



A study of the effectiveness of guarding to prevent falls through window openings

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To protect against the risk of persons falling through window openings in buildings, The Building Regulations 2010 (England) Approved Document O (ADO) – Overheating 2021 edition sets a guarding height minimum standard of 1100 mm for windows in upper floor dwellings (two meters or higher from the immediate external ground surface), which can be opened as part of the overheating avoidance / mitigation strategy for the building.

Peer-reviewed scientific primary papers, standards, building regulations, and guidance documents published between 1990 and December 2023 were sourced and reviewed for insights about heights of barriers and prevention of falls through windows. Fall risk was further characterised through anthropometric and biomechanical analysis of the ability of 800 mm and 1100 mm high guarding to protect against falls over them.

There was no empirical or epidemiological evidence in the literature comparing fall incidents at different heights of guarding.

A guarding height of 1100 mm is protective against tipping risks for practically the entire adult British population, whereas a guarding height of 800 mm is protective for less than 1% of the adult population.

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A study of the effectiveness of guarding to prevent falls through window openings

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Key Messages

To protect against the risk of persons falling through window openings in buildings, The Building Regulations 2010 (England) Approved Document O (ADO) – Overheating (2021 edition) sets a guarding height minimum standard of 1100 mm for windows in upper floor dwellings which can be opened as part of the overheating avoidance strategy for the building.

However, the ADO requirements/guidance for window guarding have been called into question on two fronts, one relating to the impact 1100 mm high guarding would have on the aesthetics of the building, and the other relating to the impact of fitted window restrictors (i.e., that their presence would compromise the overheating control strategy). As a result of these queries, HSE's Science Division was asked to gather and evaluate the current information about guarding for the prevention of falls from height through windows.

The research team sourced and reviewed peer-reviewed scientific primary papers, standards, building regulations, and guidance documents published between 1990 and December 2023 for insights about heights of barriers and prevention of falls through windows. Fall risk was further characterised through anthropometric and biomechanical analysis of the ability of 800 mm and 1100 mm high guarding to protect against falls over them.

There was no empirical or epidemiological evidence in the literature comparing fall incidents at different heights of guarding; research has so far only compared an absence of guarding with its presence.

The study found no evidence supporting the case for having different guarding heights for different storeys of a building on the basis of risk.

There was also no evidence to enable an assessment of the impact of dynamic actions on fall risk in relation to the two guarding heights. However, active play and climbing behaviours are generally reported to increase risk of children falling from windows.

The risk of a person tipping over guarding intended to prevent a fall is increased if the person's centre of mass (COM) position is above the guarding.

A guarding height of 1100 mm is protective against tipping risks for practically the entire adult British population, whereas a guarding height of 800 mm is protective for less than 1% of the adult population.

Executive Summary

Background

To protect against the risk of a person falling through window openings in buildings, The Building Regulations 2010 (England) Approved Document O - Overheating (2021 edition) sets a guarding height standard of 1100 mm for windows in upper floor dwellings (two meters or more from external ground surface), which can be opened as part of the overheating strategy for the building.

When considering the appropriate guard height, a guard height of less than 1100 mm (i.e., below an upright person's centre of mass [COM]) may result in the top end of the guarding acting as a pivot point. The pivot results in an upper torso segment of the body and a lower limb segment of the body, each with its own COM that may act separately. The likelihood of a person tipping over guarding partly depends on the mass of the segment and the distance (above) of its COM from the pivot.

However, the ADO recommendations have been called into question on two fronts: one relating to the impact high height guarding would have on the aesthetics of the building, and the other relating to the impact of fitted window restrictors, i.e. that their presence would compromise the overheating control strategy. As a result of these queries, HSE's Science Division was asked to gather and evaluate the current information about boundary guarding for the prevention of falls through windows and the prevention of falls from height.

Methods

A rapid evidence review of the literature was undertaken. This involved searches of databases and the selection of peer-reviewed scientific primary papers, standards, building regulations, and guidance documents published between 1990 and December 2023. The retrieved papers and guidance documents were analysed for insights about different heights of barriers and the level of protection they offer against window falls. Tipping risks were characterised by undertaking biomechanical and anthropometric analysis of the performance of barriers at 800 mm and 1100 mm high.

Findings

The difference in effectiveness between an 800 mm and 1100 mm high guarding for protection against falls

There was no empirical or epidemiological evidence comparing fall incidents between different heights of guarding; research has only compared an absence of guarding with its presence. Anthropometric analysis indicates that a guard height of 800 mm is likely to be

protective for less than 1% of the adult British population, whilst a guard height of 1100 mm is likely to be protective for >99%.

The most suitable guarding height for each of the different storeys of a building

The study found no evidence supporting the case for having different guarding heights for different storeys of a building on the basis of risk. The height of a barrier to protect against falls over it will not vary depending on the height of the drop on the other side of it. The majority of falls occur at a height equivalent to the second storey and falls from 1200 mm above the ground are considered potentially fatal, with serious injuries occurring from 600 mm depending on the properties of the impact surface. Falls of less than 600 mm have also been associated with an increased likelihood of head impact. Therefore, given that falls from relatively low heights are more prevalent and have the potential to cause serious injury, varying the guarding height as a function of the building storey level is contraindicated on the basis of risk.

The effect of different physical actions, such as opening a window or running, on risk at various guarding heights

There was no evidence to enable assessment of the impact of dynamic actions on fall risk. Active play and climbing behaviours are known to increase risk in children, with one report suggesting climb-over ability of at least 900 mm in 4-6 year olds. The risk is greater during warm weather when windows are left open for ventilation, particularly if parental supervision cannot be assured. It could be possible to provide additional answers to this question with further risk assessment and modelling work.

The effect of windowsills, wide enough to act as a horizontal barrier to the window opening, on the risk of falls.

Deeper sills may be protective for adults as they provide an area for fall recovery; however, for children, in one study investigating the characteristics of windows where falls had occurred, sills were found to be significantly deeper for households that reported fall accidents, compared to households which did not report fall accidents. Analysis of behavioural and biomechanical aspects of deeper sills may provide further understanding.

Conclusions

Review of the scientific literature

Few conclusions about optimal window guarding strategies can be drawn from the available academic literature. No empirical evidence directly comparing the impact of varying guard heights on any of the outcomes of interest was found. Prevention programmes demonstrate high efficacy of window guarding, but comparisons are only made against an absence of guarding. Further, academic literature is chiefly concerned with prevention efforts in children; only a single study was identified that was concerned with adults, and prevention was focused on intentional falling whereby guarding provided a psychological deterrent.

The majority of falls from windows were recorded in children under six years at heights equivalent to the second storey of a building. Peak fall incidence rates occur during summer months, presumably due to windows being opened for ventilation. Contributing factors to paediatric fall risk include low (<600 mm) sill height relative to finished floor level, large sill depth, or poorly placed furniture which may be readily scalable by children of 4-6 years. Cumulatively, it can be suggested that there may be increased fall over risk in children from guarding 900 mm or lower due to climbing behaviours.

Insights from standards and guidance documents

The general guidance provided for protection against falling at openable windows is installation of guarding that is at least 800 mm high from the floor.

A minimum guard height of 1100 mm is also suggested for windows on the second storey or above of dwellings. This is to satisfy safety requirements related to cleaning from inside and escape windows. It is during cleaning and when using the window as an escape route that people are most likely to need to open the window and reach out from it.

None of the documents reveal insights on the relative risk of fall accidents associated with different guarding heights and various window designs.

Biomechanical and anthropometric analyses

The risk of tipping over guarding is increased as the person's centre of mass (COM) position moves above the guarding level. Relative to a standing person, when dynamic and behavioural issues are ignored, guarding of a particular height may act as a pivot about which the upper body and lower body may act as two segments each with its own COM. The risk of a head-first tilt fall partly depends on the position and mass of the upper body and the position of its COM relative to the top of the guarding.

Based on a simple comparison of body size against barrier height, a guarding height of 1100 mm is protective against tipping over guarding for practically the entire British population (children and adults), whereas a guarding height of 800 mm is protective for less than 1% of the adult British population.

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1 Introduction

1.1 Background

To protect against the risks of persons falling through window openings in buildings, The Building Regulations 2010 (England) Approved Document O - Overheating 2021 edition sets a guarding height standard of 1100 mm. This is particularly for windows in upper floor dwellings (two meters or more above the external ground surface), which can be opened as part of the overheating strategy for the building.

Approved Document O also requires a minimum guarding height of 1100 mm where the change in floor level from inside to outside is ≥ 600 mm, amongst other criteria. According to Approved Document K (ADK; Section 3.2b, p.23), guarding may take the form of:

“any wall, parapet, balustrade, or similar obstruction... can resist, as a minimum, the loads given in BS EN 1991-1-1 with its UK National Annex and PD 6688-1-1”

Section 3.1a of ADK specifies guarding should be provided in any location:

“where it is reasonably necessary for safety to guard the edges of any part of a floor (including the edge below an opening window)”

Required heights are specified in ADK section 3.2a, diagram 3.1.

The ADO recommendations have been called into question by a special interest group (SIG) relating to:

- the impact that 1100 mm high guarding would have on the aesthetics of the building (lower than 1100 mm window guarding would be preferred, i.e., as low as possible but ideally back to the 800 mm height specified in ADK).
- the impact of fitted window restrictors, i.e. that their presence would compromise the overheating control strategy.

1.2 Theoretical basis for the guarding heights

The theoretical basis for a window guarding of 800 mm is protection of children, specifically, the need that the height of the guarding/sill should not offer an easy means for children to climb onto it, and the observation that children naturally want to look out of windows (Garvin and Murray, 2017). According to these authors, children generally use arms and elbows to aid climbing. The average elbow height for children aged up to 8 years is less than 800 mm. Sills above 800 mm may therefore reduce the risk of climbing. Also, it is preferable that children are able to look out of a window from a standing position on the floor so that they are less tempted to climb up. Anthropometric data for children show that

the average eye height exceeds 800 mm in 2-year-olds and 900 mm in 4-year-olds. The height of the guarding/sill above the floor need not, therefore, be lower than 800 mm.

On the other hand, the theoretical basis for a guarding height of 1100 mm is derived from the location of the centre of mass (COM) of an adult, which is located at approximately 55% of stature when stood upright, at the intersection of the frontal (front back divide), transverse (head tail divide), and sagittal (left right divide) planes of motion (NASA, 1978). See Figure 1.

Closely related, the centre of gravity (COG) is the point on the floor directly below the COM, and stability is maintained when the COG stays within the body's base of support (BOS). The maximum theoretical limit for the BOS is defined as the area outlined by the feet in contact with the supporting surface. However, the area of functional stability, where the body's COG can be controlled, is approximately 50 – 60% of the area of the BOS in healthy men when feet are hip-width apart (Holbein and Redfern, 1997). The forward functional stability limit is ~6 cm inwards from the edge of the big toes, whilst the backward functional stability limit was found to be ~5 cm inwards from the rear edge of the heel. This is illustrated in Figure 2.

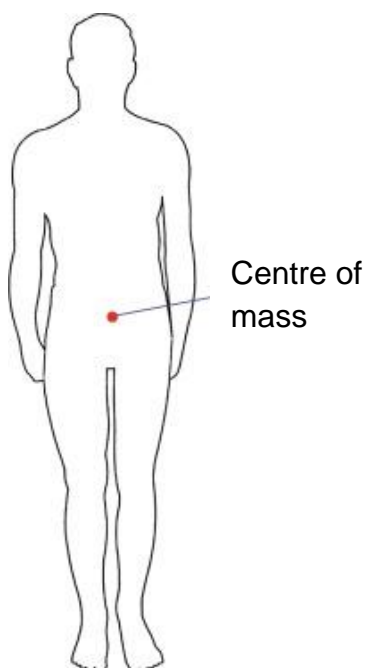


Figure 1 Illustration of the position of the centre of mass relative to stature in a standardised posture

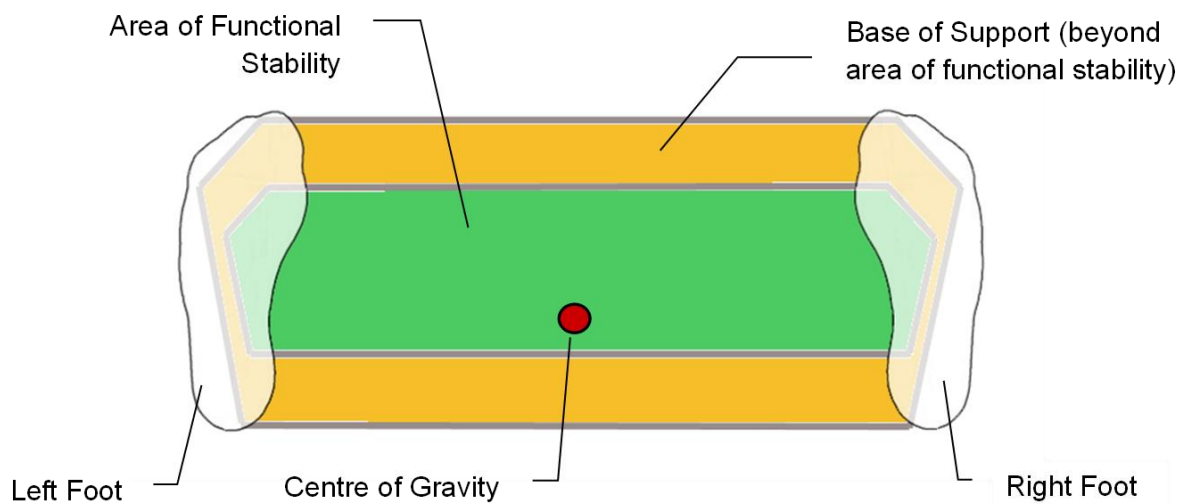


Figure 2 Diagram showing location of the body’s centre of gravity within the base of support and the area of functional stability while adopting a neutral standing posture (not to scale) (adapted from Holbein and Redfern, 1997)

When guarding height is low (below the upright person’s COM), the top of the guarding acts as a pivot point, splitting the body into an upper torso segment and a lower limb segment. Here, each segment has its own unique COM, as shown in Figure 3.

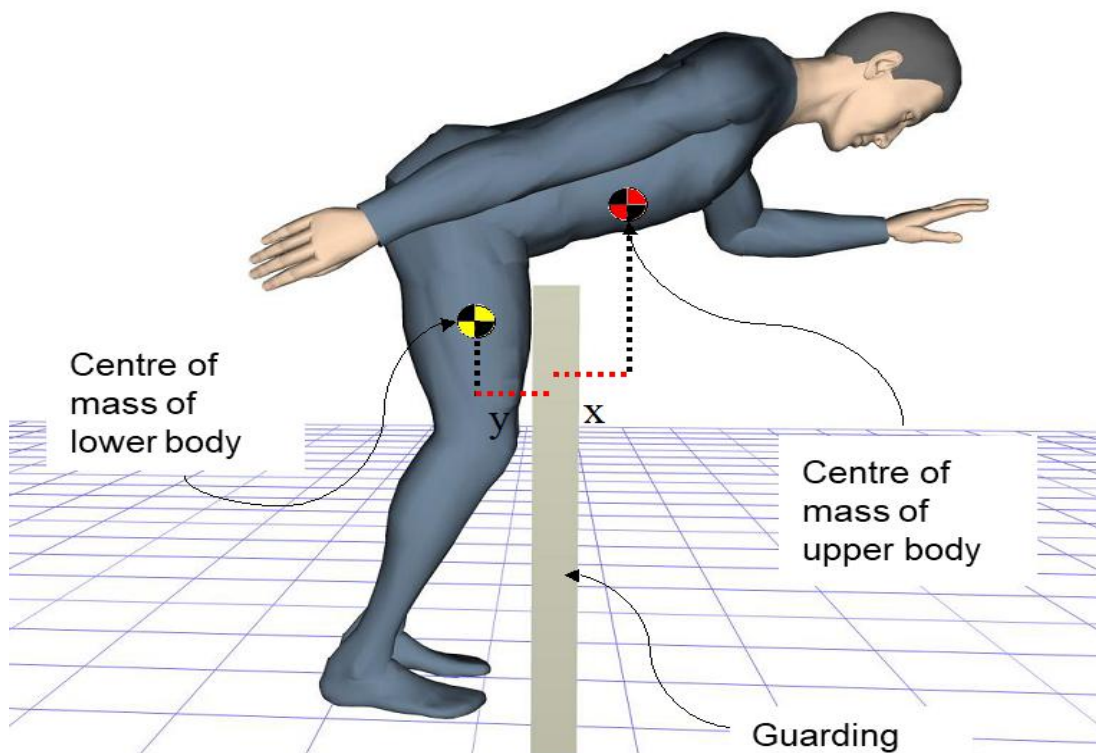


Figure 3 Illustration of the COM position of the lower body and the upper body for a person leaning over guarding that is low relative to their body size (not to scale)

The likelihood of the person tipping over the guarding depends on the mass of the segments and the distance of their COM from the pivot-top end of the guarding, as this determines the resultant rotational force that would act on the body as a whole.

Ignoring dynamic factors such as momentum, balance coordination, and fall recovery that may affect postural stability, the risk of a person tipping over the guarding is increased when they are close to the guarding with the body considerably bent over it. In such a position, the COM of the upper torso is beyond the guarding (the pivot), and a high proportion of body mass is also beyond the guarding. Thereby, a higher moment of force (rotational force) is induced on the body.

British anthropometric data suggests the overall COM of the combined upper and lower segments for a man of 99th percentile stature (i.e., only 1% of men are taller) wearing typical shoes, standing upright with arms by the side, is 1093 mm (Galley, 2005). Therefore a guard height of at least 1100 mm provides protection for most individuals against tip over falls.

1.3 Research aim

This study was commissioned to gather and evaluate current information about boundary guarding, the prevention of falls through windows, and falls from height. Four objectives were defined for the study:

- O1.** To investigate the basis for recommended guarding heights in standards and good practice guides (evidence that underpins existing, and past, guarding criteria).
- O2.** To investigate the difference in effectiveness between an 800 mm and 1100 mm high guarding for inadvertent falls and falls resulting from foreseeable misuse through window openings.
- O3.** To identify the optimal height for safety guarding that offers the best balance of protection and usability.
- O4.** To investigate the impact of windowsills on the risk of inadvertent falls through window openings and falls through window openings resulting from foreseeable misuse.

2 Methods

Two activities were undertaken in order to address the objectives:

- Review of scientific literature, standards, building regulations, and guidance documents on the heights of barriers that provide protection against falls from windows, and the influence of window sills on fall risk. This activity was undertaken to identify empirical evidence relating guard height to fall risk.
- Biomechanical and anthropometric analyses of the ability of barriers at 800 mm and 1100 mm high to protect against falls over those barriers including, where possible, the influence of window sills. This activity was undertaken to characterise the risk of falling over guarding at window openings (tipping risk).

The following questions were addressed:

- How effective is an 1100 mm guarding height requirement against falls through an opening, compared to a lower 800 mm requirement?
- What is the consequence, in terms of relative injury risks of falling through a window for different users, of setting guarding at heights of 1100 mm and 800 mm?
- How do the relative risks of falling through a window vary for different users at the specified guarding heights (800 mm and 1100 mm)?
- Which guarding height is most suitable for each storey?
- How do different actions, such as opening a window or running, affect fall risk at various guarding heights?
- Does having a window sill wide enough to act as a horizontal barrier at the window opening have an impact on the risk of falls?

2.1 Review of the scientific literature

2.1.1 Sourcing of papers and evidence gathering

A Rapid Evidence Review of the literature¹ encompassing epidemiological studies of falls from windows and from height, and the use of computer modelling for investigating falls, was undertaken. This involved the selection and review of peer-reviewed papers published between 1990 and October 2023.

The HSE Information Management (IM) Team undertook searches for relevant information on falls from window hazards / risk factors and window guarding interventions effectiveness and criteria in the scientific literature. Relevant databases (Gold Standard, OshUpdate, Web of Science, Ergonomics Abstracts, Proquest, and Science Direct) were searched to identify relevant peer-reviewed literature review papers or reports of

¹ Collins, A.M., Coughlin, D., Miller, J., Kirk, S. 2015. The Production of Quick Scoping Reviews and Rapid Evidence Assessments: A How to Guide

epidemiological studies published between 1980 and October 2023. Two searches were undertaken; a scoping search followed by a focused search. Inclusion and exclusion criteria for studies to be selected are presented in Table 1.

Table 1 Inclusion and exclusion criteria for studies to be included.

Inclusion criteria
<ul style="list-style-type: none"> ○ Period covered: 1990-October 2023 ○ English language only ○ UK and internationally-based research (if reported in English) ○ Evidence of a systematic research process ○ Sufficient data to assess validity ○ Policy documents, and conference proceedings ○ Regulations, standards, codes of practice, and good practice guides

The HSE IM Team searches were supplemented with desk-based searches by the project team using the search engines “Google” and “Google Scholar” to identify any readily available relevant literature review papers.

To facilitate the searches, terms related to hazards, exposures, musculoskeletal disorders, visual problems, and industries and work involving DSE were identified from previous publications and from discussion / consultation with subject matter experts. The following terms were then used during the searches:

- Building* / house* / office* home / window* / opening* / balcon* / storey / “building opening*”
- “fall* accident*” / injur* / “fall risk*” / “fall* from height*” / “height of fall” / “falls from building opening*” / fall* / accident* / “falls from windows”
- Barrier* / “falls prevention” / “guarding height” / “guard rail*” / “injury prevention” / “protective device*” / balustrade* / restrictor* / “window-limiting devices” / “fall protection*” / “guard rule*” / “guard standard*” / intervention* / “effectiveness of guarding / window protect* devic* / balustrade* / ”window guard*” / “fall prevention” / “guard rail*” / “guard height*”
- Specification* / characteristic* / standard* / effective* / evaluat*

These search terms were not exhaustive, and they aided development of search algorithms using Boolean operators (AND / OR / NOT). The summary information (abstracts) from the literature review papers identified was reviewed by two authors to identify those worthy of reviewing in full.

Focused searches of databases such as MEDLINE, OSHROM, and Ergonomics were undertaken as well as desk-based Web searches using the search engines “Google” and “Google Scholar,” to identify any relevant literature. Search terms and algorithms were developed in consultation with the end-users.

2.1.2 Selection of papers

Selection of papers was done in two phases. First, duplicate publications in the outputs from the searches were removed, and the titles and abstracts of the remaining publications were read by two authors and screened against the set inclusion and exclusion criteria. The abstracts that satisfied one or more of the inclusion criteria and did not satisfy any of the exclusion criteria were selected for the study.

Secondly, the full paper versions of the abstracts selected from the phase one process were sourced, read, and appraised against the aim and research questions. The papers finally selected for full review were those that addressed one or more of the questions outlined at the start of this section.

2.2 Anthropometry and biomechanical analysis

The height of a person's COM relative to the top of a safety barrier is one factor which affects how readily they might tip over a barrier.

2.2.1 Anthropometric analysis using computer modelling

Computer manikins were generated using the Jack Human & Environment modelling software version 9 (hereafter referred to as the 'Jack software'), to have COM heights of 800 mm and 1100 mm from the floor respectively (computed by the software, and based on standing heights).

The proportions of the population that are taller than the indicated corresponding standing height values were determined using these manikins and the Peoplesize 2008 Professional anthropometrics software (version 2.01, Open Ergonomics Ltd hereafter referred to as 'Peoplesize software'). Separate population databases were used for adult British women and men, and both databases covered the age ranges of 18 to 64 years and 65 years and over.

Using the population database for men, the Peoplesize software was used to identify the standing height of a 50th percentile man (i.e., the standing height whereby 50% of the male population are taller and 50% are shorter) and for a 99th percentile man (i.e., the standing height whereby 1% of the male population are taller and 99% are shorter). The Jack software was then used to generate manikins of 50th and 99th percentile standing heights, and to also compute/locate their COM (standing upright with hands by the side).

Barriers of 800 mm and 1100 mm heights from floor level were generated within the Jack software and the manikins placed close against the two barriers. The COM height of each manikin was highlighted by a marker to provide visual comparison against the barriers.

Images showing the manikins and barriers close together were exported from the Jack software for use in this report.

2.2.2 Statistical anthropometric analysis

Percentile measures of the height of the COM from the floor were computed for the British population of adult women and men (aged 18 years and over) based on the stature measures and the assumption that COM height is 0.56% of stature for both women and men (Davidovits, 2019). The following stature distribution values were used:

- Women: mean = 1623 mm, standard deviation = 62 mm;
- Men: mean = 1759 mm, standard deviation = 70 mm

(PeopleSize 2008 Professional software version 2.01).

The stature measurements are for height when standing erect with hands down by the sides (i.e., Figure 1).

Cumulative distribution plots of the COM measures were created (i.e., Ogive curves). The 800 mm and 1100 mm guarding heights are shown on the graphs as straight lines running across each plot.

3 Results

3.1 Review of the scientific literature

3.1.1 Overview of searches

Table 2 presents an overview of the abstracts identified from the searches undertaken by the HSE Information Management Team and the project team and full papers sourced for review.

Table 2 Overview of the selection of papers process

Decisions for abstracts	HSE IM Team		Project team	Total
	Scoping (35)	Focused (33)		
• Relevant	7	0	3	10
• Somewhat relevant	7	7	6	20
• Not relevant	15	13	15	43
• Duplicate abstract	5	12	0	17
• Triplicate abstract	1	0	0	1
Full papers sourced	14	7	9	30

Following the review of the abstracts returned from the searches undertaken, the abstracts for 30 papers considered relevant or somewhat relevant were selected for review and the full papers were sourced. These papers form the basis of the findings presented. Of these 30 papers, 11 were shown to be relevant, 16 were shown to be somewhat relevant and 3 showed no relevance to the aims and / or research questions.

3.1.2 Effectiveness of guarding at 800 mm vs 1100 mm

New York City's 'Children Can't Fly' fall prevention programme demonstrated an overall 96% reduction in child window falls between 1978 and 1980 following introduction of window guards to previously unguarded windows. In addition, a 65% decrease was observed following introduction of landlord liability, demonstrating the importance of enforcement (Toprani et al., 2018). However, neither contemporary nor current sources provide specific details on the required guard height or decision making used in this programme (Toprani et al., 2018, Spiegel and Lindaman, 1995). This is consistent across wider academic literature, where the effectiveness of guarding is determined through epidemiological comparisons of areas where guarding is not provided, as opposed to a comparison of various guarding heights.

Across generic fall characteristics (i.e., not necessarily from a window), one source reported that 75% of incidents with known guarding heights occurred where guarding was lower than 1100 mm (Cayless, 2001). In the U.K., Riley et al. (1998) criticised the 900 mm

stair guarding height set out in ADK after observing children aged 4 – 6 years were able to climb over 900 mm. Similarly, Istre et al. (2003) report that in 5 of 17 reported balcony falls children had climbed over guarding (height not stated). Pertinently, data from the Northwest of England between 2015 and 2020 reported that children under six were most likely to suffer a fall-based accident (Apostolopoulou et al., 2023). Combined, this suggests a guard of less than 900 mm height may not be suitable for the most vulnerable populations. However, it should be noted that control of circumstances and behaviours are not factored into these analyses (e.g., window vs balcony or stair fall, children climbing or playing, supervision, etc.).

Only a single study was identified that examined the risk of adults falling from windows (Mohl et al., 2012). This study focused on the efficacy of a single guard rail in preventing deliberate fall attempts (i.e., suicide). The authors acknowledged that guarding here aimed to provide a psychological deterrent, rather than an insurmountable physical barrier. The guard rail used was placed at a height of 1130 mm from the floor, and 180 mm above the windowsill; however, the authors were unable to comment on the effectiveness of this specific guarding height due to study design (e.g., suicide method substitution) and data protection laws. Regardless, it may be prudent to consider the psychological impact of changes to guard height in suicide prevention.

3.1.3 Suitability of guarding heights at different storeys

A number of authors report the second storeys of buildings are associated with the highest incidence of falls. In Australia between 1998 and 2019, Houlton et al. reported 47 falls from windows on the first storey, 110 from the second storey, 34 from the third storey, and 5 from the fourth (Houlton et al., 2021). There were no reported incidents at higher levels. Similarly, Flaherty et al. reported that the majority of relevant falls in the U.S. between 2007 and 2017 were from the second storey (n = 285, 57.4%) (Flaherty et al., 2021). Istre et al. report 75% of the falls that occurred in Dallas between 1997 and 1999 were from the second storey, compared to 19% and 1% at the third and fourth storeys respectively (Istre et al., 2003), whilst Vish et al. report 11, 53, 24, and 1 falls from the first, second, third and fourth storeys respectively in Chicago between 1995 and 2002 (Vish et al., 2005). In Switzerland, Mayer et al. report 27 (87%) fall accidents were from the third storey or lower (Mayer et al., 2006). Grivna et al. were the only authors reporting a higher incidence of falls between the fifth and tenth storeys than between the first and fourth storeys from a UAE study based on newspaper articles (33, vs 29 falls at storeys 0 – 5) (Grivna et al., 2017). Keall et al. estimated the fall risk posed by having no guarding on windows at the second storey and above using scenarios of high (6.5% of child fall hospitalisations are from high windows with 10% prevalence of window guards) and low risk (1.5% of all child fall related hospitalisations are from high windows with 50% prevalence of window guards). Per year, the authors attributed 18.3 deaths and 5700 disability adjusted life years in the high-risk scenario, and 3.0 deaths and 930 disability adjusted life years in the low risk scenario (Keall et al., 2011). Whilst these data cannot address optimal guarding heights at different storeys, nor U.K. risk, they do caution against reduced guarding at lower levels.

Findings from papers that reported fall heights and injury diagnoses are summarised in Appendix 1. None of the papers identified directly associated injury outcomes with guard heights at a given building storey. The majority of reported falls occurred from the second storey, and the most frequent site of injury was the head (including concussion, fractures, and contusions). The second highest prevalence was for upper and lower limb fractures, followed by similar prevalence for abdominal, thoracic, or general trunk injuries. Pressley and Barlow (2005) report an age-related pattern of injury, whereby younger children (<10 years) were more likely than older children to suffer a head injury and older children had a more even distribution of injuries. Across studies, mortality rate ranged between 0 and 19%.

3.1.4 Impact of various actions on relative risk at various guard heights

There was minimum information about actions undertaken that increase falling risk relative to a particular guarding height. Cayless (2001), citing building safety regulators (Cox and O'Sullivan, 1995), previously recognised that opening windows, climbing through windows, or children playing at windows are potentially dangerous actions. In children, commonly reported contributors to falls are spacing greater than 100 mm between guard railings, and window openings situated within 600 mm of the floor (Istre et al., 2003) which can be climbed by children if unguarded (BCA, 2016). In adults, Cayless (2001), citing Webber and Aizlewood (1993), indicated that overbalancing and slipping after deliberately climbing over guarding on to the window sill, are contributory factors.

Although no empirical evidence was found which experimentally assessed the efficacy of guard heights against these actions, the known biomechanical principles outlined in the introduction should be considered, as well as the climbing capabilities of children discussed in the previous section. Galley (2005) notes that child falls from buildings from 1200 mm high to the ground are considered potentially fatal, and that serious injuries are possible in falls from 600 mm depending on impact surface. Falls from less than 600 mm have also been associated with an increased likelihood of head impact (as opposed to feet).

Additionally, it has been observed that children under six years, particularly boys, are most frequently at risk of a fall from a window, with placement of furniture that can be climbed upon near a window being a contributing factor (Committee on Injury and Poison Prevention, 2001, Flaherty et al., 2021, Grivna et al., 2017, Houlton et al., 2021, Lallier et al., 1999, Spiegel and Lindaman, 1995, Vish et al., 2005). Lehman and Schonfeld (1993) report that 81% of child falls from window incidents they studied involved active play, whilst Mayer et al. (2006) report that 49% of child fall incidents they studied involved prior climbing of furniture.

As ADO pertains to the mitigation of overheating risk in buildings and the intention to provide adequate means to remove heat from an indoor environment, it should be noted that epidemiological evidence suggests a consistent pattern of warm weather-associated increases in child window fall incidence across summer months (Apostolopoulou et al., 2023, Grivna et al., 2017, Istre et al., 2003, Keogh et al., 1996, Lallier et al., 1999, Kocak et al., 2012, Pressley and Barlow, 2005, Sarkar et al., 2014, Vish et al., 2005). Authors

have attributed this to windows being kept open and a lack of supervision (e.g., around mealtimes), compounded by low-socioeconomic status that possibly results in a lack of time / resources dedicated to supervision.

3.1.5 Impact of windowsill-created horizontal space on fall risk

In their technical guidance, the Building Control Alliance (BCA) cite Childdata (Norris and Wilson, 1995) suggesting that around 3% of 4-year-old children can step up (while climbing) 550 mm, and that any sill lower than 600 mm from a floor may therefore be climbable by children (BCA, 2016). Where a windowsill is less than 600 mm above the finished floor level, a guard of at least 700 mm above the sill height is recommended by the BCA. The BCA report the 95th percentile of 4 year old statures as 1200 mm, hence, if a child were to climb the windowsill, the required minimum guard height to maintain static upright standing stability is 700 mm ($1200 \times 0.56 = 672$ mm). Istre et al. (2003) support this notion, observing that a climbable windowsill situated within 600 mm of the floor was present in all cases of child falls where furniture climbing was not a factor. Despite this recommendation, consideration should also be given to the 900 mm climbing capability identified by Riley et al. (1998).

Only one study characterised the sill depth of windows where falls occurred. Johnston et al. (2011) compared sill depth and height between windows where a fall occurred (mean age 4 years; denoted a 'case window') and control windows (those where a fall did not occur). The authors noted that the height of the windowsill from the floor was not different between case windows and matched controls (both ~760 mm), but case windows were more likely ($p < 0.05$) to have a deeper sill depth (159.5 ± 86.4 vs 109.5 ± 32.3 mm). However, control windows were selected from the homes of age and gender matched patients who did not experience a fall. While it may be that the average sill height satisfies the stability control issue, the authors fail to report on factors such as climbing risks positioned near windows or supervision, which may explain the fall incident at case windows beyond sill depth alone.

For adults, Galley (2005), citing Fattal et al. (1976), suggests that the depth of the sill can decrease fall over risk when the horizontal depth is greater than 152 mm, as this creates a horizontal space for fall recovery. A vertical guard height of 1220 mm less the horizontal sill depth was proposed, providing the overall vertical height is not less than 760 mm (e.g., if a windowsill was 250 mm, the proposed vertical guard height would be 970 mm). No experimental or epidemiological evidence was found to corroborate this view.

3.2 Insights from standards, regulations and guidance

Standards, regulations and guidance are all terms that those with health and safety roles and responsibilities are generally familiar with. In the eyes of the law there are real differences between them.

Standards are documented requirements that establish consistent practices and characteristics. These can apply to activities, products, or services. Standards can be developed by international organizations, industry associations, and regulatory bodies, and

they serve as a reference for ensuring uniformity, safety, or quality. Whether British ('BS') or European ('EN'), standards generally have no legal effect in themselves, however, they can be legally binding when they are incorporated into the law.

Regulations form the backbone of compliance as they are legally binding rules established by government agencies or legislative bodies. Typically, they stem from laws and aim to protect various elements like public health and the environment. Consequently, compliance with applicable regulations is mandatory, and failure to adhere to them may result in criminal / administrative sanctions.

Guidance provide non-binding recommendations, best practices, and suggestions for achieving specific objectives. They are typically developed by authoritative bodies, such as government agencies, industry associations, or expert committees. While adherence to guidance is not legally required, they serve as widely accepted best practices within a particular field. Guidance also tends to be more specific than standards and is only used as a reference or interpretation of a specific ruling.

The searches undertaken found 13 standards and regulations documents, and 5 guidance documents, which are detailed in Appendix 2. Four of the standards/regulations and 4 of the guidance sources provided some insights relevant to the study. The insights obtained from the document are not intended to be exhaustive, but instead look at specific relevant elements.

3.2.1 Definition of guarding

A definition of guarding is given in Building Regulations 2010 – ADO and ADK:

- A barrier that denies people access to another area, for example the floor below.

Another definition of guarding is given in HSE Information sheet (HSIS5)-Falls from windows or balconies in health and social care:

- Screen or barrier to prevent service user access to a window or balcony edge.

Yet another definition is given in the ASTM F2090:2021 standard, as a fall prevention window guard:

- A device designed to fit into or onto a window to prevent a child from passing or falling through an open window.

3.2.2 Relevant standards and building regulations

BS 8213-1:2004 Windows doors and roof lights. Design for safety in use and during cleaning of windows, including door-height windows and roof windows, Code of practice.

The guidance given in this standard is in addition to legislative requirements (ADK), which take precedence. This part of the standard gives recommendations on the design, construction, operation, and maintenance of windows, including door height windows, for

safety in use and during cleaning, including safe opening characteristics and the arrangement of window controls, to safeguard occupants and passers-by.

The specific information provided about guarding is as follows:

Section 5.5 – Guarding, page 8

When assessing risks, factors including the configuration and location of the opening light, the sill height above floor and adjacent ground level, and the likely occupancy should be determined. These factors could indicate the need for guarding to 1 100 mm above floor level for stability when leaning out (this height corresponds approximately to the centre of mass of an adult).

The height above floor level of the lowest part of any opening light is a particular factor to consider. It is recommended that where this is below 1 100 mm the opening should be guarded to that level, unless giving safe access to ground level or a fully guarded area.

Where there is a drop of more than 600 mm from floor level to adjacent ground level (in dwellings; less in other types of residential accommodation), inward-opening door height windows should have guarding 1100 mm high conforming to BS 6180 (unless giving access to fully guarded areas). Guarding should be designed so that it is not easily climbable by children, e.g. by the use of vertical rather than horizontal bars, or by sheet material. The tops should be formed to discourage use as temporary seats. There should be no opening in the guarding through which a sphere of 100 mm diameter could pass.

Guarding should be permanently fixed and should not be detachable to permit windows to be opened. The location of the guarding and choice of window type should be considered together to avoid obstruction when opening the window.

Other relevant information provided includes:

Section 5.1 – Basis of design

Windows should be easy to operate, open safely without being a hazard to passers-by, and minimize the risk of falling through. Safe use depends on:

- Window location
- Window type
- Safety fittings
- Guarding
- Window construction and installation

Section 5.2 – Window location (page 4)

Appropriate types and configuration of windows should be provided to help to reduce vertigo-related problems, such as the choice of narrower, inward-opening lights with external guarding to 1100 mm above floor level.

Clause 5.5 – Guarding.

When assessing risks, factors including the configuration and location of the opening light; the sill height above floor and adjacent ground level, and the likely occupancy should be determined. These factors could indicate the need for guarding to 1100 mm above floor level for stability when leaning out (this height corresponds approximately to the centre of mass of an adult).

The height above floor level of the lowest part of any opening window is a particular factor to consider. It is recommended that where this is below 1100 mm the opening should be guarded to that level, unless giving safe access to ground level or a fully guarded area.

BS 6180:2011 Barriers in and about buildings – Code of practice

As a code of practice, this British Standard takes the form of guidance and recommendations. It gives recommendations and guidance for the design and construction of temporary and permanent barriers to be provided in and about buildings and places of assembly, such barriers being positioned and designed to protect persons from various hazards and to restrict or control the movement of persons or vehicles. Its areas of application include walls, glazing and other elements of buildings or structures where such elements act as protective barriers. The document provides the following specific information about guarding:

Section 5 Preliminary considerations

5.1 Barrier design (page 6)

Where the hazard is a change in level, pedestrian guarding should be erected in dwellings where the difference in adjacent levels is greater than 600 mm. Guarding should also be erected in buildings other than dwellings where there is a difference greater than 380 mm, to take account of the greater number of building users and their possible lack of familiarity with the layout.

Section 6 Design criteria (Table 3)

Table 3 Minimum barrier heights. Reproduced from BS 6180:2011 Barriers in and about buildings – Code of practice, page 7

Use	Position	Height
Single-family dwelling	a) barriers in front of a window	800 mm
	b) stairs, landings, ramps, edges of internal floors	900 mm
	c) external balconies including Juliette balconies, edges of roofs	1 100 mm
All other uses	d) barrier in front of a window	800 mm
	e) stairs	900 mm
	f) balconies and stands, etc. having fixed seating within 530 mm of the barrier	800 mm
	g) balconies and stands, etc. having fixed seating within 530 mm of the barrier, provided the sum of the barrier width and the barrier height is greater than 975 mm	750 mm
	h) other positions including Juliette balconies	1 100 mm

Building Regulations 2010 – Approved Document O (ADO).

As an approved document, this publication sets out what, in ordinary circumstances, may be acceptable as reasonable provision for compliance with the relevant requirements of the Building Regulations to which it refers. The document provides relevant specific information about guarding, as follows:

Section 3. Ensuring the overheating mitigation strategy is usable.

Protection from falling (page 13)

3.8 Openings which are intended to be open for prolonged periods to reduce overheating risk might pose a higher risk of falls from height. Only the proportion of openings which can be opened with a very low risk of occupants falling from height should be considered to form part of the overheating mitigation strategy.

3.9 Openings that can be opened wider than 100 mm may form part of the overheating mitigation strategy where they meet all of the following conditions.

- a. Window handles on windows that open outwards are not more than 650mm from the inside face of the wall when the window is at its maximum openable angle.
- b. Guarding meets the minimum standards (height of 1100 m if change in floor level between inside and outside is more than 600 mm).
- c. Guarding does not allow children to easily climb it. For example, horizontal bars should generally be avoided.

3.10 Guarding for large openings could include, but is not limited to, either of the following.

- a. Shutters with a child-proof lock.
- b. Fixed guarding.

Building Regulations 2013 – Approved Document K (ADK).

This document sets out what, in ordinary circumstances, may be acceptable as reasonable provision for compliance with the relevant requirements of the Building Regulations to which it refers. It provides the following relevant specific information about guarding:

Section 3 – Protection from falling

Siting of pedestrian guarding (page 23)

3.1 Provide guarding where it is reasonably necessary for safety to guard the edges of any part of a floor (including the edge below an opening window, gallery, balcony, roof, any other place to which people have access, and any light well, basement or similar sunken area next to a building).

Guarding design (page 23)

3.2 Depending on building category and location, guarding should be provided to a minimum height of 800 mm, and up to 1100 mm.

3.3 In a building that may be used by children, under five years of age during normal use, guarding should be constructed to prevent children from being held fast by the guarding and, to prevent children from readily being able to climb the guarding; avoid horizontal rails.

3.2.3 Relevant guidance documents

Building regulations guidance note – NHBC BUILDING CONTROL: Glazing, guarding and restrictors in dwellings, NHBC 2014, H252 05/14.

This document notes that Part N of the Building Regulations seeks to ensure that where people are likely to come into contact with glass it is unlikely to cause injury or the glazing will resist impact or be shielded or protected from impact. Secondly, it notes that glass is increasingly being used in locations that require it to act as guarding from falling, and that in these cases the glazing needs to comply with the requirement and guidance in ADK of the Building Regulations – Protection from falling.

The publication provides the following relevant specific information about guarding:

Fixed low-level glazing (refers to a window that is not openable)

Where the design incorporates low level glazing, less than 800 mm above internal floor level such as a window, that is fixed (not openable), glazing and the framing

will need to function as guarding where the difference in floor levels exceeds 600 mm. The glass should be designed to resist the forces referred to in the relevant British Standards. Alternatively, suitable guarding, that resists the forces referred to and complies with ADK with respect to height and non-climbability must be provided.

Openable low-level glazing

Low-level glazing is glazing that is less than 800 mm above the internal floor level.

Where the design incorporates low level glazing (less than 800 mm above internal floor level) that is not fixed, e.g., an openable window, the glazing will still need to act as guarding where the difference in height exceeds 600 mm.

Openable low-level glazing as escape windows

Low level windows fitted with restrictors that can be easily released, would be acceptable but only where suitable guarding is also provided. To be suitable for means of escape, the top of the guarding should be between 800 mm and 1100 mm above the floor level and the minimum dimension, 450 mm, and area of the opening, 0.3 m², should be measured from the top of the guarding up to the top of the opening.

BRE Publication: Garvin, S. and Murray, I. (2017), An assessment of the current position in Scotland regarding window opening light restrictors in domestic buildings, Scottish government, BRE Scotland Report A16624573.

This publication reports on an investigation of the situation with regards to the installation of window opening light restrictors to new windows in dwellings, to offer additional protection to occupants, in particular children. It notes that deaths and serious injury occur to people in buildings as a result of various activities, and as such designers need to consider all aspects of design carefully to minimise risks inherent in any building. The study included a review of standards (primarily British and European standards), building regulations in the UK and other information. The review was not intended to be exhaustive, but instead looked at the critical elements.

The report identifies the following relevant specific information about guarding from the documents reviewed:

Criteria for guarding

Section 3.5 Other literature

- Page 20-NHBC (last sentence). For escape windows, guarding should be provided in addition to releasable restrictors.
- Page 21-BRE publications.

- Sills – these should be designed to discourage climbing or using them as seats or standing platforms; they could be sloped or eliminated completely. The height of the sill should not offer an easy means of climbing onto it. Children generally use arms and elbows to aid climbing. The average elbow height for children aged up to 8 years is less than 800 mm. Sills above 800 mm may therefore reduce the risk of climbing. Children naturally want to look out of windows and so a sill height of no more than 800 mm allows most 2 year old children a view out. This is also beneficial for older people, especially if they use a wheelchair.
- Guarding – should be considered to prevent children climbing up to windows, especially if the sill height is below 800 mm.
- Height above the floor – The height of the lowest part of the window opening should be such as to reduce the likelihood of access by young children, reduce the risk of vertigo and enable the cleaning of windows in a safe manner. It should also prevent occupants who overbalance or fall in the room from falling out the window. In blocks of flats, from the second floor upwards, the lowest part of the window should not be less than 1100 mm from the floor. However, as 70% of fatal accidents occur at first floor level, this height requirement should also apply to the first floor.

BRE Publication: BRE Information paper – Falls from domestic windows (Webber and Aizlewood, 1993).

This publication summarises a statistical study of the occurrence of falls from windows using data from the Home Accident Surveillance System and Coroner’s inquest notes. It describes the principal findings and their likely implications for architects, window designers and building owners and occupiers. It gives a number of recommendations for provision of guarding on windows, which can be summarised as follows:

- Height of sill and window opening should be a minimum of 800 mm above the interior floor.
- For windows on the ground floor, additional protection in the form of a safety rail / guarding is required where the opening height is below 800 mm.

The specifics of the relevant information provided are as follows:

Design implications

- Sill design. If possible, sills should be designed to discourage their use as seating or standing platforms, or for climbing – they could be sloped, or eliminated altogether. Children generally use their arms and elbows to aid climbing. The average elbow height for children aged up to 8 years is less than 800 mm. Sills above 800 mm may therefore reduce the risk of climbing. children naturally want to look out of windows. it is preferable that they are

able to do this from a standing position on the floor so that they are less tempted to climb up. Anthropometric data for children show that the average eye height exceeds 800 mm in 2-year-olds and 900 mm in 4-year-olds. The height of the sill above the floor need not, therefore, be lower than 800 mm.

- Window guarding. A safe guard or barrier, removable in case the window is needed as an emergency escape, could be placed across the entirety of a window, covering it all, or up to a minimum height of approximately 1300 mm. This height is above that which a young child may reach by standing on a chair, yet is also the average height of the armpit of adults², enabling them to reach over the guarding to clean the outside of the window safely.
- Height of the window opening above the floor. The height of the lowest part of the window opening should be such as to reduce the likelihood of access by young children, reduce the risk of vertigo and enable the cleaning of windows in a safe manner. It should also prevent occupants who overbalance or fall in the room from falling out of the window.
- The Building Regulations (ADK) indicate that the lowest part of the window be at least 800 mm above the floor; otherwise it should be guarded to a height of 800 mm.
- In blocks of flats or maisonettes, where windows may have to be cleaned from the inside by occupants, BS 8213 recommends that from the second floor upwards, the lowest part of the window opening should be at least 1100 mm above the floor for the second storey upwards. Sinnott (1985) recommends a minimum height of 1350 mm. According to this author, 1350 mm is considered to be well above the height that a child could reach by standing on a chair or table.

Window design

- The study did not reveal the relative risk of fall accidents associated with window design.

Building Control Alliance (BCA) technical guidance note 16 Guarding to openable windows with low sill heights.

BCA technical guidance notes are for the benefit of its members and the construction industry, to provide information, promote good practice and encourage consistency of interpretation. They are advisory in nature.

This guidance note 16 concerns the requirements of Building Regulations with regard to protection from falling in relation to openable windows (including French windows) in external walls to dwellings. It applies where there is a risk of falling from a height of more than 600 mm. A key issue of concern identified for redress is the observation that

² Note: guarding set at average adult armpit height actually only enables half of the adult population to readily reach over, not all the adults in the population.

increasingly, designers are incorporating deeper windows or French windows with low level sills into their dwelling designs. The sills to these windows can provide platforms to aid climbability by children. As such, the recommendations for guarding height to windows may not be appropriate to afford the required protection and to ensure the safety of the occupants and hence achieve compliance with the functional requirements.

The publication provides the following relevant information for guarding:

Guidance (page 1-3)

French windows. When considering guarding to French windows, a minimum guard height of 1100 mm measured from finished floor level is required to ensure adequate protection from falling.

Where an upstand is formed (up to 300 mm high) to the base of the opening, then an 800 mm guard height should be maintained above this level.

Openable windows with low sill height. When the sill height is between 300 mm and 600 mm from finished floor, a minimum non-climbable guard height of 700 mm from the sill should be maintained (i.e., a guard height ranging from 1000 to 1300 mm).

When the sill height is between 600 mm and 800 mm, the guard height should be a minimum of 800 mm from finished floor.

When the base of an openable window is less than 700 mm above the sill, and the sill is less than 600 mm from floor, additional guarding such as fixed glazing is required. It should be provided to be a minimum of 700 mm above the sill level and designed to act as a barrier to falling and also to provide impact resistance.

Conflict between barrier height and the use of a window as a means of escape (page 4).

Whilst the Building Regulations (ADK) contain a minimum height for guarding to openable windows for the purpose of protection from falls, there is also a maximum height to satisfy means of escape. The base of the window opening in this case needs to be no more than 1100 mm above floor level to satisfy requirements for escape window.

In certain situations, or when the above guidance is applied retrospectively to windows with low sill heights that have been installed without the necessary forethought, conflicts may arise. This conflict is most likely to occur where the sill height is between 400 mm and 600 mm above floor level, as the requirement to maintain a 700 mm barrier height above this level will then cause the overall height of guarding to exceed 1100 mm.

National Housing Building Council (NHBC) Technical newsletter August 2004 Issue 30, Standards Extra.

This publication provides relevant information about guarding, as follows:

Section 2. Balustrading – What is easily climbable?

In this section of the publication is a BRE study that investigated the ability of four, five, and six-year-olds to climb six different barrier designs: intricate, horizontal bars with overhang inside, diagonal bars, solid infill, vertical bars, and vertical bars with overhang inside (Figure 4). Unfortunately, the height of the barriers investigated was not stated.

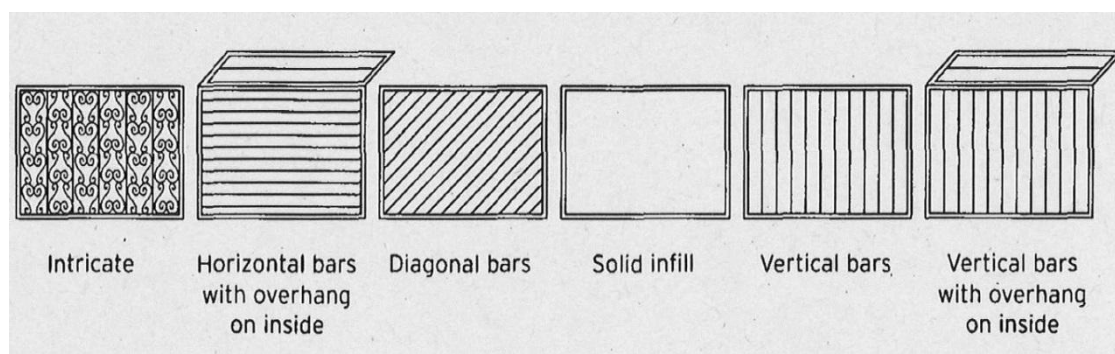


Figure 4 The tested guarding designs. Reproduced from National Housing Building Council (NHBC) Technical newsletter August 2004 Issue 30, Standards Extra.

The results showed that:

- All 6 year olds were able to climb the intricate and horizontal bar designs.
- Eighty percent of the oldest group (6 year olds) could climb the solid infill design.
- None of the 4 year olds were able to climb the solid infill design or either vertical bar design.
- The vertical bar designs were found to be the hardest to climb; however 35% of the oldest children were still able to climb over these designs.
- The intricate design was found to be the easiest to climb.

Section 7. Protection from falling – Opening windows with low sill height

There are various considerations in the design of openings to provide safety from falling and one key consideration is the height of the sill.

Requirement K2 of the Building Regulations (ADK) in England and Wales requires that barriers be provided to protect people from falling from a height of more than 600 mm.

For houses and flats, the guidance in Approved Document K2 specifies a minimum guard height of 800 mm to window openings in the external wall. This would normally be achieved by forming window openings at least 800 mm above finished

floor level. The wall beneath the opening is therefore considered to be the barrier to falling.

Where window openings are formed less than 800 mm from the finished floor permanent guarding should be provided to the opening in accordance with the design requirements specified in Approved Document K2, section 3, paragraphs 3.2 and 3.3.

3.3 Anthropometry and biomechanical analysis

3.3.1 Computer modelling

Justification for the use of modelling to consider falls risks from windows

Mathematical and computer models have been used by researchers and investigators to help understand the anthropometrics (body measurements) and biomechanics (body movement and forces) that play a role in the risk of falls from height, windows and balustrades (Adamec et al., 2010, Han and Park, 2022). There are ethical issues with performing tests using people, so mathematical and computer models can provide useful data where there is a lack of data from falls incidents.

Models can help examine the comparative risks of 800 mm and 1100 mm high barriers, however, caution needs to be applied in their use and interpretation. The computer modelling employed for the current work does not consider behavioural and/or dynamic factors such as momentum, balance coordination, postural stability and fall recovery that may affect the risk of falls from windows and balustrades. The limited search of the literature in the field of computer modelling of falls indicates there have been some attempts to consider dynamic factors, but the modelling and validation of results is complex and currently requires considerable time and computing resources. Mathematical models for calculating the static tipping point of a human body over a barrier are available.

Because the height of a person's COM relative to the top of a safety barrier is one factor which affects how readily the person can tip over the barrier, some basic analyses were performed with computer human manikins to compare the COM of the British population (18 years and over) with barrier heights of 800 mm and 1100mm.

Outputs from the modelling

The following estimated values were sought from the modelling work:

- Proportion of the British population of men and women with a COM at or below 1100 mm
- Proportion of the British population of women with a COM above 800 mm
- Difference between the height of the COM of a 50th percentile male manikin and the 800 mm barrier
- Difference between the height of the COM of a 99th percentile male manikin and the 800 mm barrier

Table 4 presents a summary of the tests that were performed, and the results. Figure 5 and Figure 6 provide images of the manikins referred to in Table 3, which demonstrate the manikins in relation to 1100 mm and 800 mm barriers, respectively. Manikins in blue indicate a man and woman with a COM of 1100 mm. The man in green indicates the height of the COM for a 50th percentile man. The woman in orange indicates a female with a COM height equivalent to 800 mm.

Table 4 Summary of modelling tests and results

	Test purpose	Test manikin	Result
1	Estimate the percentage of the population of British women that have a COM of 1100 mm or lower	Female manikin with a centre of mass at 1100 mm from the floor (<i>blue manikin #1 in Figure 5 and Figure 6</i>)	99.99% of British women (effectively all) have a COM at or below 1100 mm Tipping risk from an upright posture is theoretically reduced for the entire population of British women
2	Estimate the percentage of the population of British men that have a COM of 1100 mm or lower	Male manikin with a centre of mass at 1100 mm from the floor (<i>blue manikin #2 in Figure 5 and Figure 6</i>)	99.8% of British men (nearly all) have a COM at or below 1100 mm Tipping risk from an upright posture is theoretically reduced for most of the population of British men
3	Estimate the percentage of the population of British women that have a COM of 800 mm or higher	Female manikin with a centre of mass at 800 mm from the floor (<i>orange manikin #4 in Figure 5 and Figure 6</i>)	Only 0.3% of British women have a COM at or below 800 mm – this figure will be even lower for men Nearly the entire population of British women (and men) has their COM above 800 mm
4	Estimate the difference in height between an 800 mm barrier and the COM for a British man with 50 th percentile stature	Male manikin with a 50 th percentile stature (<i>green manikin #3 in Figure 5 and Figure 6</i>)	The difference in height between the COM of a 50 th percentile British man and an 800 mm barrier was found to be 212 mm Half of British men have their COM 212 mm or more above an 800 mm barrier

	Test purpose	Test manikin	Result
5	Estimate the difference in height between an 800 mm barrier and the COM for a British man with 99 th percentile stature	Male manikin with 99 th percentile stature (<i>not illustrated</i>)	The difference in height between the COM and the 800 mm barrier was found to be 322 mm Members of the population at the upper extremes of stature will be at greater risk

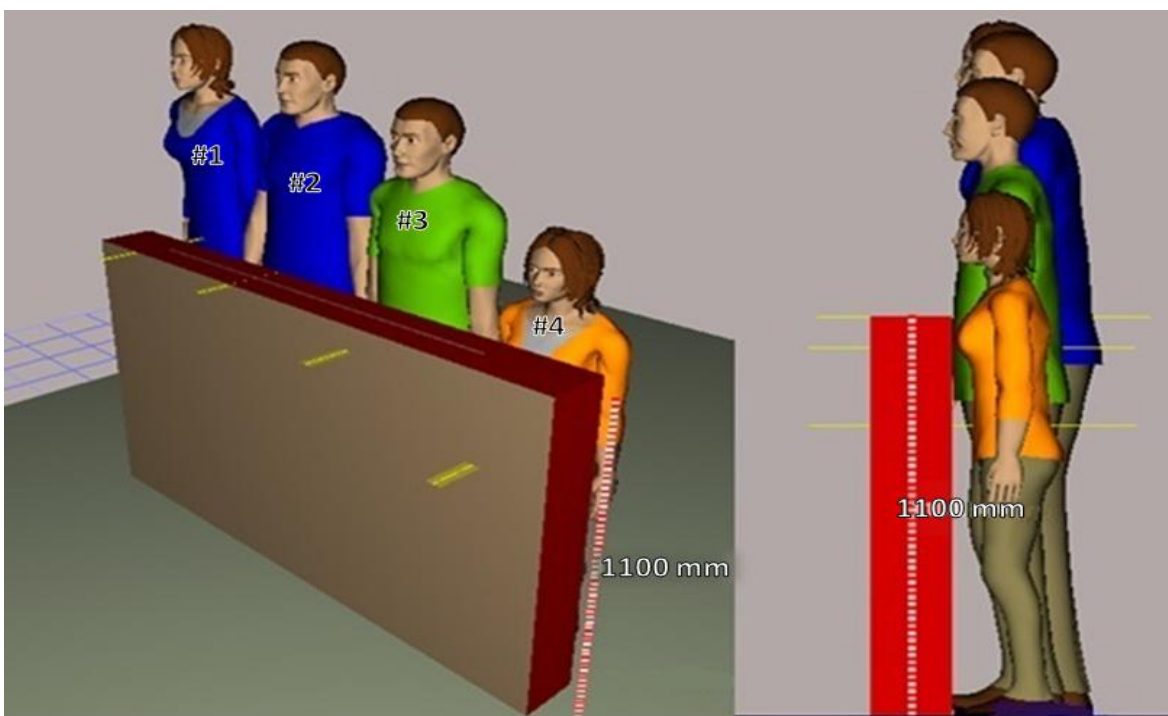


Figure 5 Views of the investigated manikins relative to an 1100 mm barrier (refer to Table 4). Horizontal yellow lines indicate the respective height of COM for each individual

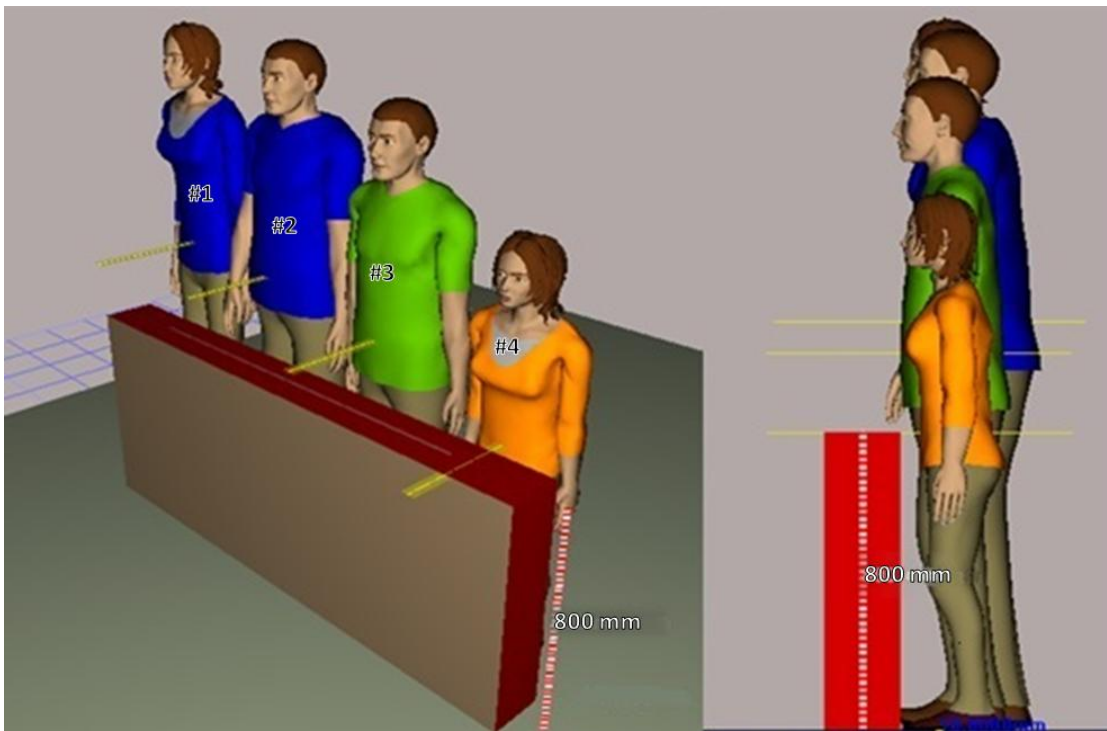


Figure 6 Views of the investigated manikins relative to an 800 mm barrier (refer to Table 4). Horizontal yellow lines indicate the respective height of COM for each individual.

Observations

Manikins with a COM height of 1100 mm were used to estimate the percentage of British individuals with a COM at or below 1100 mm. Results suggest 99.99% of women and 99.8% of men have a COM at or below 1100 mm when standing upright with their hands at their sides. Conversely, using the female manikin with a COM height of 800 mm, the percentage of women with a COM at or below 800 mm was estimated at only 0.3%. This percentage will be even lower for men because: a) anthropometric data show that the overall male population is taller than the female (giving an overall higher COM), and b) for the same standing height, men tend to have a higher COM than women. Nearly the entire British adult population is estimated to have their COM above 800 mm.

From the above observations it can be concluded that a barrier height of 1100 mm is, at a simplified level of analysis, protective of nearly all adults, whereas an 800 mm barrier is protective of a very small proportion of the population. Additionally, the 800 mm barrier may be expected to allow a large proportion of the adult population to move their COM over a barrier relatively easily, which presents a predictably significantly heightened risk. The computer manikin tests excluded footwear, thereby adopting a conservatively positive estimate – when taking footwear into account, the risks will be higher.

The difference in height between the COM and an 800 mm barrier was investigated for a British male manikin with a 50th and 99th percentile stature. At the 50th percentile, the

difference in height was found to be 212 mm; at the 99th percentile, the difference was found to be 322 mm. To summarise these figures, half of the population of British men is estimated to have their COM 212 to 322 mm above an 800 mm barrier. This provides some indication of the dimensions involved.

3.3.2 Anthropometric analysis

To understand the relative risk of tipping from an upright posture from the height of COM being above a barrier, the cumulative percentile height of the COM of British adult men and women population aged 18 years and over was computed (Figure 7).

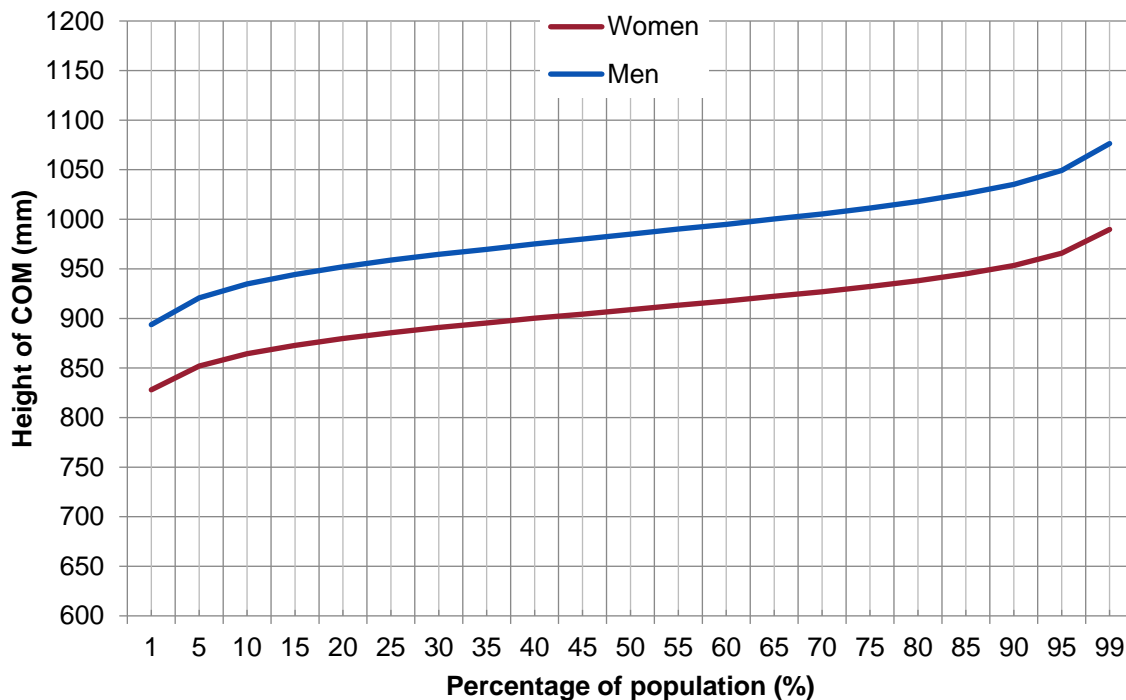


Figure 7 Cumulative percentile of centre of mass (COM) height measures for the population adult British men and women (aged 18 and over)

Table 5 presents the results of the analysis for the proportion of the population with defined heights of COM between 800mm and 1100mm (in 50 mm intervals) for both men and women (based on the data in Figure 7). As an example, Table 5 indicates that 35% of British adult men have a COM above 1000 mm. Cumulative percentiles of the population with height of COM above defined guarding heights are presented in

Table 6 (based on data in Figure 7).

Table 5 Proportions of the population adult British men and women (aged 18 years and over) with a centre of mass (COM) height above defined guarding heights (GH)

Guarding height (GH) (vertical, mm)	% of population with COM > GH	
	Women	Men
800	>99%	>99%
850	95%	>99%
900	60%	97%
950	12%	82%
1000	<1%	35%
1050	<1%	5%
1100	<1%	<1%

Table 6 The heights of centre of mass (COM) corresponding to different percentiles of the population of adult British men and women (aged 18 years and over)

Percentile (%)	COM height (mm)	
	Women	Men
1	828.0	893.7
5	851.9	920.8
10	864.4	934.9
15	872.8	944.3
20	879.7	952.1
25	885.6	958.8
30	890.8	964.7
35	895.3	969.8
40	900.2	975.2
45	904.4	979.9
50	908.9	985.0
55	913.4	990.1
60	917.6	994.8
65	922.4	1000.3
70	926.9	1005.4
75	932.1	1011.3
80	938.0	1018.0
85	945.0	1025.8
90	953.3	1035.2
95	965.8	1049.3
99	989.8	1076.4

3.4 Overall summary of the results

The difference in effectiveness between an 800 mm and 1100 mm high guarding for protection against falls

There was no empirical or epidemiological evidence comparing fall incidents between different heights of guarding; research has only compared an absence of guarding with its presence. Basic anthropometric analysis indicates that a guard height of 800 mm is likely to be protective for less than 1% of the adult British population, whilst a guard height of 1100 mm is likely to be protective for >99%.

The most suitable guarding height for each of the different storeys of a building

No clear judgement could be made on the suitability of guard heights for a given storey. However, the majority of reported falls occur at a height equivalent to the second storey. Falls from 1200 mm are considered potentially fatal, with serious injuries occurring from 600 mm depending on the properties of the impact surface. Falls of less than 600 mm are also associated with an increased likelihood of head impact. Therefore, given short falls are more prevalent and have the potential to cause serious injury, varying guard height by building storey is contraindicated on the basis of risk. The most suitable guarding height that is protective for falls from openings in all building storeys is 1100 mm.

The effect of different physical actions, such as opening a window or running, on risk at various guarding heights

There was no evidence to enable assessment of the impact of dynamic actions on fall risk. Active play and climbing behaviours are known to increase risk in children, with one report suggesting climbing ability of at least 900 mm in 4-6 year olds. These risks are greater during warm weather when windows are left open for ventilation, particularly if parental supervision cannot be assured. It should be possible to provide additional answers to this question with further risk assessment and modelling work.

The effect of windowsills, wide enough to act as a horizontal barrier to the window opening, on the risk of falls.

The Building Control Alliance report 3% of 4 year olds can step up 550 mm and consider any windowsill less than 600 mm high to be climbable by children. Where a windowsill height is lower than 600 mm, a fixed guard of at least 700 mm above sill height should be used to reduce fall risk. Although theoretically deeper sills have been proposed to be protective, in one study investigating the characteristics of windows where falls occurred sills were found to be significantly deeper compared to households which did not report fall accidents (159.5 ± 86.4 vs 109.5 ± 32.3 mm). Analysis of behavioural and biomechanical aspects of deeper sills may provide further understanding.

4 Discussion

Scientific literature, standards, regulations, and guidance was reviewed, in addition to anthropometric and biomechanical analysis, in order to provide answers to the following questions:

- How effective is a 1100 mm guarding height requirement against falls through an opening, compared to a lower 800 mm requirement?
- What is the consequence in terms of relative injury risks of falling through a window for different users, of setting the guarding at heights of 1100 mm and 800 mm.
- How do the relative risks of falling through a window vary for different users at the specified guarding heights?
- Which guarding height is most suitable for each storey?
- How do different actions, such as opening a window or running, affect fall risk at various guarding heights?
- Does having a windowsill wide enough to act as a horizontal barrier to the window opening have an impact on the risk of falls?

4.1 Findings from the scientific literature

There was little information to comment on the efficacy of guarding at 800 mm as opposed to 1100 mm. Numerous reports confirm the efficacy of providing window guarding against scenarios with no window guarding in reducing fall incidents in children, particularly those under five years of age. The Building Control Alliance (BCA) suggest that a guard height of at least 700 mm will provide protection against falls induced by a loss of upright stability (BCA, 2016). However, applying adult anthropometry (i.e., a COM height of 55% of stature) in children may be inaccurate and does not consider behaviours such as climbing and play. Indeed, Riley et al. (1998) have observed children climbing a 900 mm stair guarding. Further, an 800 mm guard height is likely ineffective for the adult population (see biomechanical modelling).

Similarly, there was little information to compare different users as the scientific literature was only concerned with paediatric falls. It was frequently reported that individuals from lower socio-economic backgrounds were at higher risk, which was attributed by various authors to a reduction in available resources for supervision. Within children, those under six years of age were the most vulnerable group and displayed the highest incidence of head injuries.

Again, there was no specific information on the suitability of specific guard heights at specific building storeys. However, a clear pattern emerged from epidemiological data whereby the majority of falls occurred from the second storey or lower. Previous advice suggests falls involving a change in height as low as 1200 mm are considered potentially fatal, with serious injury from as little as 600 mm. This may be a result of the higher

prevalence of head injuries, particularly in younger children. Overall, the findings caution against reduced guarding at lower storeys.

In the majority of falls, active play, poorly positioned furniture, and low sill height relative to finished floor level were identified as increasing risk. Opening of windows in summer months, presumably to increase ventilation, demonstrated a consistent increase in fall incidence. Finally, deeper horizontal windowsill spaces can act as a risk factor for falls where they may be climbed by children. However, deeper sills may also reduce risk in adults by allowing balance recovery of the upper body segment.

In summary, guard heights of 700 mm or greater may satisfy the risk of falls from toppling in a static upright position in children due to the location of their centre of mass being lower than 700 mm. However, guarding heights greater than 900 mm may provide additional protection against common risk factors, such as climbing of furniture or sills, or lack of supervision, particularly during warm summer months when windows are left open. It should be considered that efficacy of either height has not been confirmed by experimental research, and further that guarding at 900 mm or lower is protective for only a small percentage of adults (i.e., Figure 7).

4.2 Comments about standards, regulations and guidance

The main source of guidance found was the British standard BS 8213-1:2004, which gives recommendations for factors to consider when assessing fall risk at windows, and advice that consideration of these factors could indicate the need for guarding of up to 1100 mm above floor level (Clause 5.5). This could be required when there is a need to lean out of the window, such as for cleaning of the pane, as it ensures stability for the majority of the adult population (1100 mm corresponds approximately to the centre of mass of the largest adults).

The standard notes that a particular factor to consider is the height above floor level of the lowest part of an openable window. In some situations, legislation permits (ADK) unguarded opening heights down to 800 mm above floor level. The standard recommends that inward-opening door-height windows should have 1100 mm high guarding where there is a drop of more than 600 mm from floor level to the adjacent level. An exception to this would be if the window gives access to fully guarded areas. The provision of guarding needs to be such that it is permanently fixed, not easily climbable by children, and that the top discourages use as temporary seating. Similar recommendations are made in the other sources identified.

Generally, the sources indicate that to protect against falling out of windows:

1. Windows/window openings on the ground floor and first storey of high-rise living spaces can have:
 - a. the lowest part no less than 800 mm above the floor,
 - b. fixed guarding across the whole width that is at least 800 mm high if the lowest part is less than 800 mm from the inside floor,

- c. guarding that cannot be readily climbed by children and resists the force of a person against it,
 - d. a sill depth that is no more than 100 mm.
2. Windows/window openings on the second and higher floors of high-rise living spaces should have:
- a. the lowest part no less than 1100 mm above the floor,
 - b. fixed guarding that is at least 1100 mm high from the inside floor, if the lowest part is less than 1100 mm from the floor. The guarding can be up to 1300 mm high from the floor in order to enable safe cleaning of the window from inside by an adult occupant.
 - c. guarding that cannot readily be climbed by children.

The general guidance for protection against falling from openable windows is the installation of guarding that is at least 800 mm high from the floor. However, a minimum 1100 mm height of guarding is also recommended to satisfy requirements for escape windows and cleaning from the inside, particularly when the window is on the second storey or above. None of the documents reveal insights on the relative risk of fall accidents associated with different guarding heights and various window designs.

4.3 Anthropometry and biomechanical analysis

4.3.1 Results from statistical analysis and computer modelling

The results of the statistical analysis and simplified tests that were carried out with computer manikins indicate that an increasing proportion of the population becomes at risk as the barrier height is lowered from 1100 mm towards 800 mm. The results indicate that an 1100 mm barrier is protective of almost the entire British population whilst an 800 mm barrier is protective of almost none of the population.

The data in Table 5 and

Table 6 indicate the proportion of adult men or women with a COM height greater than a given guarding height value. For example, the 40th percentile women have an estimated COM height of 900.2 mm (Table 5). This suggests that 60% of women have a COM height equal to or greater than 900 mm, and in turn indicates a barrier of 900 mm would not protect against tipping falls for 60% of British adult women.

Setting a barrier height of less than 1100 mm raises the ethical issue of what proportion of the population being unprotected is tolerable.

4.3.2 Limitations of the anthropometrics and biomechanical analysis

Due to project constraints, a number of variables or factors were not accounted for in the basic tests carried out, including:

- The effects that various footwear will have on raising the COM.

- Variations of body proportions that exist in the population, for example people of the same standing height that have longer legs and shorter body, or vice versa, producing different COM heights for the same standing height.
- The effects that body postures other than standing upright with hands at the side have on the COM in relation to a barrier. When a person bends forwards / backwards at the waist, their COM moves forwards / backwards; this can increase the possibility of their COM extending over a barrier, with a consequential increase in the risk of toppling over a barrier.
- As well as the COM height, the height of a person's hip joint in relation to a barrier will be a significant factor that affects the risk of the COM extending over the barrier.
- The variety of foreseeable scenarios of window use and misuse, which have a significant role to play in the fall risk.
- The effects on fall risk that are to be expected due to variation in the depth of the barrier (i.e., the depth of the horizontal area at the bottom of a window opening, both inside and outside of the building).

It should also be mentioned that the best available anthropometrics data for the British and UK populations were not obtainable within the timescale of this current work. Further, only British women and men were included in the modelling – a more complex population database may provide a more precise representation of the population. Finally, COM is commonly estimated to be 56% of stature for males and 54% for females, however the Jack software generates COM values directly from the manikin models which differ slightly from the common estimate.

4.3.3 Considerations for further analysis

Current advancements in mathematical and computer modelling make it feasible to, for example, examine dynamic collisions between a car body and a pedestrian. This same technology could be applied to obtain a greater understanding of the relative risks of 800 mm and 1100 mm barriers but requires significant (possibly prohibitive) resources to carry out. Theoretically, there is scope to dynamically consider foreseeable scenarios of window use and misuse and how this affects the position of the body COM in relation to window openings.

5 Conclusions

5.1 Review of the scientific literature

Few conclusions about optimal window guarding strategies can be drawn from the available academic literature. No empirical evidence directly comparing the impact of varying guard heights on any of the outcomes of interest was found. Prevention programmes demonstrate high efficacy of window guarding, but comparisons are only made against an absence of guarding. Further, academic literature is chiefly concerned with prevention efforts in children; only a single study was identified that was concerned with adults, and prevention was focused on intentional falling whereby guarding provided a psychological deterrent.

The majority of falls from windows were recorded in children under six years at heights equivalent to the second storey of a building. Peak fall incidence rates occur during summer months, presumably due to windows being opened for ventilation. Contributing factors to paediatric fall risk include low (<600 mm) sill height relative to finished floor level, large sill depth, or poorly placed furniture which may be readily scalable by children of 4-6 years. Cumulatively, it can be suggested that there may be increased fall over risk in children from guarding 900 mm or lower due to climbing behaviours.

5.2 Information from standards, regulations and guidance

The general guidance provided for protection against falling at openable windows is installation of guarding that is at least 800 mm high from the floor.

A minimum guard height of 1100 mm is also suggested for windows on the second storey or above of dwellings. This is to satisfy safety requirements related to cleaning from inside and escape windows. It is during cleaning and when using the window as an escape route that people are most likely to need to open the window and reach out from it.

None of the documents reveal insights on the relative risk of fall accidents associated with different guarding heights and various window designs.

5.3 Simple anthropometric and biomechanical analysis

The risk of tipping over guarding is increased as the person's centre of mass (COM) position moves above the guarding level. Relative to a standing person, when dynamic and behavioural issues are ignored, guarding of a particular height may act as a pivot about which the upper body and lower body may act as two segments each with its own COM. The risk of a head-first tilt fall partly depends on the position and mass of the upper body and the position of its COM relative to the top of the guarding.

Based on a simple comparison of body size against barrier height, a guarding height of 1100 mm is protective against tipping over guarding for practically the entire British population (children and adults), whereas a guarding height of 800 mm is protective for less than 1% of the adult British population.

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7 Appendix 1 – Summary of papers about fall heights and injury diagnoses.

Reference	Height of fall	Reported injuries	Limitations
<p>Flaherty et al. (2021)</p> <p>Reviewed data from 10 US paediatric centres of 496 falls in <18 year olds</p> <p>Years studied: 2007-2017</p> <p>Country: United States</p>	<p>23% from 1st storey</p> <p>58% from 2nd storey</p> <p>18% from 3rd storey</p> <p>2% from 4th storey</p> <p>0.5% unknown</p>	<p>Location:</p> <p>58% head and face</p> <p>26% lower extremities</p> <p>26% abdomen/trunk</p> <p>21% upper extremities</p> <p>5% neck</p> <p>2% other</p> <p>Type:</p> <p>51% fracture</p> <p>34% other head injury</p> <p>33% soft tissue</p> <p>25% laceration</p> <p>8% other</p> <p>2% mortality rate, more likely from 3rd storey, 89% head or neck injuries.</p>	
<p>Houlton et al. (2021)</p> <p>Reviewed data from 218 falls in <15 year olds</p> <p>Years studied: 1998-2019</p> <p>Country: Australia</p>	<p>22% from 1st storey *</p> <p>53% from 2nd storey</p> <p>16% from 3rd storey *</p> <p>3% from 4th storey *</p> <p>13% unknown *</p>	<p>42% of window fall injuries were head injuries</p>	<p>*Estimated from available data</p>

Reference	Height of fall	Reported injuries	Limitations
<p>Rajagopal et al. (2021)</p> <p>Reviewed data from 89 falls in <7 year olds</p> <p>Years studied: 2009-2017</p> <p>Country: Canada</p>	<p>Median height of falls 4.3 m (3.0-5.5 m)</p>	<p>58% severe injuries 36% minor 6% no injury</p> <p>49% concussion 25% fractured upper limb 22% thoracic or abdominal 19% fractured skull 4% skin injury</p> <p>No deaths</p>	
<p>Grivna et al. (2017)</p> <p>Reviewed 96 falls from newspaper sources in <15 year olds</p> <p>Years studied: 2005-2016</p> <p>Country: United Arab Emirates</p>	<p>42% 5 to 10 storeys 37% < 5 storeys 21% > 10 storeys</p>		<p>No information on injuries.</p>

Reference	Height of fall	Reported injuries	Limitations
<p>Kocak et al. (2012)</p> <p>Reviewed data from 133 falls in <17 year olds</p> <p>Years studied: 2009-2010</p> <p>Country: Turkey</p>	<p>36% from 1-2 m</p> <p>25% from 2-3 m</p> <p>25% from 3-5 m</p> <p>18% > 5 m</p>	<p>63% head trauma</p> <p>17% multiple</p> <p>14% limb fracture</p> <p>9% thorax</p> <p>8% abdominal</p> <p>5% mortality rate</p>	<p>Does not specifically address falls from windows</p>
<p>Mayer et al. (2006)</p> <p>Reviewed data from 31 falls in <16 year olds</p> <p>Years studied: 1998-2005</p> <p>Country: Switzerland</p>	<p>45% from 1st storey</p> <p>22% from 2nd storey</p> <p>19% from 3rd storey</p> <p>3% from 4th storey</p> <p>6% from 5th storey</p> <p>3% from 9th storey</p>	<p>84% of falls in under 5 years</p> <p>100% head injuries (see limitation)</p> <p>36% thoracic</p> <p>29% spine, pelvic, or extremity</p> <p>16% abdomen</p> <p>19% mortality rate, all under 5 years</p>	<p>Includes balconies and window falls. Head injuries were an inclusion criteria, so not necessarily representative of all fall injuries</p>

Reference	Height of fall	Reported injuries	Limitations																																																																		
Pressley and Barlow (2005) Reviewed fall data from 27 U.S states in <18 year olds Year studied: 2000 Country: United States		<table border="1"> <thead> <tr> <th>Age (years)</th> <th>0-4</th> <th>5-9</th> <th>10-14</th> <th>15-18</th> <th>All</th> </tr> </thead> <tbody> <tr> <td>Total injuries (n)</td> <td>447</td> <td>219</td> <td>160</td> <td>259</td> <td>1091</td> </tr> <tr> <td>Head (%)</td> <td>38</td> <td>31</td> <td>19</td> <td>23</td> <td>30</td> </tr> <tr> <td>Spinal (%)</td> <td>n/a</td> <td>n/a</td> <td>n/a</td> <td>8</td> <td>3</td> </tr> <tr> <td>Internal (%)</td> <td>10</td> <td>12</td> <td>9</td> <td>14</td> <td>11</td> </tr> <tr> <td>Skull fracture (%)</td> <td>23</td> <td>13</td> <td>9</td> <td>8</td> <td>15</td> </tr> <tr> <td>Upper limb fracture (%)</td> <td>11</td> <td>28</td> <td>36</td> <td>25</td> <td>21</td> </tr> <tr> <td>Lower limb fracture (%)</td> <td>7</td> <td>11</td> <td>26</td> <td>32</td> <td>17</td> </tr> <tr> <td>Other fracture (%)</td> <td>3</td> <td>6</td> <td>14</td> <td>32</td> <td>12</td> </tr> <tr> <td>Open wound on head, neck, trunk (%)</td> <td>13</td> <td>11</td> <td>8</td> <td>11</td> <td>11</td> </tr> <tr> <td>Open wound on extremity (%)</td> <td>n/a</td> <td>n/a</td> <td>n/a</td> <td>6</td> <td>3</td> </tr> </tbody> </table>	Age (years)	0-4	5-9	10-14	15-18	All	Total injuries (n)	447	219	160	259	1091	Head (%)	38	31	19	23	30	Spinal (%)	n/a	n/a	n/a	8	3	Internal (%)	10	12	9	14	11	Skull fracture (%)	23	13	9	8	15	Upper limb fracture (%)	11	28	36	25	21	Lower limb fracture (%)	7	11	26	32	17	Other fracture (%)	3	6	14	32	12	Open wound on head, neck, trunk (%)	13	11	8	11	11	Open wound on extremity (%)	n/a	n/a	n/a	6	3	Detail on site of fall (e.g., window or balcony) and height of fall not provided.
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Vish et al. (2005) Reviewed data from 90 falls in <16 year olds Years studied: 1995-2002 Country: United States	12% from 1 st floor 59% from 2 nd storey 27% from 3 rd storey 1% from 4 th storey 1% from 5 th storey	45% head injuries (fracture or intracranial contusion) 32% other minor injuries 23% skeletal fracture (upper or lower limb) 13% chest, pelvic, or thoracic injury 3% abdomen injury 3 deaths from head trauma, one from falls at each of the 1 st , 2 nd , and 3 rd floors (age: 0.75, 1.5, and 2 years)																																																																			

Reference	Height of fall	Reported injuries	Limitations
Istre et al. (2003) Reviewed data from 108 falls in <15 year olds Years studied: 1997-1999 Country: United States	75% from 2 nd storey 19% from 3 ^d storey 1% from 4 th storey 5% unknown	40% head injuries 16% arm/leg fracture 15% soft tissue 7% face/eye/mouth 3% trunk/back 3% liver/spleen 17% unknown No deaths	

Note. percentages are rounded for convenience. Multiple injured sites were possible in most data sets.

8 Appendix 2 – Identified standards, regulations, and guidance documents.

8.1 Standards and regulations

Document	Description	Decision
AS 5203:2016 Protection of openable windows/fall prevention - Test sequence and compliance method. Australian standard	Description: This Standard sets out methods for determining the performance of devices intended to prevent the risk of injury and death associated with accidental falls through open windows by children five years old and younger.	Not relevant Not clear on requirements for window guarding, specifically height.
ASTM F 2090 : 2021 Standard Specification for Window Fall Prevention Devices With Emergency Escape (Egress) Release Mechanisms	Description: This specification establishes requirements for devices intended to address the risk of injury and death associated with accidental falls through open windows by children five years old and younger. The specification applies to window fall prevention devices, including window opening control devices (WOCs), window fall prevention screens, and fall prevention window guards that are to be used on operable windows, including those that are designated for emergency escape (egress) and rescue (ingress).	Not relevant Not clear on requirements for window guarding as a fixed barrier.
ASTM F 2006 : 2021 Standard Safety Specification for Window Fall Prevention Devices for Non-Emergency Escape (Egress) and Rescue (Ingress) Windows	This safety specification establishes requirements for devices intended to address the risk of injury and death associated with accidental falls through open windows by children five years old and younger. It applies only to devices intended to be applied to windows installed at heights of more than 23 m above ground level in multiple family dwelling buildings.	Not relevant Not clear on requirements for window guarding, specifically height.
BS 8213-1:2004, Windows, doors and roof lights – Part 1: design for safety in use and during cleaning of windows, including door-height windows and roof windows –Code of	Description: This Standard gives recommendations on the design, construction, operation and maintenance of windows, including door height windows, for safety in use and during cleaning, including	Relevant Contains advice and recommendations for provision of

Document	Description	Decision
practice, BSi, ISBN 0 580 44492 9	safe opening characteristics and the arrangement of window controls, to safeguard occupants and passers-by.	window guarding
BS 6180:2011 Barriers in and about buildings – Code of practice	Description: This Standard gives recommendations and guidance for the design and construction of temporary and permanent barriers to be provided in and about buildings and places of assembly, such barriers being positioned and designed to protect persons from various hazards and to restrict or control the movement of persons or vehicles. The Standard applies to: Barriers, walls, glazing and other elements of buildings or structures where such elements act as protective barriers.	Relevant Contains advice and recommendations for provision of window guarding
BS EN 13126-5:2011 +A1:2014 Building Hardware–Hardware for windows and door height windows – Requirements and test methods Part 5: Devices that restrict the opening of windows and door height windows, BSi, ISBN 978 0 580 63821 3	Description: This Standard specifies requirements and test methods for durability, strength, security and functionality of devices that restrict the opening of windows and door height windows	Not relevant Does not contain advice and recommendations for provision of window guarding
BS EN 14351-1:2006+A2:2016 Windows and doors. Product standard, performance characteristics - Windows and external pedestrian door sets.	Description: This is the first part of the multi-series Standard that identifies material independent performance characteristics, except resistance to fire and smoke control characteristics, that are applicable to windows external pedestrian door sets (and their assemblies, including unframed glass door sets, escape route door sets) and screens.	Not relevant Does not contain advice and recommendations for provision of window guarding
BS EN 16281:2013 Child protective products – Consumer fitted child resistant locking devices for windows and balcony doors –Safety requirements and test methods, BSi, ISBN 978 0 580 74966 7	Description: This European Standard specifies requirements and test methods for locking devices fitted by consumers for restricting the opening of windows and balcony doors by children younger than 51 months and intended to prevent the passage of young children.	Not relevant Does not contain advice and recommendations for provision of window guarding
DD CEN/TS 13126-5:2004 Building hardware, fittings for windows and door height windows – Requirements and	Description: This Standard specifies the requirements and test methods for durability, strength, security and function of devices that restrict the	Not relevant Does not contain advice and

Document	Description	Decision
test methods – Part 5: devices that restrict the opening of windows, Draft for development, BSi, ISBN 0580 43691 8	opening of windows.	recommendations for provision of window guarding
DIN EN 12209:2016-10 Building hardware - Mechanically operated locks and locking plates - Requirements and test methods	Description: Gives requirements and test methods for durability, strength, security, and function of mechanically operated locks and latches and their locking plates for use in doors, window doors and entrance doors in buildings.	Not relevant Does not include information about guarding and its provision
DIN EN 14846:2008-11 Building hardware - Locks and latches - Electromechanically operated locks and striking plates - requirements and test methods	Description: This standard specifies requirements and test methods for strength, security, durability and function of electrical and electronic components for all types of electromechanically operated locks and striking plates used on doors, window doors and entrance doors in buildings.	Not relevant Does not include information about guarding and its provision
PAS 24:2022 Enhanced security performance requirements for door sets and windows in the UK. Door sets and windows intended to offer a level of security suitable for dwellings and other buildings exposed to comparable risk	Description: This standard provides a method for testing and assessing the enhanced security performance requirements of door sets and window types intended to resist the levels and methods of attack experienced in the UK and normally associated with the casual or opportunist burglar. It is believed that these attacks are the result of an opportunity presenting itself with no particular regard to the likely reward that success might bring. Not relevant: Does not contain advice and recommendations for guarding and its provision	Not relevant Does not contain advice and recommendations for provision of window guarding
Building Regulations 2010 – Approved Document O (ADO) Requirement O1: Overheating mitigation Regulations: 40B	Description: This approved document contains: General guidance on the performance expected of materials and building work in order to comply with each of the requirements of the Building Regulations, and Practical examples and solutions on how to achieve compliance for some of the more common building situations.	Relevant Contains advice and recommendations for provision of window guarding
Building Regulations 2010 – Approved Document K (ADK) 2013 Edition: Protecting from	Description: This approved document includes advice on protection from falling, collision and	Relevant Contains advice

Document	Description	Decision
falling, collision and impact:	impact. Guidance for avoiding collision and impact is detailed in the positioning of doors and windows within a property, ensuring that no injuries occur due to occupants colliding with open windows, skylights, ducts etc., that large panes of glass are marked to avoid accidental impact with them, and that doors and windows are not positioned in a way that could trap someone.	and recommendations for provision of window guarding

8.2 Guidance documents

Document	Description	Decision
Building regulations guidance note – NHBC Building Control: Glazing, guarding and restrictors in dwellings, NHBC 2014 H252 05/14	Description: Part N of the Building Regulations seeks to ensure that where people are likely to come into contact with glass it is unlikely to cause injury or the glazing will resist impact or be shielded or protected from impact. However, glass is increasingly being used in locations that require it to act as guarding from falling. In these cases the glazing needs to comply with the requirement and guidance in Part K2 of the Building Regulations – Protection from falling.	Relevant Contains recommendations for provision of window guarding
BRE Publication: Webber, G.M.B. and Aizlewood, C.E. (1993), Falls from domestic windows, Building Research Establishment, BRE Information paper	Description: The paper summarises a statistical study of the occurrence of falls from windows using data from the Home Accident Surveillance System and coroners' inquest notes. it describes the principal findings and their likely implications for architects, window designers, and building owners and occupiers.	Relevant Contains advice and recommendations for provision of window guarding
BRE Publication: Garvin, S. and Murray, I. (2017), An assessment of the current position in Scotland regarding	Description: This is a report of an investigation of the current situation with regards to the installation of window opening light restrictors to	Relevant Contains advice and

Document	Description	Decision
window opening light restrictors in domestic buildings, Scottish government, BRE Scotland Report A16624573	new windows in dwellings, which could offer additional protection to occupants, in particular children. The report provides an analysis of the current situation with regard to the fitting of window restrictors.	recommendations for provision of window guarding
Building Control Alliance (BCA) technical guidance note 16 Guarding to openable windows with low sill heights.	Description: BCA technical guidance notes are to provide information, promote good practice and encourage consistency of interpretation. They are advisory in nature. This guidance concerns the requirements of Building Regulations with regard to protection from falling in relation to openable windows (including French windows) in external walls to dwellings. This guidance applies where there is a risk of falling from a height of more than 600mm.	Relevant Contains advice and recommendations for provision of window guarding
National Housing Building Council (NHBC) Technical newsletter August 2004 Issue 30, Standards Extra		Relevant Contains advice and recommendations for provision of window guarding
HSE Information sheet (HSIS5) – Falls from windows and balconies in health and social care	Description: This information sheet provides advice on controlling risks to people who use health and social care services (service users) associated with falls from windows or balconies. It aims to help providers of health and social care services comply with their legal duties.	Not relevant Does not contain advice and recommendations for provision of window guarding

To protect against the risk of persons falling through window openings in buildings, The Building Regulations 2010 (England) Approved Document O (ADO) – Overheating 2021 edition sets a guarding height minimum standard of 1100 mm for windows in upper floor dwellings (two meters or higher from the immediate external ground surface), which can be opened as part of the overheating avoidance / mitigation strategy for the building.

Peer-reviewed scientific primary papers, standards, building regulations, and guidance documents published between 1990 and December 2023 were sourced and reviewed for insights about heights of barriers and prevention of falls through windows. Fall risk was further characterised through anthropometric and biomechanical analysis of the ability of 800 mm and 1100 mm high guarding to protect against falls over them.

There was no empirical or epidemiological evidence in the literature comparing fall incidents at different heights of guarding.

A guarding height of 1100 mm is protective against tipping risks for practically the entire adult British population, whereas a guarding height of 800 mm is protective for less than 1% of the adult population.

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