid decisions; creating simplified mental lists of response options based on associations between the given situation and similar past experiences. This research suggests these judgements usually produce skilled, appropriate and successful decisions (ibid).

One study identified also suggested systematic errors can occur if firefighters lack suitable experience. Cohen-Hatton et al. (2015), suggests firefighter rapid decision-making can lead to so called ‘decision traps’. This is where firefighters may skip planning processes and therefore risk making decisions that do not appropriately consider tactical plans or broader incident objectives, and risk basing decisions on single environmental cues, as opposed to the full context of

the incident (ibid).

4.3 Factors in decision-making

A key part of the evidence base is the acknowledgement of the significant amount of information firefighters must assess in their decision-making. Such information includes, but was not limited to:

- **smoke**: colour, amount, toxicity, rate of change
- **fire**: amount, location/seat, explosion potential, chemicals, rate of change/movement
- **weather**: temperature, moisture, wind - velocity and direction
- **resources**: equipment and personnel - what is available / required, special needs
- **occupants**: number, location and vulnerability

(Adapted from Klein et al. 2010)

The type, structure and design of buildings and the impact this has on firefighter decision-making regarding access and navigation is also discussed within the identified literature. For example, in a literature review exploring the challenges faced by firefighters during rescue operations in Saudi Arabia, Hassanian (2009) outlined that some high-rise buildings have internal and external features that restrict access, including utility poles, overhead wires, sealed windows, concealed spaces, and locked doors requiring master keys or forceable entry.

Based on experiments involving a fire evacuation drill in four mid-rise apartments in Canada, Proulx (1994) also suggests firefighters' awareness of occupant vulnerabilities is an important consideration, and knowledge of occupant adherence to requests to defend-in-place or use refuge areas.

Considering the significant amount of information firefighters must assess in their decision-making, Okoli et al. (2016), having undertaken critical decision method interviews with 16 firefighters across the UK and Nigeria, suggested firefighters' ability to differentiate between cues that do and do not trigger action is a significant part of effective decision-making.

This is reinforced by Klein et al. (2010), who suggests firefighters' experience of similar fire scenarios, and subsequent level of situational awareness and recognition response, has a direct positive relationship on their ability to pick out and assess relevant cues.

The evidence provides limited insight into what can be done to improve firefighters' decision making. Klein et al. (2010) suggest training that improves situational awareness, critical-cue inventory and experience matching is key. This can include the use of imagery (to improve strategy formation) and analogies (to improve analogical reasoning), as well as the standard practice drills.

This evidence therefore suggested that if firefighters gain more context-rich experience, they can more rapidly evaluate options, and therefore make effective decisions (ibid).

5. Conclusion

Overall, the findings of this review show that despite there being a high-volume of research focused on fire evacuation generally, the availability of evidence focused specifically on fire evacuation in high-rise residential settings is significantly limited. Of that which is available the vast majority is international, with only a handful of studies providing UK-based evidence. Furthermore, the quality of studies was mixed, with many based on focused qualitative studies and small-scale quantitative surveys.

While this review was conducted to provide comprehensive insight into fire evacuation in UK high-rise residential buildings, it is limited by a paucity of research and an evidence base largely developed in non-UK settings meaning transferability of findings to the UK is unclear. As such, while the findings provide some relevant contextual insight into fire evacuation within high-rise buildings, they do not directly answer the three core research questions central to this review.

5.1 What are the most effective methods of evacuation from fires in high-rise residential buildings?

Considering the limited evidence base within scope of this review, the findings

of this review tentatively suggest that, if evacuation is necessary and effective fire safety arrangements such as compartmentation are in place, phased and partial evacuation strategies (in the form of 'defend-in-place' and delayed evacuation) are safer than simultaneous evacuation within high-rise residential settings.

The evidence also identifies the importance of 'delayed evacuation' for those unable to evacuate unassisted, and the necessary requirements to ensure refuge areas are safe and effective. The success of phased or partial evacuation, however, depends on effective compartmentation and communication systems to provide occupants with sufficient and ongoing information.

Nonetheless, despite these overarching findings, the body of evidence suggests that no single strategy is universally appropriate for the evacuation of high-rise residential buildings. Instead, every high-rise residential building should have a bespoke fire evacuation plan, developed in full consideration of the building design, the composition of occupants and crucially, the presence, or indeed absence, of effective compartmentation.

Synthesis of international modelling and simulation studies suggested that fire safe lifts can reduce overall evacuation time in high-rise buildings. There is however a distinctive lack of UK-specific research on the effectiveness of lifts for fire evacuation within high-rise residential settings. The extent to which this finding can be applied to the UK is therefore unclear.

5.2 How do occupants make decisions about fire evacuations from high-rise residential buildings?

Collectively UK and international evidence suggested occupants do not immediately evacuate upon recognising fire cues, but first check to validate risk, gather belongings and communicate with other residents. Both UK and international studies also suggest occupants of high-rise residential settings are reluctant to use lifts during fire evacuation, which in UK context is in line with the current NFCC 'stay put' position (https://www.nationalfirechiefs.org.uk/Stay-Put-position) statement that in general in the event of an evacuation stairs should always be used rather than a lift (NFCC 2020).

This is due to long-standing beliefs that lifts are not safe during a fire, and concerns around safety and delayed evacuation times. Some non-UK evidence suggested occupants of high-rise buildings are more likely to use lifts during fire

evacuation if instructed by firefighters. No research on UK occupants' willingness to use lifts upon firefighter instruction was identified in the review. The extent to which these findings are transferable to UK high-rise residents is therefore unclear.

5.3 How do firefighters make decisions about evacuating occupants from high-rise residential buildings?

This review identified a significant lack of independent peer reviewed academic evidence into how firefighters make decisions regarding the evacuation of occupants from high-rise residential buildings in the event of a fire. Of the limited evidence available, most was international and focused on the decision-making of firefighters in general, rather than specifically in high-rise residential settings.

Considering the limited evidence base, the UK and international evidence outlines two main factors that inform firefighter decision-making: pre-determined procedures and previous experience. International evidence also identifies significant amount of information firefighters must assess in their decision-making. This includes specific features of high-rise buildings, and awareness of occupant vulnerabilities and knowledge of occupant adherence to requests to 'defend-in-place' or use refuge areas.

5.4 Future research and evidence gaps

While the findings from this review provide some insight into fire evacuation in high-rise residential buildings, the ability to identify the most effective methods of evacuation is limited by a paucity of high-quality research and an evidence base largely developed in non-UK settings. An important contribution of this review is therefore the identification of significant and wide-ranging evidence gaps, which would need to be addressed in order to improve the peer reviewed academic evidence base.

These includes research on:

- comparisons of the effectiveness of different evacuation strategies in UK high-rise residential settings

- the effectiveness of lifts for fire evacuation within UK high-rise residential settings
- UK high-rise residents' willingness to use lifts during fire evacuation upon instruction
- the effective evacuation of vulnerable groups from UK high-rise, residential settings. This includes residents with reduced cognition, residents with small children, residents with English as an additional language, and residents' potentially limited knowledge of evacuation procedures, such as those who are short-term, un-tenured or guests
- firefighters' decision-making regarding the evacuation of occupants within UK high-rise residential settings

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Appendix 1. Descriptive tables for included articles

Author and year	Country	Study design	Summary of findings	Score
Andrée et al. (2016)	Sweden	Virtual reality experiments studying exit choice and the waiting time for lifts in high-rise	A simple way-finding system using green flashing lights can influence people to more likely choose the lift as their first	5.25

Author and year	Country	Study design	Summary of findings	Score
		buildings	evacuation choice. Findings also suggested people wait for either a limited time (<5 min) or a long time (>20 min) for a lift.	
Atila et al. (2018)	Multi-country	Modelling of occupant escape in a 10-storey high-rise using a system that provides real-time information regarding changing fire conditions	Evacuation time using real-time intelligent systems was longer, but safer through the avoidance of (simulated) toxic gas, heat, and thick smoke.	6
Barlund et al. (2005)	Multi-country	Conference paper about the logistics of total evacuation by lift	Sets out ways that lifts should be programmed in order to improve efficiency of total fire evacuations.	4.5
Butler et al. (2017)	USA	Qualitative interviews with 51 participants with mobility impairments	Participants appreciated the independence provided by lifts during evacuation, and the ability to keep their mobility devices with them. Existing lifts did raise concerns about safety, crowding, lack of communication, wait time, and lack of priority use.	6
Chen et al. (2011)	Multi-country	Evidence review on requirements	Evidence suggested that if lifts are used in a	4.5

Author and year	Country	Study design	Summary of findings	Score
		for elevator evacuation in high-rise settings	fire, they must be smoke-proof and protected from hose water.	
Chow et al. (2013)	Multi-country	Case study research about sky bridges, focused on two 57-story buildings	Findings suggested sky bridges can greatly reduce evacuation time compared to stairs and can be combined with stairs and lifts to provide additional evacuation routes.	4.5
Cohen-Hatton et al. (2015)	UK	Analysis of video footage from 33 incidents attended by six UK Fire and Rescue services	Firefighters followed established protocol and training. Decision-making did not follow the sequence of phases assumed by normative models and conveyed in current operational guidance but instead was influenced by both reflective and reflexive processes.	5
Fahy and Proulx (2009)	Multi-country	Analysis of case studies of different real-life fire incidents in Canada	There is evidence that ‘panic’ is rare in fires; what is described as ‘panic’ is often fear or anxiety. People can still behave rationally.	4
Galea (2014)	Multi-country	Review of Fire Safety Engineering Group research	Wayfinding could be improved with red X dissuasive signage. Even if lifts were safe to use in a fire situation, only 33% of people	5

Author and year	Country	Study design	Summary of findings	Score
			would consider using them.	
Gerges et al. (2018)	Multi-country, including UK	Survey research with 72 occupants of UK multi-storey buildings and interviews with experts within the field of fire engineering from the UK, New Zealand and Sweden	Outlines challenges people face during fire evacuation. Evidence indicates that more information about evacuation procedures would enable better decision-making. People are reluctant to use lifts.	7
Gerges et al. (2017)	Egypt	Survey and interviews of residents	Findings indicate that occupants have limited knowledge and skills on how to deal with fire emergencies. Occupants tend to initially ignore the fire alarm and usually they investigate if it is true or false.	7
Groner (2016)	Multi-country	Modelling of a decision-making approach for evacuation	Outlines pros and cons of different evacuation strategies. The choice of strategy will depend on the fire scenario, building characteristics and resident characteristics.	5.25
Hassanian (2009)	Saudi Arabia	Evidence review investigating challenges faced by occupants and firefighters	Evacuating from high rise buildings found to be challenging for occupants. Some high-rise buildings have	4.5

Author and year	Country	Study design	Summary of findings	Score
		during evacuation	internal and external features that restrict access for firefighters.	
Hu and Liu (2018)	Multi-country	A modelling study focused on group evacuation in high-rise environments	Findings suggested evacuating in groups of three can optimise evacuation.	6
Kinateder et al. (2015)	Multi-country	Review of evidence on risk perception in fire evacuation behaviour	Evidence shows that the pre-evacuation time can be substantial. Sets out the factors that influence perception of risk.	4.75
Kinateder et al. (2019)	USA	Experiment - simulated emergency evacuation using virtual reality	Participants considered green as the most appropriate colour for signposting exit routes.	4
Kinsey et al. (2012)	Multi-country	Simulations of full building evacuation scenarios based on a hypothetical 50 floor building with four staircases and 7840 agents	Results indicated stair-lift combined evacuation times were 50% faster than stair-only evacuations.	6
Kinsey et al. (2019)	Multi-country	Evidence review - the influence of cognitive biases on decision-making	The review identifies cognitive biases that may influence a person’s decision-making process during a fire evacuation.	4.5

Author and year	Country	Study design	Summary of findings	Score
Klein et al. (2010)	USA	Interviews with 26 experienced fire ground commanders from seven fire departments	Findings indicated commanders used their experience to directly identify a situation as typical of a standard prototype and to identify a course of action accordingly. Training and pre-determined standard procedures were key contributors to decision-making.	4.75
Kobes et al. (2010)	Multi-country	Review of available literature on human behaviour in a fire	Psychonomics appear to have significant influence on occupants' fire response performance. The review found little evidence about the interaction between human behaviour and the characteristics of a building.	5.5
Kodur et al. (2020)	Multi-country	Comparative modelling of fire scenarios in a 32 story building	Modelling indicated that residents having situational awareness of the fire can improve evacuation efficiency.	5.25
Koo et al. (2013)	Multi-country	Comparative modelling of evacuation strategies for disabled people	When wheelchair users evacuated by lift and non-wheelchair users evacuated via stairs, overall evacuation time decreased by at least 21.5%.	6.25

Author and year	Country	Study design	Summary of findings	Score
Kuligowski et al. (2015)	USA	Experiment -stairwell evacuation speeds of older and disabled residents	Having two firefighters (one in front, and one behind) assisting occupants via a stair-chair was the most efficient evacuation method.	7
Kulkarni and Agashe (2016)	Multi-country	Evidence review of evacuation egress components and intelligent evacuation systems	Lifts are essential component of high rise fire evacuations, but must be protected from smoke and fire. Total evacuation takes longest out of all evacuation strategies; phased or defend-in-place are quicker.	4.5
Lay (2007)	Multi-country	Evidence review - the role of lifts and stairs; alternative evacuation designs	Found that lifts and stairs in modern high rise buildings can be adapted to be used during evacuation, rather than adopting novel alternatives.	5.5
Liu and Lo (2011)	Hong Kong	Post-fire survey of 72 occupants in two buildings in Hong Kong	Only 14% responded to fire cue by evacuating immediately. 80% of occupants would investigate the source of fire alarms rather than evacuate immediately.	7

Author and year	Country	Study design	Summary of findings	Score
Lo et al. (2000)	Hong Kong	Post-fire survey of 45 occupants in two high rise Hong Kong apartments	Found that pre-evacuation decision-making can be divided into phases: recognition, validation, definition, and evaluation. The sight and sound, and so the threat, of a fire may be hidden in complex residential high rise buildings.	6
Liao, et al. (2014)	China	Interviews with 381 randomly selected participants across two Chinese cities	Findings show that 88% of participants would use a lift if instructed to by a firefighter.	6
Lu et al. (2017)	USA	Virtual reality experiment - the impact of anxiety on evacuation behaviours of 33 students	Findings suggested high anxiety encourages occupants to herd when selecting evacuation routes.	5
Mateev et al. (2018)	Russia	Study modelling use of a range of self-rescue equipment in a high-rise hostel in Russia	Self-rescuer bars and rescue fixed ladders improved evacuation within the first seven minutes.	5
McConnell and Boyce (2015)	UK	Survey of disabled people's views and experiences of refuge areas	Results indicated low awareness of refuge areas; good communication with users of refuge points felt to be essential; suggested	7

Author and year	Country	Study design	Summary of findings	Score
			improvements to design.	
Min and Yu (2013)	Multi-country	Evacuation simulation of 100 people from the 10th floor of a high-rise building	Simulations indicated that while lifts are faster than stairs, lifts lose speed advantage as the number of occupants increases; mixed lift-stair evacuation becomes best choice.	5
Nilsson and Jonsson (2011)	Multi-country	International evidence review on information required to convince people to use an lift during evacuation in high-rise buildings	Evidence identified common concerns with using lifts and said information for occupants must be tailored to address those concerns. Also, willingness to use lifts in fire is low if they are frequently out of order.	5
Okoli (2016)	UK, Nigeria	Critical decision method interviews with 16 firefighters across the UK and Nigeria	Firefighters' ability to differentiate between cues that do and do not trigger actions is significant part of effective decision-making.	4
Olander et al. (2017)	Sweden	Questionnaire investigating design of dissuasive emergency exit signage	Results show that features which clearly negate the exit-message of the original positive exit signage are most effective; for instance, a red X placed across the entire exit signage.	5

Author and year	Country	Study design	Summary of findings	Score
			Other notable features: red flashing lights, alternating colours.	
Peacock et al. (2016)	USA	Comparison of fire drill data covering 22,000 mobility impaired and non-mobility impaired people	Analysis found stair movement time to be slower in buildings that housed older and mobility-impaired people.	7
Pelechano and Badler (2006)	Multi-country	Modelling and simulation study on crowd wayfinding behaviour during evacuation	Trained leaders can speed up evacuation times significantly; although it is not clear how well their simulation of a 'complex building' maps onto a residential building setting, nor whether findings apply to UK residents.	4
Proulx (1994)	Canada	Experiment - observing evacuation drills of occupants in four apartment buildings	Results showed occupants were less likely to hear alarms in corridors and more likely hear alarms in apartments. Firefighters' awareness of occupant vulnerabilities is an important consideration, and knowledge of occupant adherence to requests to defend-in-place or the use of refuge areas.	6
Proulx (1995)	Canada	Experiment - observing	Findings indicate occupants may not	7

Author and year	Country	Study design	Summary of findings	Score
		evacuation time and movement in four apartment buildings during simulated fire emergency	trust fire alarms due to previous false alarms. 62% of occupants moved in small 'herds' of 2-3 people. This herding behaviour can slow down evacuation, as occupants tend to assume the speed of the slowest person in the group.	
Proulx (1996)	Canada	Survey of people who had experienced a fire in a residential high-rise building	Survey findings showed that people were less likely to hear fire alarms because they were situated in corridors. Older people less likely to hear alarms. Some occupants had blocked/covered up their alarms in response to previous false alarms. People evacuated in groups and tended to stay together, slowing their evacuation. Occupants closer to the fire are more likely to use lifts.	6
Proulx and Pineau (1996)	Canada	Experiment comparing office evacuation times in simulated fire emergency with previous study of drill times in residential buildings	Findings suggested office workers are less reluctant to evacuate in response to fire cues, compared to residential occupants, who are engaged in day-to-day activities such as watching television or bathing.	7.25

Author and year	Country	Study design	Summary of findings	Score
Proulx (1999)	Canada	Post-fire survey of survivors of residential high-rise building fire in Ottawa	Post-fire survey of survivors of residential high-rise building fire in Ottawa.	8
Proulx et al. (2000)	Canada	Experiment - simulated office building evacuation	Photoluminescent material found to be effective in guiding occupants evacuating via low-lit or dark stairwells.	4.25
Proulx (2001a)	Multi-country	Evidence review of human behaviour in fires	Findings suggested that in certain high-rise conditions ‘defend-in-place’ can be safer than simultaneous and phased evacuation. It also outlines the conditions in which a ‘defend-in-place’ strategy should be implemented in high-rise settings.	5
Proulx (2001b)	Multi-country	Evidence review of occupant behaviour during evacuation	Review concludes that there is little evidence of people actually panicking in fires; people seem able to make rational decisions. It also provides a comprehensive list of factors influencing behaviour in fires. Occupants tend not to evacuate immediately upon hearing a fire alarm; voice	5

Author and year	Country	Study design	Summary of findings	Score
			communication systems and trained staff can prompt movement.	
Proulx (2003)	Multi-country	Evidence review exploring reasons why people linger in burning buildings	Occupants are likely to be resistant to phased evacuation, preferring to evacuate immediately. People are prepared to move through smoke to try and escape. Time is spent in pre-movement activity before evacuating. Response times depend on fire cues and occupant characteristics.	4.5
Proulx and Laroche (2003)	Canada	Field study of 307 participants in public buildings to assess response to Temporal-Three fire alarm sound	Participants did not consider the Temporal-Three sound as conveying urgency. Findings suggested that it is unrealistic to expect that occupants will immediately start evacuation upon hearing such a signal; further information provided to the occupants will always be necessary to prompt evacuation movement.	4.5
Proulx (2004)	Multi-country	Think piece - proposed procedure for using lifts for evacuation	High rise building occupants are capable of following an lift evacuation procedure as long as instructions are readily available,	4.5

Author and year	Country	Study design	Summary of findings	Score
			regular training takes place and information is provided to the occupants during an emergency to support their use of lifts.	
Proulx et al. (2009)	Multi-country	Review of evidence on the use of lifts for egress	Review concludes that lifts are considered an essential form of evacuation in buildings above 6 metres; they can greatly increase evacuation speed. But occupants are reluctant to use lifts in a fire.	5.5
Rahman et al. (2012)	Multi-country	Proposes a system in which safe exit routes are pre-programmed into radio frequency tracking devices that notifies occupants of the safest evacuation route	Testing the system on five students in a real building found it functioned as intended, but no evidence on whether it would deliver safe or efficient evacuation in fire conditions.	5.25
Ronchi and Nilsson (2003)	Multi-country	Evidence review of human behaviour in fires and modelling studies of evacuation strategies	The review discusses pros and cons of different evacuation strategies and advises each building should have a tailored plan. The review also concluded that modelling and simulation studies of fire evacuation are	5.5

Author and year	Country	Study design	Summary of findings	Score
			limited because they often fail to consider human behavioural insights.	
Sekizawa et al.	Japan	Post-fire survey and interviews with occupants who survived a residential high rise fire	Findings suggest occupants are unlikely to evacuate if they perceive fires to be low risk, particularly if they doubt the fire will reach their apartment. Lift use was high from higher floors.	7
Sharma et al. (2008)	Multi-country	Risk assessment of the use of lifts in emergency fire evacuation using a MODA approach	Combining stair and lift evacuation (75% and 25% respectively) was comparable to 100% lift or 100% stair evacuation in terms of safety and speed.	6.25
Siikonen and Hakonen (2002)	Multi-country	Comparative modelling of evacuation strategies	Within ‘typical’ residential buildings, with less than 50 floors and a population of less than 200 per floor, stairs are the fastest means of evacuation. However, lifts can reduce evacuation time in residential settings if used by a small proportion of occupants.	5.25
Sørensen and Dederichs (2015)	Sweden	Experiment evacuating 40 visually impaired participants from	Occupants who were less severely visually impaired could evacuate at a similar	5

Author and year	Country	Study design	Summary of findings	Score
		two-and three-storey buildings	speed to non-impaired people if accompanied by others. Evacuee speed was slower if they had a guide dog or a mobility stick.	
Tancogne-Dejean and Laclémence (2016)	France	Qualitative research on differences in fire risk perception and building evacuation of vulnerable persons	Risk perception identified to be highly subjective. Building evacuation is more complicated that simple escape response, but rather a combination of cognition and emotion. Individuals adopt building evacuation strategies based on the degree of uncertainty of the emergency.	5
Wales and Thompson (2013)	UK	Ten interviews and preliminary analysis of 177 survey responses from people injured in accidental dwelling fires	Findings show occupants do not always evacuate immediately even when they are convinced of the validity of a fire cue. Occupants had a strong desire to tackle the fire themselves.	7.25
Wei et al. (2019)	Multi-country	Modelling of family groups evacuating a 30-storey residential building	Found that family groups can make it difficult for other occupants to evacuate because they take up more space during evacuation.	7
Williamson and	Multi-country	Evidence review of the use of lifts	Lifts are not always available during	6

Author and year	Country	Study design	Summary of findings	Score
Demirbilek (2010)		and refuge floors during fire evacuations	evacuations. Refuge areas can be a useful tool in fire evacuation by supporting the evacuation of people with mobility difficulties, and offering a place of rest for occupants fatigued from descending stairs.	
Wood et al. (2005)	Multi-country	Evidence review of the efficacy of sky bridges in evacuations	Concludes that sky bridges offer additional horizontal evacuation options and can therefore increase evacuation efficiency.	6
Wood (2007)	Multi-country	Evidence review of alternative means of evacuation from tall buildings	Sky bridges offer real benefits to evacuation from height. They can improve evacuation efficiency and can link to refuge points. Refuge points can also act as a command point for firefighter teams.	5.5
Wong et al. (2005)	Multi-country	Computational evacuation models simulating the total building evacuation of a ‘super-high rise’ building	Results showed that total building evacuation time can be shortened significantly by adopting this strategy.	5
Wong et al, (2009)	Hong Kong	Survey of 327 high-rise residential	Respondents who had experienced fire before would undertake an	7

Author and year	Country	Study design	Summary of findings	Score
		building occupants in Hong Kong	immediate evacuation response. This compares to respondents who had not experienced a fire, who would treat the cue as a false alarm or fire alarm test.	
Zhang (2017)	Mutli-country	Theoretical proposal of a spiral slideway in a figure of eight shape to evacuate a building from the outside	Simulation tests on real humans found participants did not become dizzy. Theoretically, the device would be a quicker evacuation mode than descending via stairs.	5
Zmud (2008)	USA	Survey research high-rise building occupants on preparedness to evacuate	Public suggested that more fire drills are the best way to improve evacuation safety. Most occupants believe using lifts unsafe during a fire. Findings suggested need for continued public education about emergency evacuation procedures in high-rise buildings.	6

Appendix 2. Additional studies identified but not prioritised for synthesis

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Appendix 3. Analytical charts for data extraction

Table 6: Contextual information

Aim: to summarise contextual information about the study and the evacuation approach discussed.

1.1 Research question	State which research question you feel the study answers (e.g. evacuation effectiveness, resident decision making and/or fire-fighter decision-making).
1.2 Evacuation or decision-making topic	In a word or sentence, concisely state the evacuation or decision-making topic (or aspect) being explored, evaluated or tested. This could be crowd behaviour, evacuation times, egress components (e.g. lift v stairwells), technology, signage, building design, evacuation approaches (e.g. full, phased, partial, routes), preparing residents (e.g. drills) etc… For evidence reviews there may be multiple topics discussed, please list.
1.3 Theoretical framework of the approach	Please state if the research is grounded in a theoretical framework or model. Name the framework/model and provide a sentence or two descriptors. A theoretical framework frames the evacuation approach. e.g. forces-based models to examine crowd behaviour.
1.4 Other	

Table 7: Effectiveness of evacuation approach

Aim: to summarise what approaches are seen to be effective, in what context and for whom (including vulnerable groups).

2.1 Description of approach	A brief description of evacuation approach. Describe using the following headings: Rationale for approach - why it is seen to be important (e.g. similarities and departures from other approaches). Description of approach - what does the approach involve. Please also state any overlapping elements, (e.g. a combination of technology and process), describe each element and how they combine.
2.2 Strength of approach	A brief description of the key strengths of the evacuation approach and reasons for this. Use a separate heading for each strength. If multiple approaches are mentioned, please list the strengths of each under separate sub-headings.
2.3 Limitations of approach	Brief description of the stated limitations of the evacuation approach and the reasons for this. Use a separate heading for each limitation. If multiple approaches are mentioned, please list the limitations of each, using higher level headings for each approach.
2.4 Evidence of strengths and limitations	Please briefly state the quantitative or qualitative findings that support the strengths and limitations discussed in 2.1 and 2.2.
2.5 Circumstances least/most effective	Describe the physical, social and other situations the evacuation approach is seen to be effective/less effective (e.g. super-high-rise, certain age of building, certain legal contexts etc.). Clearly state the reasons why this is the case. Use appropriate headings for each circumstance where appropriate.
2.6 Whom it is effective	Describe for whom the approach works well/less well for and why. Include here any discussion of vulnerable groups.
2.7 Transferability of international findings	If the study is not UK based, state any explicit evidence that the study could be applied to the UK. This may include direct mentions or comparisons to UK structures or policy, or that a particular model is generalisable globally, across Europe etc.

2.8 Charter's thoughts	Summarise in a sentence or two the key take-away messages from the study (e.g. what can help better decision making).
2.9 Other	

Table 8: Resident decision making

Aim: to understand decision making, whether this varies between residents, the factors influencing decisions and any solutions.

3.1 Type of decision-making behaviour	In a sentence, state the type of decision-making behaviour discussed (e.g. exit pathway, deciding whether to bring belongings, priorities during fire).
3.2a Description of decision making	Summarise what decision-making looks like - including the context in which it is made, its features and implications for resident safety.
3.2b Resident type variation	Summarise any differences in decision making between different types of residents (including vulnerable ones) discussed and the reasons for these.
3.4 Improving decision making	Where stated, summarise of what is seen to improve decision making and why (e.g. what factors can help residents to make safer decisions in evacuations).
3.5 Charter's thoughts	Summarise in a sentence or two the key implications to practise from the study (i.e. what help better decision making).
3.6 Other	

Table 9: Firefighter decision making

Aim: to understand firefighters' decision making, the factors influencing decisions and any solutions.

4.1 Type of decision-making	A sentence summarising the type of decision making discussed (e.g. entry decision, prioritisation during fire, method of evacuation, equipment used etc).

behaviour	
4.2 Description of decision making	Summarise what decision-making looks like - including the context in which it is made, its features and implications for fire fighter and resident safety.
4.3 Resident type variation	Summarise any differences in firefighters' decision making between different types of residents (including vulnerable ones) discussed and the reasons for these.
4.4 Factor influencing decision making	Explain the range of factors that are seen to affect decisions (e.g. building design and facilities, firefighters' emotions, firefighting equipment - e.g. smoke hoods, training programmes and policy and the individual characteristics of fire fighters). Use a separate sub-heading for each factor.
4.5 Improving decision making	Where appropriate, summarise what is seen to improve decision making and why (e.g. training).
4.6 Charter's thoughts	Summarise in a sentence or two the key implications to practise from the study (i.e. what help better decision making).
4.7 Other	

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