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A Review of Fire Resistance Expectations for High-Rise UK Apartment Buildings

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Abstract. In the UK, prescriptive fire safety guidance offers a simple means of meeting statutory building regulation requirements, for most common building situations. In the context of prescriptive structural fire resistance, buildings are afforded a fire resistance period based upon their height and use. This fire resistance expectation is either to be achieved inherently by structural elements or via protection to them. The broad aim of such prescriptive guidance is the delivery of a consistent level of risk across all building types. For this to be achieved, as the frequency of fires and consequence of failure increases, the reliability of the fire resistance system must increase. This typically manifests in an increase in a building's fire resistance expectation as height increases. Despite this common practice, this paper fundamentally reviews the concept of fire resistance as a height dependant metric for residential buildings, identifying the limitations of such an approach, utilising single stair apartment buildings as a basis for demonstration and further investigations. A risk correlation is proposed that seeks to explicitly define the structural fire resistance design goal (reliability of the fire resistance system) as a function of both height and occupancy. The correlation is calibrated against UK statistical data to determine what might constitute a common building. It is found that in single stair buildings, an appropriate benchmark case would constitute 7 apartments per level, ranging in size from 1 to 3 bedrooms (28 m^2 to 101 m^2). This benchmark case is used to determine a risk score which, for the purpose of achieving a consistent level of risk, becomes a constant in the proposed risk correlation. Four example building cases are chosen to demonstrate the application of the correlation. The cases are of the same notional height, but constitute differing occupancy (apartment) numbers. The proposed correlation indicates that the four cases, despite being of the same height, have significantly different fire resistance system reliability demands (96.3% to 98.5%) and, thus, fire resistance demands (154 min to 173 min). In light of the findings, it is concluded that, if conventional structural fire resistance thresholds are not to be exceeded (in the UK typically limited to 120 min), then, in tall residential buildings, the reliability/efficacy of the sprinkler system becomes increasingly important. Finally, a brief discussion is provided regarding the limitations of the approaches presented.

Keywords: High rise, Fire resistance, Reliability, Monte Carlo, Apartments

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1. Introduction and Background

The trend to build taller is not just confined to the commercial sector, with an increasing number of tall residential towers proposed throughout the World's metropolitan areas. Often increased height is also associated with increased complexity, both in terms of architectural and structural form. Such increases in complexity mean that fire engineering input will be increasingly important in the delivery of modern buildings, in lieu of reliance on prescriptive recommendations, which are intended to cater for the more straightforward situations.

1.1. UK Prescriptive Guidance and Fire Resistance

In England and Wales, prescriptive guidance, such as Approved Document B [1] (ADB) or BS 9999 [2], offers a simple means of meeting the requirements of the fire aspects of the Building Regulations, for most common building situations.

In the context of structural fire resistance, buildings are afforded a fire resistance period based upon their height and use. The requirement is that stability is retained for an appropriate period.

The broad aim of such prescriptive guidance [1, 2] is the delivery of a consistent level of risk across all building types and heights. For this to be achieved, as the frequency of fires and consequence of failure increases, the reliability of the fire resistance system must increase. This manifests in the tabulated data of ADB, etc., through increases in fire resistance with increasing height. In mathematical form, the concept can be expressed as shown in Eq. 1:

$$Risk = f \times P(f) \times C \tag{1}$$

where f is the frequency of fire occurrence, $P(f)$ is the probability that a given fire results in failure and C is the consequence of failure.

The concept of increasing fire resistance as a function of height is predicated on two crude substitutions, as indicated in [3]:

(i) *Probability of fire occurrence substitution* It is accepted that, in general, the probability of a fire is proportional to a building's area [4]. However, often prescriptive guidance operates on the premise that building area is proportional to the number of storeys and, for ease of application, this is simply expressed in terms of overall building height. That is, two buildings of the same use & height, regardless of plan area or floor to floor height (and thus number of storeys), are assumed to have the same annual likelihood of fire occurrence.

(ii) *Consequence of failure substitution* By virtue of correlating building height with the number of storeys and, thus, area, often prescriptive guidance inherently makes the extension that the number of people affected by a structural failure is also proportional to height. In practice, the consequence of failure associated with the occupants of a building depends upon the number of people in that building at that time. This is better described by area and the number of storeys (not height). The consequence of failure associated with those not in the building of origin (or those that enter the building in the process of tackling a fire), should it fail, is largely dependent upon the building's size. That is, the larger a building is, the greater the impact it has on surrounding areas, public spaces and, thus, people. In this regard, height is a reasonable metric by which to assess one of the two aspects of 'consequence of failure' that must be addressed.

It is clear from the above that the specification of fire resistance on the basis of only height doesn't fundamentally address the concept of delivering consistent levels of risk, due to the crudeness of the substitutions identified. Nor does it cater for the more unusual or uncommon situations relative to the origins of the prescriptive guidance [5]. Specifically, in the context of residential buildings, it doesn't address the array of differing guises under which a residential building might manifest.

Given the crude substitutions identified, the more rational expression of risk requires that the consequence of failure must be considered to comprise two components:

(i) The consequence of failure in the context of those in the building of origin (C_i),
(ii) The consequence of failure in the context of those in the vicinity of/or external to the building (C_e).

This results in the general form of the risk expression presented in Eq. 2:

$$Risk = f \times P(f) \times (C_i + C_e) \quad (2)$$

1.2. Fire Resistance and Residential Buildings

Residential buildings, like any other building designed prescriptively in England and Wales, would be afforded fire resistance solely based upon height. Where the topmost qualifying storey breaches certain generic height-bands, step changes in fire resistance occur, as shown in Table 1.

Table 1
Fire Resistance Periods for Apartment Buildings Based on UK Guidance [1]

Height not exceeding (m)	Prescriptive fire resistance (min)
5.0	30
18.0	60
30.0	90
>30.0	120 + sprinkler protection

The frequency of fire occurrence in apartment buildings is less governed by the area of the building and more influenced by the number of dwellings contained therein [6]. This is because a high proportion of all dwelling fires originate in the living room and kitchen (64% of all fires according to 2014 London Fire brigade statistics versus 9% in bedrooms [7]), which are typically present in all types of dwelling. Thus, the greatest ignition risks present themselves across nearly all apartment typologies. For this reason, it is common to express the frequency of fire occurrences in residential buildings as being directly proportional to the number of dwellings [4].

The consequence of structural failure in fire (in terms of the impact on the building's occupants) will be a function of the number of people directly affected. In simplistic terms, this can be related to the number of dwellings contained within a given apartment building.

Analogous to many other building types, the size (height) of the residential building will influence the area of damage associated with its failure and, thus, the consequences for those in the vicinity. In addition, the height of the building will have a significant bearing on the time taken for the FRS to access and, ultimately, tackle the fire.

1.3. Expression of Risk in Residential Buildings

In apartment buildings it is proposed that the frequency of fire occurrence is directly proportional to the number of dwellings (N). The probability of failure concerns only those fires that exceed the design confidence of the overall fire resistance system (R_{FRS}—inclusive of any contribution from active measures, such as sprinklers) and is expressed in terms of those fires that might lead to collapse.

The resulting risk correlation is, therefore, as shown in Eq. 3:

$$Risk = N \times (1 - R_{FRS}) \times (C_i + C_e) \tag{3}$$

1.4. Context and Societal Risk

Any risk correlation must be framed in the context of levels of performance that are the minimum tolerated in any given society. In the case of England and Wales, it is accepted that common buildings designed in accordance with the recommendations of ADB (and subsequently constructed appropriately) deliver an acceptable standard of health and safety. That is, in the current environment, society (and by extension the Government) is content with the statistics associated with fire fatalities.

The risk correlation presented can, therefore, be tethered to an 'accepted' design for a common building that delivers an acceptable level of risk. This level of risk (or risk score) is then considered a constant in appraising the performance of less common (or unusual) building situations, leading to correlations describing the required reliability of the fire resistance system for any apartment building variant.

2. Defining a Common Apartment Building

2.1. Published Data on Flat proportions

The UK Department for Communities and Local Government (DCLG) retain statistics regarding permanent dwellings completed, by house and flat, number of bedrooms and tenure [8]. These statistics are made publicly available and collate data from throughout England.

A 15-year trend regarding the percentage of all apartments completed that are either one, two, three or four bedroom variants is shown in Figure 1.

Over the 15-year period, the statistics indicate that:

(i) For every one bed apartment constructed, 2.9 two bedroom apartments are completed,
(ii) There are 0.16 three beds completed for every one bed apartment constructed,
(iii) Four bedroom apartments represent <0.5% of all completed dwellings and, thus, would not be considered common.

A study completed by Scott Wilson [9] on behalf of the Chartered Association of Building Engineers (CABE) in 2010 reviewed 250 residential schemes, randomly selecting 200 samples to inform the internal floor area ranges noted for various dwelling types. This data was broken down by number of bedrooms and typology (flats vs. houses). In terms of apartments, the dataset comprised area surveys for studio, one, two and three bedroom typologies.

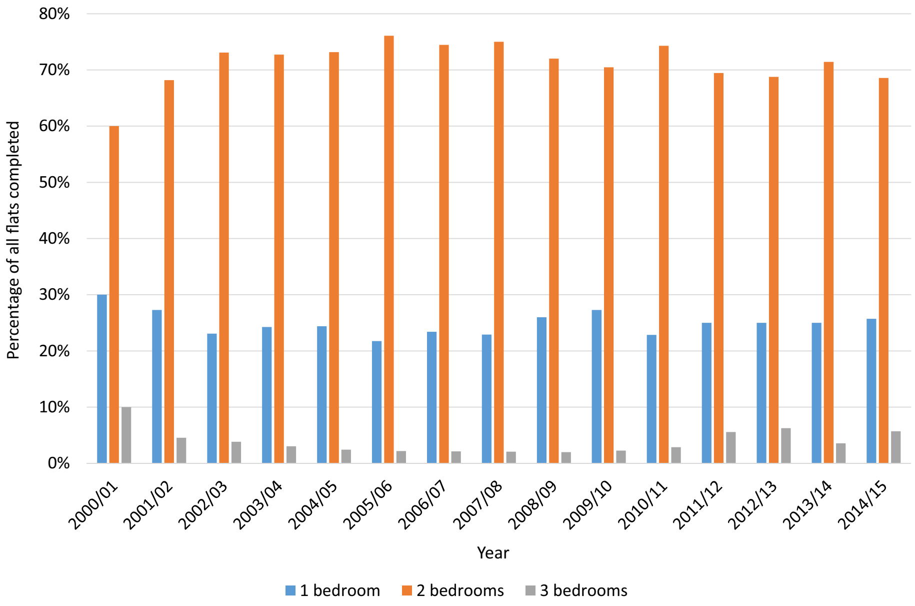

Figure 1. 15 year trend—percentage of all completed apartments by number of bedrooms [8].

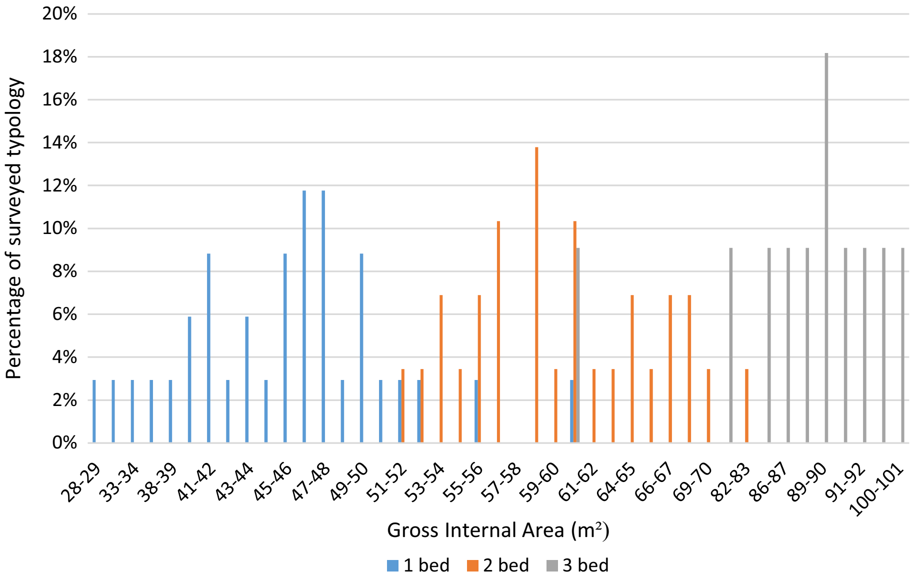

Figure 2. **Distribution of apartment sizes by area for different typologies [9].**

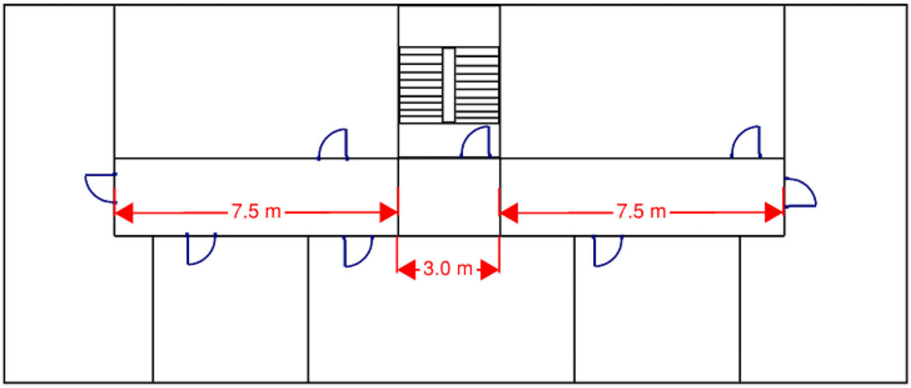

Figure 3. **A common single stair floor plate [1].**

Area distributions by typology are presented in Figure 2. For analysis purposes, studio apartments (only 4 of the 200 dataset) are grouped with the one bedroom typologies.

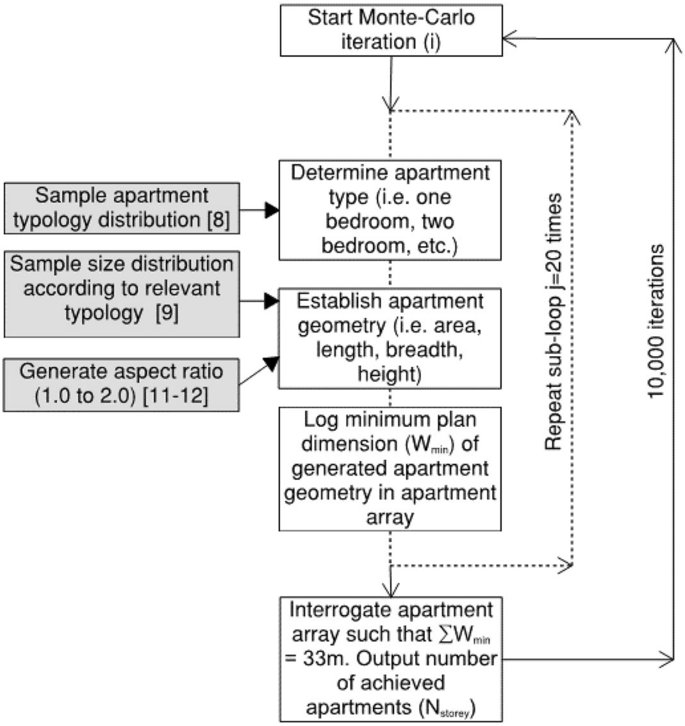

Figure 4. Monte Carlo procedure for assessing distribution of flat numbers (per storey) achievable within ADB [1], Diagram 7a constraints.

The Scott Wilson dataset shows good consistency with other data sources, such as that presented in the Royal Institute of British Architects (RIBA) "Case for Space" report of 2011 [10].

2.2. Space Planning of Common Buildings: The Influence of ADB

As the primary fire safety guidance document in use in England and Wales in recent decades, ADB has had a profound influence on building design. Diagrams 7 (single stair) and 8 (multi-stair) in the current version of ADB significantly limit (in practical terms) the number of apartments that can be, and typically are, contained on a single floor of a 'code compliant' common building. However, no restriction on the number of acceptable storeys is explicitly defined in the case of either a single or multi-stair building (that is, high-rise single stair buildings are permissible and commonplace).

In the case of single-stair buildings, Diagram 7 is the relevant case, with Diagram 7a offering the best efficiency (number of dwellings) per core (and thus greatest risk). In such an arrangement, all apartments must be accessible within 7.5 m of a sterile protected entrance lobby (upon to which no apartments open),

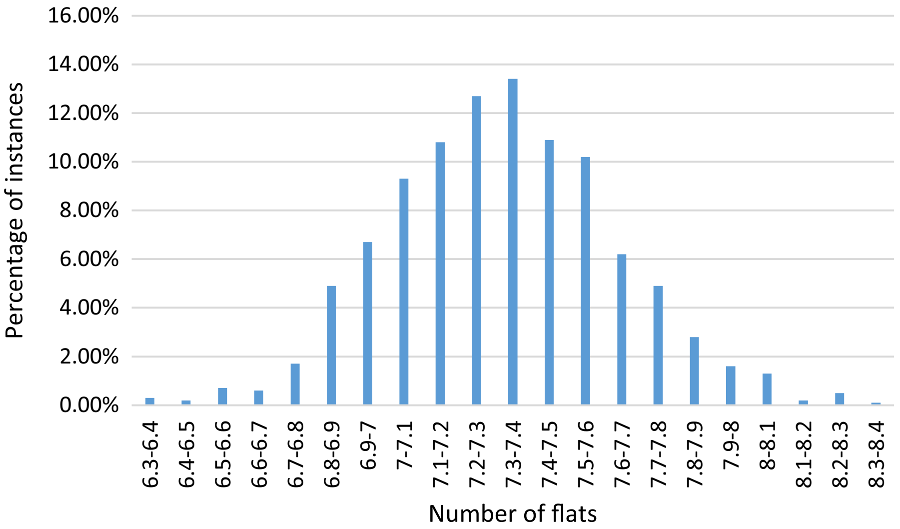

Figure 5. Distribution of flat numbers achievable around a single 'common' stair core.

thus restricting the number of apartments that can be accessed from a single stair (i.e. only a finite number of apartments can be sited along two portions of unvented corridor).

This restriction can be expressed as a wall length upon which apartments can reasonably be sited (Figure 3). With appropriate allowance for stair width, this distance can be approximated as 33 m (albeit variations will exist depending upon stair widths, lift provision, etc.), inclusive of four 7.5 m walls and a 3 m allowance for wall length opposing the access stair. In addition, two other apartments may be included, one at each end of the corridor. The distances are predicated on no more than two unventilated corridors being located off of one ventilated lobby, which is consistent with Diagram 7a and typical of the apartment buildings being constructed in England and Wales in recent years and currently (albeit, again, variations will exist).

Adopting the flat typology statistics from [8] over a 15 year period and flat size distributions from [9], it is possible to determine the typical number of apartments present on a typical floor, with a single escape stair. In doing so, it is necessary to assume an aspect ratio range for apartments. Planning guidance does not dictate internal space criteria. However, practically, it is accepted that a minimum dwelling frontage is required so as not to compromise internal planning. 4.25 m is proposed within the metric handbook [11]. Housing space standards set by the Mayor of London's office note habitable rooms are to have a minimum aspect ratio of 2:1 [12]. In the case of flats, this is likely to lead to apartments of overall similar proportions. A minimum aspect ratio of 1 and a maximum of 2 is, therefore,

Table 2
Variability of Time Equivalence Study Inputs

Metric	Unit	Range	Distribution type	Ref
Apartment typology	(–)	Min-1 bedroom Max-3 bedroom Mode-2 bedroom	Log-normal	[8]
Apartment floor area (A_f)	(m^2)	1 bedroom: min-28; max-61; mean-45 2 bedroom: min-51; max-83; mean-61 3 bedroom: min-61; max-101; mean-87	Normal	[9]
Fire load density (q_{fd})	(MJ/m^2)	80th fractile-870 90th fractile-920 95th fractile-970	Gumbel	[15]
Ventilation area as a % of floor area (α_v)	(%)	Min-10 Max-25	Linear	[15]
Conversion factor (k_b)	(min m^2/MJ)	0.09	Not applicable	[15]

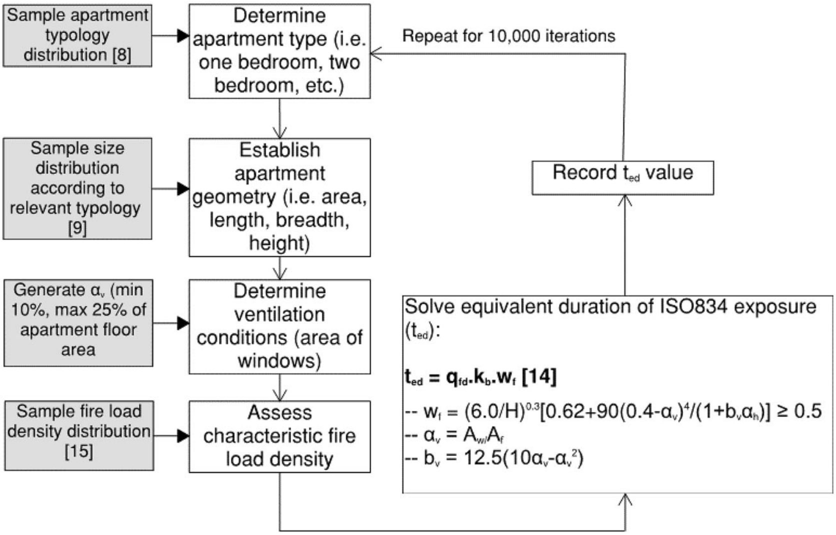

Figure 6. Monte Carlo process adopted for the assessment of fire severity (time equivalence).

adopted, with an equal likelihood of every variation between these limits (i.e. a constant or flat distribution).

The inputs referenced are utilised within a Monte Carlo study undertaken by the author to establish the number of apartments that can reasonably be achieved on a floor within the constraints imposed by Diagram 7a of ADB. The process undertaken is as outlined in Figure 4.

Results in terms of the number of apartments that can reasonably be located around an ADB diagram 7a layout are shown in Figure 5. This is based upon 10,000 Monte Carlo iterations.

The average outcome is 7.4 apartments per level, which can be pessimistically rounded down to 7.0 apartments per level. The instances which result in exactly seven apartments per level are limited as a proportion of the overall data sample. However, in terms of those within a range of ±0.1 apartments, this represents 16% of the dataset or 1600 of the 10,000 samples. Any one of these could be considered to represent a typical floor. Albeit, each sample would likely only subtly vary relative to any other.

2.3. A Baseline Case

The average ADB-compliant storey of an apartment building, designed in accordance with diagram 7a, would have up to seven apartments per level according to Figure 5.

The minimum acceptable floor to ceiling height is governed by planning restrictions, such as those advocated in the newly published UK Government planning guidance titled “Nationally Described Space Standard” [13], which sets a minimum floor to ceiling height for new dwellings of 2.5 m (in terms of floor to floor level this can be approximated as 3.0 m, albeit this will vary according to servicing strategy and structural form).

3. Calibration of Risk Correlation

3.1. Revisiting the Risk Correlation

The baseline case of a single-stair apartment building, comprising seven apartments per level is used as a basis for calibrating the risk correlation proposed in Sect. 2.3.

As noted in Sect. 2.4, common buildings designed in accordance with ADB are accepted as delivering an appropriate level of health and safety for those within and in the vicinity of the building. Therefore, they are consistent with the UK's level of acceptable societal risk.

If multiples of the baseline floor are stacked to form a building, this is proposed as being representative of a 'common building' on the premise that it is synonymous with a code-compliant building that has apartment typologies and sizes consistent with recent & historical national statistical trends.

Depending upon the height of the resulting multiplication of floors, the building would be expected to achieve the relevant fire resistances proposed in Table A.2. of ADB, if it were designed in accordance with that document (see Table 1).

Revisiting the correlation in consideration of frequency of fire occurrence, the number of fires a year in an apartment building will be proportional to the number of dwellings contained within.

Reviewing the correlation in the context of consequence and to ensure dimensional consistency:

(i) The consequence for the occupants of building origin (C_i) can be expressed as an 'effective number of typical occupant storeys' which is measured relative to the baseline case. That is, the total number of flats in the building (N) divided by the baseline floor apartment number (7).

(ii) The consequence for those externally influenced by the fire (C_e) can be expressed as an 'effective number of typical height-associated storeys'. In this instance, the height of any building is normalised relative to the baseline case storey to storey height.

The outcome is a combined consequence metric ($C_i + C_e$) expressed in terms of effective storeys. The updated risk correlation is shown in Eq. 4, with risk units of (*Apartment.Storeys*):

$$Risk = N \times (1 - R_{FRS}) \times \left(\frac{N}{7} + \frac{H}{3}\right) \tag{4}$$

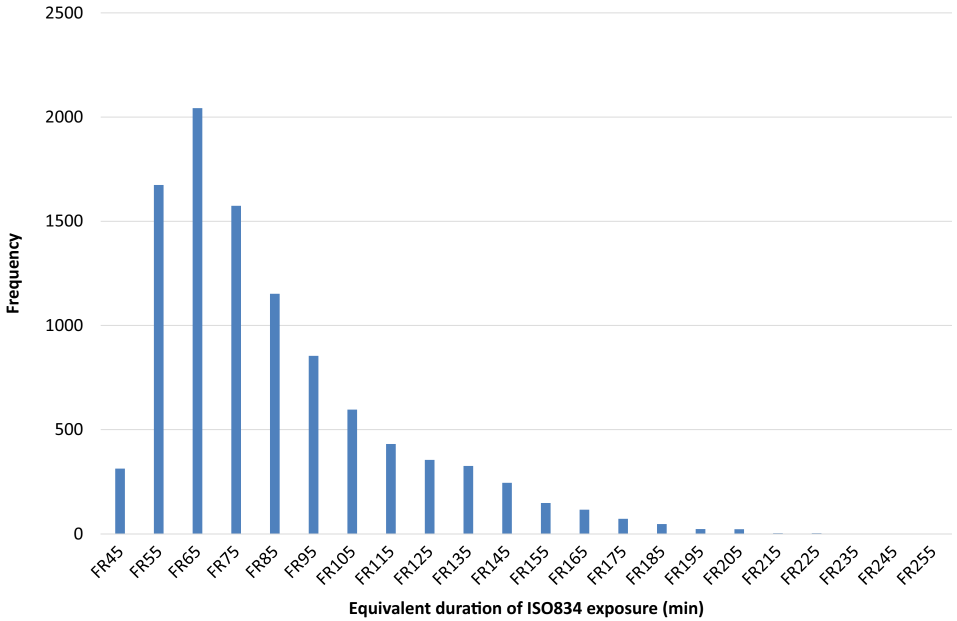

Figure 7. Distribution of fire severities expressed as equivalent durations of ISO 834 exposure.

3.2. Baseline Fire Severities and 'Time Equivalence'

The range of severities of fires expected within a common apartment building will be highly variable. They will be influenced by apartment geometry, fire load, linings, as well as other considerations, such as demographic.

Adopting the time equivalence methodology proposed in BS EN 1991-1-2 [14] (and associated national documentation, such as PD 6688-1-2 [15] for the UK) it is possible to define the range of severities of fires expected by expressing severity as an equivalent duration ofurnace exposure (ISO 834 conditions [16]).

To develop a range of severities, variability in the inputs of the analysis are considered, as shown in Table 2. These feed into a Monte Carlo study undertaken by the author to explore the full range of possible fire severities that might manifest in a common UK apartment building. The Monte Carlo process adopted in the assessment of fire severity (time equivalence) is as shown in Figure 6 for completeness.

10,000 iterations are completed for the Monte Carlo study. In terms of geometry, per iteration, firstly, a flat typology is selected based upon historical statistics, secondly, a flat area is sampled according to the relevant distribution for the chosen typology. The floor to ceiling height (H) of the apartment is fixed at 2.5 m [13]. Finally, depending upon the flat proportions, the ventilation area is fixed between 10% and 25% of the flat area (the lower bound is informed by Table 27 of BS 9999 [2], whilst the upper represents the limit of application for the time

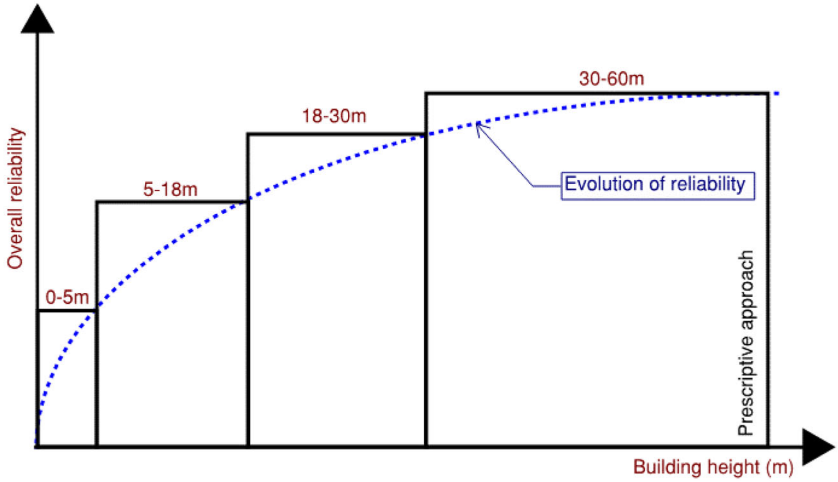

Figure 8. Prescriptive guidance—'steps' in required design confidence/reliability.

equivalence method, as presented in BS EN 1991-1-2 [14]). This ventilation area normalised relative to apartment floor area (α_v) is randomly selected between the proposed limits, resulting in a unique ventilation condition per apartment, per iteration.

The conversion factor (k_b) is fixed at a constant value of 0.09 min m^2/MJ and is intended to be representative of a typical plasterboard lined apartment.

Fire load density (q_{fd}) is selected according to the distributions documented in [15].

The range and distribution of fire severities for a non-sprinkler-protected baseline common apartment building, based on the inputs given in Table 2, are shown in Figure 7. Data has been grouped into 10 min statistical bins, with plots representing the central point of each statistical bin. The prefix FR refers to fire resistance.

As indicated by the distribution, the most common outcomes are in the region of 50-80 min equivalent exposure to the ISO 834 curve, the average outcome being 85 min, with a standard deviation of 30 min.

3.3. Calibration of Risk Correlation

Guidance such as ADB and BS 9999 groups buildings into height bands which means, in practice, consistent levels of risk aren't delivered. By way of an example the fire resistance recommendations within BS 9999 are predicated on the principle that an 18.1 m high building is expected to resist collapse when subject to the same fractile of fires as a 30 m tall building. This is shown diagrammatically in Figure 8.

For the purposes of calibrating the baseline case against the prescriptive guidance, the anchor point must, therefore, be at the topmost point of a given height grouping.

With reference to Table A.2. of ADB, an apartment building of height exactly 30 m (measured to the topmost occupied floor, not roof), would require 90 min structural fire resistance.

For a storey to storey height of 3.0 m, there would be 11 storeys (inclusive of ground), upon which a fire might originate, equating to 77 apartments in the baseline common building case (seven per level).

With reference to Figure 9, the fractile at which 90 min fire resistance is achieved is 67.6%. Solving for the risk score (*Apartment.Storeys*) yields Eq. 5:

$$Risk = N \times (1 - R_{FRS}) \times \left(\frac{N}{7} + \frac{H}{3}\right) = 77 \times (1 - 0.676) \times \left(\frac{77}{7} + \frac{30}{3}\right) = 523.9 \tag{5}$$

Rearranging to derive overall reliability for the fire resistance system (–):

$$R_{FRS} = 1 - \frac{523.9}{N\left(\frac{N}{7} + \frac{H}{3}\right)}. \tag{6}$$

To test the calibration, if the baseline case was reduced in height to 18 m, the number of relevant storeys reduces to seven and the resulting apartment number reduces to 49, yielding an overall fire resistance system reliability requirement of 17.75%.

With reference to a fractile of 17.75%, the equivalent duration of fire exposure according to Figure 9 is 58.96 min. The prescriptive structural fire resistance recommendation within either ADB or BS 9999 for a building of such height would be 60 min. That is, for a 'common' single-stair building, with statistically relevant apartment typologies and, thus, apartment numbers, the methodology delivers the same outcomes as the prescriptive guidance of ADB.

4. Fire resistance and Tall Single Stair Residential Buildings

4.1. Application to Tall Buildings: Defining the Design Goal

The correlation outlined in Sect. 4.3, whilst consistent with prescriptive guidance for a low to medium rise 'common situation', will become increasingly inconsistent when applied to taller buildings offering a greater or lesser number of apartments per level (relative to the baseline).

Table 3
Demonstration Cases

Case	Apartments per level	Qualifying storeys	Floor to floor height (m)	Building height (m)
A	7	41	3.0	120
B	5	41	3.0	120
C	9	41	3.0	120
D	7	31	4.0	120

Table 4
Overall Reliability of the Fire Resistance System for Each Case

Case	Total number of flats (N)	Qualifying storeys (–)	Building height (m)	R_{FRS} (%)
A	287	41	120	97.75
B	205	41	120	96.31
C	369	41	120	98.47
D	217	31	120	96.60

For demonstration purposes, four buildings are considered which comprise those typical flat typologies and corresponding area distributions presented in Sect. 3.3. These are summarised in Table 3.

Applying the correlation presented in Sect. 4.3, the overall reliability requirements of the fire resistance system (R_{FRS}) for each apartment building case proposed in Table 3 is shown in Table 4.

Table 4 serves to demonstrate how four buildings of identical height require differing levels of overall fire resistance system reliability due to variations in the frequency of fire occurrence and associated consequence (should one of those fires lead to collapse).

4.2. *Structural Fire Resistance Expectations*

On the premise that the four demonstration buildings are formed of statistically typical apartments, corresponding with those typology and area distributions previously identified in Sect. 3, the fire resistance requirements can be established with reference to Figure 9. Resulting values are shown in Table 5. Results are presented on the premise of no sprinkler protection, initially. That is, the structure is the only means why which the fire resistance can be achieved (either inherently or via protection). Were the method to be applied to a specific project, Figure 9 would be regenerated in consideration of the nuances of the particular building in question.

All cases, by virtue of their height, fall at the severe ends of the structural fire resistance expectation distribution. However, despite this, there is still a range of circa 20 min from the lowest to the highest fire resistance expectation.

Table 5
Un-Sprinklered Fire Resistance Requirements for Demonstration Cases

Case	R_{FRS} (%)	Structural fire resistance (min)
A	97.75	165
B	96.31	154
C	98.47	173
D	96.60	156

4.3. Impact of Sprinkler Protection

It would be typical to provide sprinkler protection to all UK apartment buildings exceeding 30 m in height. Therefore, those structural fire resistance figures presented in Table 5 would be assuaged in cognisance of this.

The impact of sprinkler protection may be considered in a number of ways. In the case of BS EN 1991-1-2 [14] and associated guidance in the form of PD 6688-1-2 [15], the fire load density may be reduced by 39%. This is on the proviso that life safety sprinklers, in accordance with BS EN 12845 [17], are provided. However, this has the impact of distorting the resulting fire dynamics as the principle is applied to a post-flashover fire model that, in practice, would not reach such severity should the sprinklers operate successfully.

Alternatively, more contemporary approaches [18] seek to distinguish the structural reliability from the overall reliability of the fire resistance system through consideration of sprinkler reliability.

The structural (or passive) reliability (R_p) governing the fire resistance requirements of structural elements will depend upon the contribution (if any) from any proposed suppression systems of a given reliability (R_a). Adopting a component based approach, the structural/passive reliability can be expressed as follows [18]:

$$R_p = \frac{R_{FRS} - R_a}{1 - R_a} \tag{7}$$

The grade of suppression system will impact the reliability of the active system (R_a). Indicative sprinkler reliabilities, taken from PD 7974-7 [4] and adopted in comparable studies [18], are shown in Table 6. Brief commentary is provided regarding the reasoning for variability in reliability as a function of grade.

Resulting structural (or passive) reliability expectations for each building case, afforded differing grades of sprinkler system, are shown in Table 7.

Again with reference to Figure 9, the corresponding structural fire resistance expectations are as shown in Table 8.

The results shown in Table 8 serve to demonstrate that if conventional UK structural fire resistance thresholds are not be exceeded for tall residential buildings (typically not more than 120 min structural fire resistance), then a contribution is required from active fire protection. The extent of this contribution will

Table 6
Sprinkler Reliability for Different Grades [4]

Grade	Reliability[a] (–)	Comment
Life safety	0.90	System is provided with a superior water supply (e.g. mains and tank) and pump set redundancy (run and standby)
Property protection	0.80	System is not required to have a superior water supply and may be served via a town’s main or boosted town’s main, without pump redundancy
Un-specified	0.75	The grade of system is unknown and the quality of water supply is not readily distinguishable

[a] Reliability is defined as instances where sprinklers operated successfully. That is, no more than four heads are required to control the growth of the fire [4]. Whilst not explicit within [4], reliability is taken to include instances where the water supply has been consciously “switched off”, based upon other relevant studies indicating comparable reliabilities [19]

Table 7
Sprinkler Protected Structural Reliability for Demonstration Cases

Case	R_{FRS} (%)	R_p (%) for differing sprinkler reliabilities		
		$R_a = 75\%$	$R_a = 80\%$	$R_a = 90\%$
A	97.75	90.99	88.73	77.46
B	96.31	85.25	81.56	63.11
C	98.47	93.87	92.34	84.69
D	96.60	86.40	83.00	66.00

Table 8
Sprinkler Protected Fire Resistance Demand for Demonstration Cases

Case	Fire resistance (min) for differing sprinkler reliabilities		
	$R_a = 75\%$	$R_a = 80\%$	$R_a = 90\%$
A	133	126	102
B	117	109	86
C	143	137	116
D	120	112	88

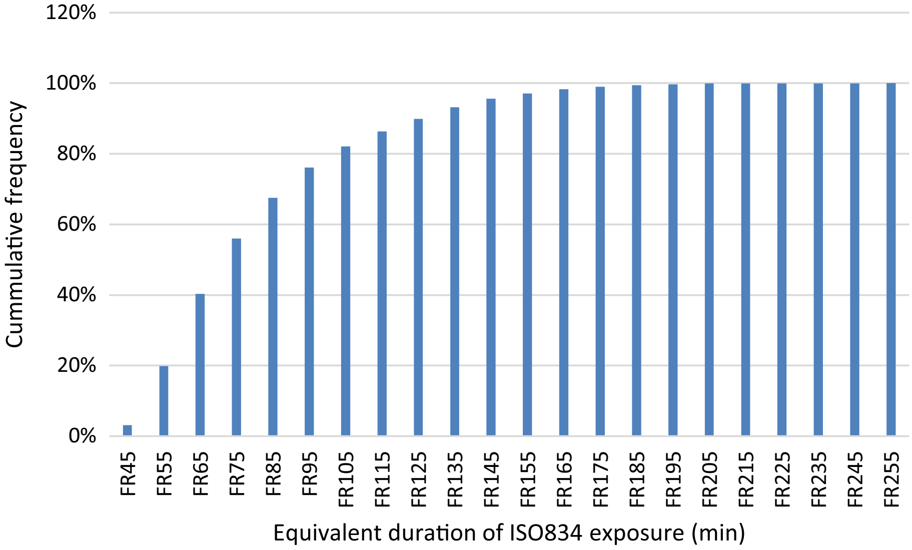

Figure 9. Cumulative distribution of fire severities expressed as equivalent durations of ISO 834 exposure.

vary from case to case and, thus, will influence of the grade of system required. Taller buildings or those with an increased number of apartments will require more resilient sprinkler systems, relative to mid-rise buildings.

5. Summary and Conclusions

A new methodology is developed where the design goal for tall single stair residential buildings is expressed in the context of frequency of fire occurrence, probability of failure and consequence of failure.

The methodology is tethered to UK statistics regarding what might constitute a typical ‘common’, single stair, apartment building and the associated fire resistance expectations. Whilst tethered to UK statistics and societal risk tolerances, the methodology is applicable to other countries, subject to re-calibration.

The findings demonstrate that the levels of risk presented by different apartment buildings of the same height varies substantially. Therefore, if a consistent level of risk is to be achieved, fire resistance must be specified in consideration of variables other than just building height.

The total number of apartments proposed influences both the likelihood of fire occurrence and consequence. Consequence of failure is considered both in terms of the impact on building occupants and those either in the vicinity or, subsequently, entering the building (e.g. the fire service). The outcome is a correlation that explicitly seeks to define the life safety goal as a function of apartment number and building height.

The methodology is provisionally developed in consideration of tall single stair UK residential buildings (as is becoming common to construct). In the case of tall multi-stair residential buildings, other complexities arise that have yet to be considered. Namely, what impact (if any) the failure of a limited number of structural elements would have (i.e. those confined to the flat of fire origin) on the stability of the building as a whole (and, thus, the associated impact on consequence of failure).

The method is premised on single occupancy buildings and doesn’t consider the impact of mixed use tenancies.

If conventional structural fire resistance thresholds for tall single stair apartment buildings are not to be exceeded (in the UK typically limited to 120 min), then in tall residential buildings the reliability of the sprinkler system becomes increasingly important and extra resilience will likely be necessary.

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