Theoretical Whole Building Evacuation

Kristian Farr, Alastair Bartlett

[1]AECOM, Aldgate Tower, 2 Leman Street, London, E1 8FA

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Abstract. This paper assesses the evacuation time for a 25-storey office building. The scenario modelled assumes that a fire has arbitrarily taken place at Level 11, and a whole-building evacuation is required. The evacuation will be via a phased evacuation strategy utilising the stairs for those who are able to self-evacuate, and evacuation lifts for those who are unable to self-evacuate by stairs. The stair widths have been designed to be compliant with BS 9999 recommendations. The lift evacuation strategy is operator assisted evacuation operation.

To determine the suitability of the evacuation strategy, a comparative analysis of stair evacuation times against the total lift evacuation times is undertaken.

As a base design assumption, the building is provided with two escape stair cores and one evacuation lift per escape stair core. The proportion of users who are likely to require the use of the lifts for evacuation has been taken as 15% in line with the Department for Work and Pensions family survey information.

Initial findings indicate that the estimated stair evacuation time, when calculated in line with PD 7974-6, is approximately 53 minutes, while the lift evacuation time extends to approximately 3 hours and 53 minutes. The initial calculation results indicate a significant disparity in evacuation time, which would likely raise concerns with the available evacuation lift capacity in line with the Fire Strategy requirements and other human factors.

This paper aims to explore strategies for providing lift evacuation times more in line with the stair evacuation times and enhancing overall evacuation efficiency.

1 INTRODUCTION

In recent years, evacuation lift technology has developed, and fire safety policy and guidance has started to recommend or require their inclusion in tall buildings. Clause 7.4.1 of BS 9991:2024 recommends that “buildings that are provided with passenger lift access to an upper or lower level should also be provided with a means of using lifts for escape.” It goes on to recommend that “at least one evacuation lift should be provided for each escape stairway” [1].

BS EN 81-76 (Evacuation lifts) states that it is assumed that the selected number and size of evacuation lifts, as determined by a capacity assessment, is sufficient to evacuate users within the “defined duration” [2], which is explored further in this paper.

In London, the London Plan requires that buildings, regardless of height, are provided with one evacuation lift “per core” or more, subject to an evacuation lift capacity assessment [3].

These documents recommend that more lifts should be provided “if required by capacity assessment”, but these documents do not provide guidance as to how this should be undertaken.

This report sets out a methodology for undertaking an evacuation capacity assessment for a fictitious office building utilising a phased evacuation.

2 BUILDING DESCRIPTION

To develop and test a methodology, a fictitious office building has been developed. A typical floorplate is indicated in Figure 1.

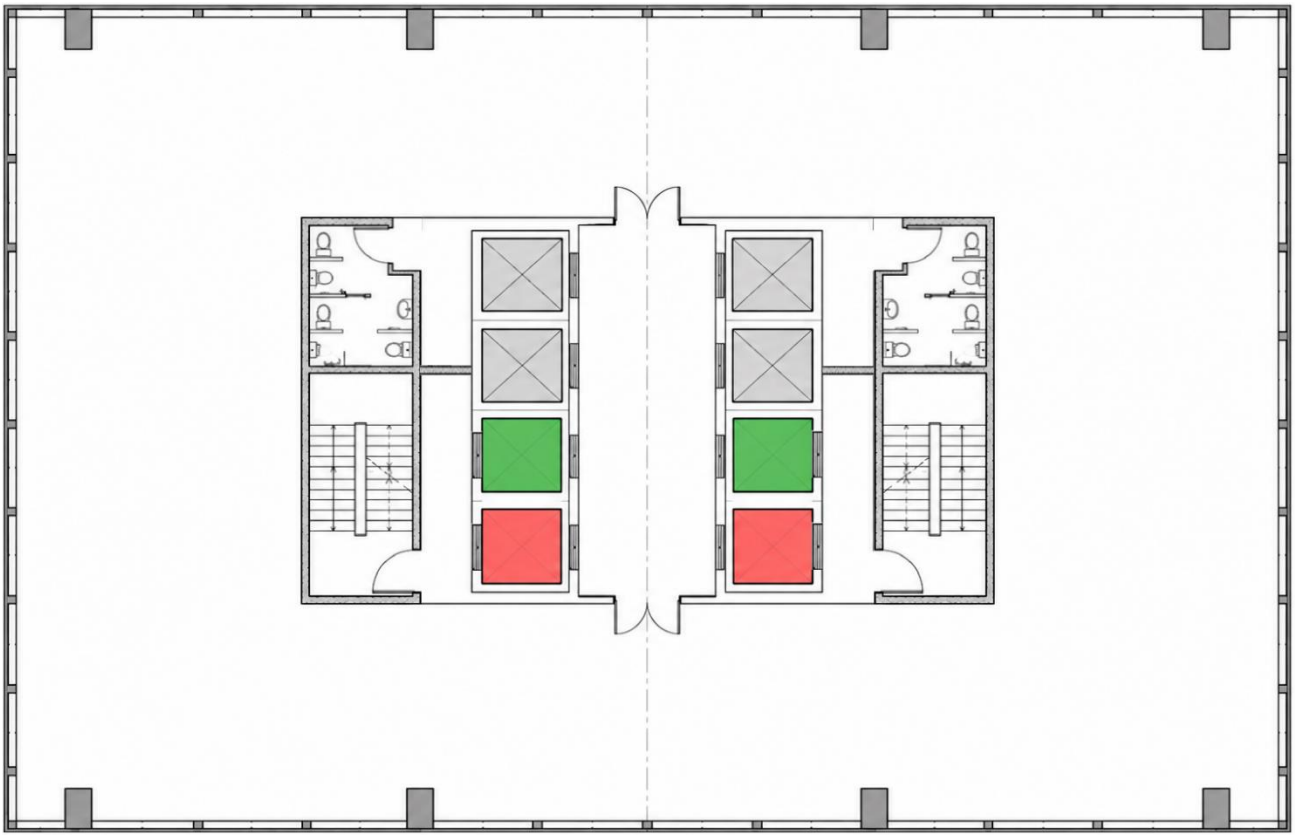


Figure 1 Typical Floor Area

The building is a 25-storey (G+24) office building, with the ground floor having independent final exits direct to outside. For simplicity, the layout (and therefore population) of the majority of floors have been kept uniform, with some exceptions to provide a more "realistic" assessment of an actual building. The baseline building population has been assessed on the maximum allowable population from the Fire Strategy requirements.

Level 1 has arbitrarily been assumed to have a 2862 m^2 NIA (excluding lifts and stairs), resulting in an occupancy of 477 (assuming 1 occupant per 6 m^2, which is typical for a "normal" office density from Table 9 of BS 9999; see Section 5.2 for a sensitivity analysis on this aspect).

Levels 2 and upwards have arbitrarily been assumed to be 2172 m^2 NIA, resulting in an occupancy of 362.

Level 24 has been assumed to have a roof garden area (assumed for the purposes of this paper to be occupied only by occupants of Level 24), reducing the NIA to 1986 m^2, resulting in an occupancy of 331.

The building has been assumed to adopt a phased evacuation regime, where the fire floor evacuates first, and evacuation then proceeds in pairs of floors going upwards, then continuing downwards in pairs below the fire floor. The ground floor will also evacuate in the first phase, but as this has exits direct to outside, this will not impact the stair or lift assessment. For this assessment, the fire has been assumed to start on Level 11.

The lift evacuation order has been assumed to follow the stair evacuation approach – i.e. evacuating Level 11 first, then continuing up the building, before evacuating users from Levels 10 downwards.

2.1 Lift provision

The two evacuation lifts in the satellite cores are provided as 2000 kg / 26 person lifts, operating at 3.0 m/s, serving Ground (G), Level 1-24 (L1-24).

The lifts are provided with a car size of 2350 mm wide x 1700 mm deep, providing an associated car area of 3.995 m^2. Door recesses are ignored and assumed to be less than 100 mm in line with the area requirements of EN 81-20.

The Evacuation Exit level (EEL) for the lifts is Ground. For the purposes of this report, it is assumed there is only one active EEL (Ground); this EEL remains free from smoke and remains safe for evacuation.

An average floor-to-floor height of 4.758 m has been utilised.

The lifts are located in a protected core area and associated with an escape stair, in line with fire guidance for location of evacuation lifts.

The lifts are specified to be provided with driver assisted evacuation operation as defined in BS EN 81-76. It is assumed that all functional requirements are met and that upon receipt of an evacuation recall signal, the lifts shall ground, landing calls will cancel, and the lifts will wait at the EEL until the driver assisted signal is operative.

Appropriate statutory signage and evacuation communication systems will be provided in compliance with BS EN 81-76.

2.2 Stair provision

Two stairs have been assumed for this assessment. A building of this height would typically require two stairs but not necessarily require a third unless needed to support travel distances, hose-laying distances, or exit capacity, which is not the case here. As shown in Figure 1, these stairs are lobbied at each level (which would be required to support the phased evacuation regime) and contain two entrances into each lobby. In the event of a fire, it is therefore not necessary to discount a stair, thus simplifying the analysis. One exit into a lobby would be discounted on the floor of fire origin to consider the effects of a fire in that location blocking an exit; however, based on there being two entries to each lobby, the other would remain available, and therefore both stairs would be accessible.

As there are two exits into the stair, the bottleneck would form within the lobby queuing into the stair, and therefore the width of the stair will govern.

Based on a sprinklered office building, and two floors evacuating at once per a phased evacuation regime, guidance in BS 9999 would recommend a total stair width of 3.40 mm/person [1]. The worst case of two adjacent floors of 477 and 362 occupants (levels 1 and 2) gives a total required width of 2852.6 mm; splitting this over two stairs gives 1426.3 mm. 2 x 1450 mm stairs have therefore been considered in the analysis.

3 METHODOLOGY

3.1 Building population analysis

Overall building population has been estimated based on typical floor space factors from Table 9 of BS 9999; see Section 2. To determine the number of users expected to rely upon evacuation lifts in the event of a fire, data from the Department for Work and Pensions (DWP) Family Resource Survey

have been adopted. This states that 15% of users will be assumed to use evacuation lifts. This is split between mobility impaired, those with stamina/breathing issues/fatigue, and wheelchair users [4].

It should be noted that this is a simplistic analysis, and does not fully consider human behavioural aspects, which are discussed later.

Table 1 shows the split for the levels considered.

Table 1 Occupants expected to use evacuation lifts

Floors	Total occupancy (Baseline maximum population)	Occupants using stairs	Mobility impaired occupants	Occupants with stamina/ breathing issues/ fatigue	Wheelchair users	Total occupants per floor using lifts
1	477	406	40	29	2	71
2-23	362	308	31	22	1	54
24	331	282	28	20	1	49

3.2 Lift analysis

Due to the layout of the proposed building, and that the evacuation lifts are of the same specification, it is assumed that those who require the lifts to be evacuated will be split evenly between the lift cores. The populations presented in Table 1 have therefore been halved.

As the evacuation operation is Driver assisted, an allowance for a driver has been utilised as they will be in the lift car at all times. The driver area is 0.21 m^2. To allow for the driver within the simulations, the car area has been reduced by 0.21 m^2, providing a car area of 3.785 m^2.

The individual passenger loading times and passenger areas have been adjusted based on the specific user group who require the lifts for evacuation, which are detailed respectively in Table 2 and Table 3 below.

The capacity factor by mass has been set at 80%, and the capacity factor by area has been set at 100%.

The simulations have assumed a 5-minute shutdown period to allow queues to form at the evacuation floors. This is to simulate the operation of the lifts recalling to the active EEL, allowing for passenger to leave the car and await the driver assisted signal. Additionally, the operator and fire wardens will need to communicate with the refuge spaces. The 5-minute shutdown is arbitrary to form queues within the simulation software.

Passenger loading times have been utilised as detailed below, based on the splits presented in the DWP survey. It should be noted that the loading and unloading times require further evidence-based validation.

Table 2 Passenger Loading Times

User Group	Loading Time (s)	Unloading Time (s)
Mobility Impairment	7	7
Stamina / Breathing / Fatigue	5	5
Wheelchair Users	10	10

Passenger areas have been utilised as detailed below:

Table 3 Passenger Areas

User Group	Passenger Dimensions (mm)	Passenger Area (m^2)
Mobility Impairment	600 x 800	0.48 [5]
Stamina / Breathing / Fatigue	380 x 560	0.21 [6]
Wheelchair Users	900 x 1400	1.26 [6]

The analysis and overall results have been undertaken as per the methodology set out in Farr's paper titled "Theoretical Evaluation of Evacuation Lift Capacity Assessments" [7].

3.3 Stair analysis

To calculate evacuation time down the stairs, it is necessary to calculate flow rates based on the evacuation regime. PD 7974-6 provides flow rates for different treads and risers of stairs, ranging from 0.94-1.16 persons/s/m [8]. For this analysis, a riser of 165 mm and a tread of 305 mm have been arbitrarily assumed, giving a flow rate of 1.09 persons/s/m.

Section G.2 of PD 7974-6 notes that a "boundary layer" exists when considering flow down stairs, which considers aspects such as handrails, and to accommodate lateral body sway and assure balance. Assuming the worst case from Table G.1 of PD 7974-6 gives a boundary layer of 150 mm each side of the stair, resulting in an effective width of 1150 mm and a flow rate down the stairs of 1.2535 persons/s. As there are two stairs per level, this results in a combined flow rate of 2.507 persons/s. This has been rounded down to 2.5 persons/s for the analysis.

Flow rate calculations have been undertaken in line with the methodology in PD 7974-6. The more onerous case of a dominant upper floor has been considered (this means that occupants waiting to enter the stair will give way to occupants already in the stair and passing them). As a phased evacuation regime is in place, it has been assumed that the next phase (i.e. pair of floors) will commence evacuation as soon as the last occupant from the previous phase has entered the stair and thus left the floorplate. Additional users waiting to use the evacuation lifts have not been considered, as evacuation of all disabled users should normally commence on the sounding of the initial alert per Clause M.2 of BS 9999 (noting that the lifts in this example have followed the stair phasing as a sensible approach to prioritising those on the fire floor and higher up the building than this in line with the stair approach). This results in the values shown in Section 4.

4 RESULTS

Lift traffic simulations have been undertaken utilising the building assumptions in the preceding sections. The analysis results can be seen in Table 4.

Table 4 Evacuation Times

Level	Time taken to evacuate 15% of the floorplate population by lift (min:sec)	Time taken to evacuate 85% of the floorplate population by stair (min:sec)
11 (Fire Floor)	09:17	02:03
12-13	18:51	04:06
14-15	19:53	04:06
16-17	20:34	04:06
18-19	21:13	04:06
20-21	22:02	04:06
22-23	22:45	04:06
24	12:00	01:53
9-10	18:04	05:59
7-8	17:11	04:21
5-6	16:16	04:21
3-4	15:37	04:21
1-2	16:55	05:07
Total Time Taken	**3 hours 53 minutes 38 seconds**	**52 minutes 45 seconds**

It can be seen that the total evacuation time using the lifts is 3 hours 53 minutes. This greatly exceeds the assumed stair evacuation time of 53 minutes.

These are the times to evacuate everyone outside the building to allow a comparison between lifts and stairs; fire engineering guidance typically looks to distance/time into a stair.

5 SENSITIVITY

Sensitivity studies have been undertaken to understand how it may be possible to bring the lift evacuation time more in line with the stair evacuation time. These studies consider occupancy density and the provision of additional lifts.

The sensitivity studies are summarised as follows:

- Reduction from 15% of building users to be evacuated, to 10%. Maintaining a design occupancy of 1 person per 6 m^2.
- Reduction of the base build design criteria from 1 person per 6 m^2 to 1 person per 12.5 m^2. Maintaining 15% of the building users to be evacuated.
- Increasing the total number of lifts available for use for evacuation. Maintaining a design occupancy of 1 person per 6 m^2 with 15% of the building users to be evacuated.

5.1 Reducing the proportion of users

The base case scenario is based on each floor being occupied at 1 person per 6 m^2. The scenario also assumes that 15% of the population will require the use of the lifts for evacuation. This data is based specifically on the London Region [4].

BS EN 81-76 states that "typically at least 10% of the population has difficulties using the stairs percentage increasing as the building height increases" [2]. As a starting point, analysis has been undertaken using this 10% to determine the populations. This reduces the populations who use the lifts by 33%.

Reducing the number of people who use the lifts will increase the number using the stairs. This will have a minor negative impact on the total stair evacuation time.

Table 5 10% of Occupants expected to use evacuation lifts

Floors	Total occupancy	Occupants using stairs	Mobility impaired occupants	Occupants with stamina/ breathing issues/ fatigue	Wheelchair users	Total occupants per floor using lifts
1	477	429	27	19	1	47
2-23	362	326	20	15	0.5	35 and 36
24	331	298	19	14	1	34

5.2 Reducing the overall occupancy

The next study that has been undertaken takes into account the base build criteria. While the Fire Strategy will require 1 person per 6 m^2, the building, including vertical transportation systems, is generally designed to an effective occupancy density of 1 person per 12.5 m^2 [9]. Using the 15% from the local guidance, the populations can be determined. This reduces the populations who use the lifts by 48%.

Reducing the assumed building occupancy also means that the populations using the stairs will decrease, with an overall benefit to the stair evacuation time.

Table 6 15% of Occupants expected to use evacuation lifts with a 1:12.5 occupancy

Floors	Total occupancy	Occupants using stairs	Mobility impaired occupants	Occupants with stamina/ breathing issues/ fatigue	Wheelchair users	Total occupants per floor using lifts
1	229	195	19	14	1	34
2-23	174	147	15	11	0.5	26 and 27
24	159	135	13	10	1	24

5.3 Increasing the number of lifts

Each lift will continue to move the same number of people. Adding additional lifts will increase the overall handling capacity of the system.

Given that the lifts will all be operator-assisted evacuation lifts, even if the additional lifts are located directly adjacent to each other, they are assumed to operate as simplex lifts (not grouped). Providing eight simplex lifts will provide four times extra capacity than what is assumed within the base case.

5.4 Results of sensitivity studies

The evacuation times from the above studies are tabulated below.

Table 7 Sensitivity studies results

Option	Total Lift Evacuation Time	% change in lift evacuation time from base scenario	Total Stair Evacuation Time	% change in stair evacuation time
Base Scenario	3 hrs 53 min 38 s	-	52 min 45 s	-
10% of building occupants using the lifts	2 hrs 14 min 34 s	- 41 %	54 min 55 s	+ 4 %
Reduced building occupancy density	2 hrs 0 min 0 s	- 47 %	25 min 43 s	- 51 %
Increased number of lifts (8x simplex lifts)	54 min 31 s	-76 %	52 min 45 s	-

6 CONCLUSION AND NEXT STEPS

The results draw a simple conclusion: the fewer people there are using the lifts, the quicker the evacuation time. The more lifts there are with a stable number of people, the quicker the evacuation time. Similarly, the fewer people using the stairs, the quicker the stair evacuation time.

It is noteworthy that, if we just analysed the evacuation of the fire floor with a time of 9 minutes 17 seconds, this may be considered an acceptable solution, but evacuation times expand significantly when extending to the full building.

This building example dispels the assumption that one evacuation lift per core is automatically acceptable; it is clear that, with providing only one evacuation lift per core, the full building evacuation time by lift is several times larger than the evacuation time by stair. Reducing the proportion of users expected to use lifts in the event of a fire can significantly reduce this ratio, and the results are particularly sensitive to this aspect. The refinement of the populations who use the stairs is key, with human factors needing to be assessed. Is it possible that in a full building evacuation scenario, more people may wish to take the stairs to ensure they get out of the building? Especially given that over the years, advice has always been to not take the lifts in the event of a fire. Or conversely, will using lifts in the event of a fire become a more accepted norm, driving more people to use the lifts, perhaps including those who could manage the stairs, but with difficulty? This will likely increase for upper storeys – people will be more likely to take the stairs down two storeys than down twenty-two storeys [10]. Further research into the human factor element is critical to refine and understand the proportion of people who will use evacuation lifts, by necessity or by choice, and what will impact this decision.

However, several questions on the wider building design need to be addressed – determining how to practically implement the required number of evacuation lifts is also critical. This will necessitate an

approach agreed between the members of the design team to ensure that life safety is at the core of the design, in parallel with due consideration to floorplate efficiency and capital expenditure to ensure that the building remains feasible. Currently, evacuation lifts are associated with stair cores to ensure that users can retreat to the stairs as a backup if required. Typical VT design often incorporates banks of lifts for day-to-day use, which are typically not linked to stair cores. To avoid adding more and more evacuation lifts to the stair cores to reach the eight lifts needed to "match" evacuation times, a significant shift in either fire engineering, VT engineering, or architecture with respect to evacuation lifts will be needed. This could either be a fire engineering approach to using central lift banks as evacuation lifts, without protected routes to stairs for backup, or a VT/architecture approach stepping away from a traditional central lift bank – this could include the use of a central evacuation core with multiple stairs accessible from the central lift bank. This will require multi-disciplinary collaboration to develop an efficient, optimised lift and stair layout. Similar strategies are readily specified in line with the ASME A17.1 requirements for Occupant Evacuation Operation (OEO). Could a shift in thinking allow for what is more common in some other countries?

A target evacuation time needs to be defined to determine the required number of lifts. Human factors may not allow us to leave people in the building waiting for a lift for four hours, but the construction of the building potentially could (there is a common misconception that a 2-hour fire resistance period means that the building will only last for 2 hours, whereas this is not the case. Fire resistance periods bear no relation to "real" time in a fire, and a properly designed and constructed building should be able to withstand burnout – i.e. withstand the full duration of a fire from ignition, through growth, peak, and decay). This paper has attempted, within reason, to bring the lift evacuation in line with the stair evacuation. This seems like a sensible attempt at trying to define a target, although this clearly does have a significant impact on the base building design criteria, requiring an additional 3 lifts per core in this instance (total eight provided in two cores). Standard fire safety guidance such as Approved Document B and BS 9999 have taken target evacuation times and translated these into tabulated, simplified, recommended stair widths. Consideration of whether, and how, this could be undertaken for evacuation lifts should be considered.

In summary, this paper presents a methodology for assessing the number of evacuation lifts needed to bring evacuation time in line with stair evacuation time. However, additional work is needed to determine:

- The proportion of users likely to use evacuation lifts in the event of a fire
- Guidance on determining target evacuation times
- Practical measures of providing additional evacuation lifts without unduly compromising usable floor area
- Evidence-based loading and unloading times
- Effect of method of evacuation (driver assisted or automatic)

Given the available modes of evacuation as defined in BS EN 81-76, benefits may arise from the utilisation of automatic evacuation. Whilst it is unclear at the time of writing, automatic evacuation may allow for grouping of lifts for evacuation. Allowing the lifts to operate as a group will provide benefit for overall available handling capacity. Supplementing this with driver assisted evacuation and additional evacuation lifts could lead to robust evacuation strategies.

As taller and taller buildings become more prevalent, there are some within the industry who recommend that in tall buildings, evacuation lifts should be designed to ensure a significant majority of people within the building, if not all, are able to be evacuated by the lifts. Looking at the figures presented in this report, depending on the evacuation strategy of the building, this could have a significant impact on the evacuation lift requirements.

7 REFERENCES

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BIOGRAPHICAL DETAILS



Kristian Farr MEng, LCIBSE EngTech

Kristian joined the lift industry as a Vertical Transportation consultant in 2020 and now works as a Senior VT Engineer for AECOM. He has worked on hundreds of projects across many sectors and countries over the years, designing VT systems.

Kristian won the “Dr Gina Barney Emerging Excellence” award for his paper titled “Theoretical Evaluation of Evacuation Lift Capacity Assessments” presented at the Lift and Escalator Symposium 2024, which proposed a methodology to undertake the first phase of an evacuation in an office building.



Alastair Bartlett MEng PhD CEng MIFireE

Alastair holds a PhD in fire safety engineering, focussing on timber construction, and now works as an Associate Director in AECOM’s fire engineering team, working on strategies for a wide range of buildings including high-rise hospitals, offices, and government buildings necessitating the inclusion of evacuation lifts.