Title:	**Alternative Evacuation Design Solutions for High-Rise Buildings**
Author:	Simon Lay, WSP Group
Subject:	Fire & Safety
Keywords:	Elevators Evacuation Fire Safety Performance Based Design
Publication Date:	2008
Original Publication:	CTBUH 2008 8th World Congress, Dubai
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. **Conference proceeding** 4. Unpublished conference paper 5. Magazine article 6. Unpublished

Alternative Evacuation Design Solutions For High Rise Buildings

Simon Lay B.Eng, MIFireE

WSP Group, Tel: +44 (0) 161 886 2400, Email: simon.lay@wspgroup.com

simon.lay@wspgroup.com

Biography

Reaching for the sky was always Simon's passion which led him to study aeronautics and then work in fluid mechanics research at the University of Manchester. Simon entered Fire Engineering through the Nuclear sector and realised that he had found an engineering discipline that could mix his desire to always question presumptions with analytical design and a desire to strive always for the best in design.

In 2002, Simon left Arup Fire to join WSP, a company which had just acquired the high-rise specialists of Flack and Kurtz and Cantor Seinuk. In the period following September 11, 2001, this was in some ways a strange move, but Simon saw the opportunity to re-think tall building design.

Simon's work focuses on a deconstruction approach to fire safety design. Disecting every rule and standard practice to ask "why?". Challenging anyone who thinks that it is acceptable to adopt a design, just because it was the way it was done last time is Simon's signature.

On projects such as the 48 storey Beetham Tower in the UK, Simon lead the development of a single core design approach which is now fundamental to the viability of high-rise projects across the UK. Since joining WSP he has developed holistic design strategies for over 2500 storeys of high-rise residential, hotel and office design. Current projects include his involvement in projects which now exceed 1000m in height and 3 no. projects in the UK which will exceed 250m.

Simon leads the Fire Engineering team for WSP in the UK and supports the international collaboration of Fire Engineering skills across the Global Fire Engineering Teams. He is chair of the CTBUH Working party on Fire Safety in High Rise, on the CTBUH steering committee and the author of many papers and articles on fire engineering and high-rise design.

Alternative Evacuation Design Solutions For High Rise Buildings

Simon Lay B.Eng, MIFireE

WSP Group, Tel: +44 (0) 161 886 2400, Email: simon.lay@wspgroup.com

Abstract

There have been many proposals for novel and innovative evacuation solutions for high rise buildings, particularly since September 11, 2001. There has been much confusion with regards to what evacuation processes are appropriate for tall buildings and some condemnation of traditional evacuation practices.

This paper investigates in detail the role to be played by elevators and stairs in novel evacuation solutions which can deliver safe, efficient evacuation using current technology and well tested products. The practicalities of modern high rise evacuation design are presented

Keywords: Fire, tall buildings, evacuation, performance based design, stairs, elevators

A Need To Consider New Evacuation Methods

In recent times, tall buildings have not only continued to be built, but have become more prevalent and more complex than ever before. Buildings are getting taller with schemes over 1000m approaching a start on site and routinely projects mix residential, hotel, retail, bars, restaurants and offices in a single tower.

As we are finally creating true cities in the sky, we are also faced with the need to maintain both safety and efficiency in the design of our escape systems. Also, in a post World Trade Centre era it is necessary to not only rely on traditional building codes, but to demonstrate safety in our tall buildings.

This paper considers the practicalities of alternative escape solutions for today's high-rise buildings.

Evacuation Philosophies

The two primary evacuation philosophies for buildings are either *simultaneous* or a *phased* evacuation. There are further subtleties that can be applied, but in principle either:

a. *Simultaneous Evacuation*: All occupants are evacuated at the same time, regardless of what threat they are exposed to prior to evacuation; or,

b. *Phased Evacuation:* Only occupants who are at an elevated risk are evacuated initially, others remain in place for later egress.

Simultaneous evacuation is considered by many to be the ultimate in terms of safety. Removing all occupants from a building can ensure that no-one is left at risk. However, for a tall building, simultaneous evacuation can lead to escape stair sizes and numbers which are not compatible with a viable lettable floor plan. Instead, phased evacuation has evolved to address these issues and is the standard evacuation philosophy for high-rise buildings.

The practicalities of simultaneous evacuation are such that in a very tall building, even if all occupants begin their evacuation at the same time and there is adequate escape provisions, the physical movement of occupants can still take a long time. This is addressed by the premise that the escape cores are places of relative safety and it is the movement into the core that defines how quickly the evacuation should take place.

Phased Evacuation

Phased evacuation is a common approach applied in tall commercial buildings. It relies on the premise that compartmentation between floors will prevent rapid fire spread and only the fire floor and the floor above (sometimes also the floor below) will be evacuated. For a high-rise scheme, this process typically requires sprinklers, compartmentation, good communication systems and a high level of fire safety management to be present.

The stair sizes generated using phased evacuation can be calculated using simple models such as the following from the Approved Document B to the Building Regulations:

UK Approved Document B:

w = (P x 10) – 100
(P) is the occupants per storey that can be served
(w) is the width of the stair, in mm

Comparing for example a 30 storey office scheme with 1500 m^2 of typical UK office, a simultaneous evacuation design would require 4 no. 1200 mm wide stairs, whilst a phased evacuation design would require only 2 no. 1200 wide stairs. This would represent an increased Net:Gross of c. 2.4 %.

The reliance on good fire safety management and a reliance on occupants doing as they are instructed, even though they may see smoke, has lead to the validity of phased evacuation being questioned. The potential for occupants to presume that they are in a situation akin to the World Trade Centre incident has highlighted such concerns.

In practice, phased evacuation is normally applied in commercial office buildings. The occupants of such schemes can be educated and properly informed and trained to overcome such concerns and anecdotal evidence from evacuations in high-rise commercial buildings in London Docklands since 2001 have suggested that concerns over the obedience of occupants can be tempered as time passes.

Whilst core robustness is important for simultaneous evacuation, it is even more critical for phased evacuation and it is recommended by the author that dry-wall or masonry type systems should not be avoided in high-rise buildings which employ phased evacuation philosophies. Instead either concrete cores or a concrete filled, permanent steel shutter type system should be used.

Simultaneous Evacuation Of Buildings Designed For Phased Evacuation

It is possible to evaluate the overall evacuation period (to outside, rather than just into a stair) even when the stairs may not have been adequately sized for the overall occupancy. This type of approach is often used to test what would happen in a building designed for phased evacuation, when the management regime fails.

There is limited published data on what constitutes an acceptable total evacuation time for simultaneous evacuation to final exits in a high rise building when the evacuation provisions in the building are designed on a phased evacuation basis. It is considered by the author that a reasonable design basis could be formed as follows (Table 1):

	Recommended maximum egress time for all persons to reach a final exit (outside)		
	Up to 50 storeys	50 – 100 storeys	Over 100 storeys
Buildings designed for *simultaneous* evacuation	30 minutes	30 minutes	30 minutes
Buildings designed for *phased* evacuation	60 minutes	90 minutes	90 minutes

Table 1: Maximum recommended total evacuation times

In deriving the proposed maximums in Table 1, the importance of being able to achieve reasonable egress times under security alert conditions has been taken into account by the author. The basis of limiting the maximum recommended egress period to 90 minutes is due to structural fire protection limitations.

Whilst some standard codes may suggest up to 240 minutes fire resistance, the most common maximum fire resistance requested in standard codes is 120 minutes fire resistance. This is commensurate with typical fire severity analyses (BSI, 2002) which rarely generate a structural fire resistance period in excess of 120 minutes (based on likely compartment fires). Fixing the maximum egress time at a value below 120 minutes (90 minutes is proposed) ensures that even if the building design or operation inadvertently invalidates the assumptions of the fire severity analyses, the evacuation process will still have time to be completed.

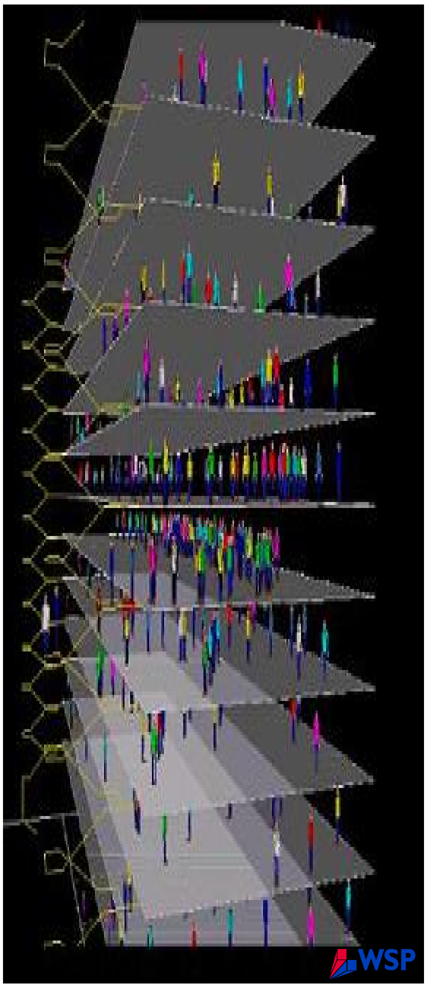


Figure 1: Typical Computational Evacuation Model (CEM) for a high rise study using The STEPS Evacuation software (© WSP Fire Engineering)

To achieve a total evacuation period of 90 minutes or less under simultaneous conditions, it is likely that measures other than simple stair evacuation will be necessary in a very tall high rise building.

It is recognised that when evaluating the simultaneous evacuation of occupants in a building designed originally for phased evacuation, the crowding in the stair core will most likely invalidate simple design calculations and it is recommended that for such studies a Computational Evacuation Model (or CEM) is applied (Figure 1).

Often the use of a CEM approach will produce less onerous results than a simple hand calculation, provided that the actual stair geometry is properly represented. As an example, on a study by the author for a 40+ storey office complex in Moscow, simple hand calcs overestimated the overall evacuation time under simultaneous conditions at over 120 minutes. With a detailed CEM approach, the evacuation (using stairs) was shown to be well under 60 minutes with the opportunity of using elevators to reduce this further to below 30 minutes.

Role Of Elevator Evacuation

In addition to evacuation philosophy, the other differentiating variable for evacuation strategies is the physical process applied to move occupants vertically. Whilst stairs are a tried and tested approach to evacuation, there are innovations still to be found in the use of stairs in buildings. However, much of the focus on evacuation mechanics for high-rise schemes has been on the use of elevators for evacuation.

Design guidance on the use of elevators in evacuation is limited. A common query which has not been addressed in current design guidance is advice on when the use of elevators becomes useful or essential. An attempt to provide guidance on this question is provided by the author in Table 2.

In developing the proposals in Table 2, as well as the fatigue aspect of walking down stairs, the author has given consideration to the likely space savings of using elevators for evacuation, the complexities of management required to control elevator evacuation, the need for training when used for high numbers of occupants and the need for groups of people to stay together in some situations.

The proposals set out in Table 2 suggest a trend for consideration, but it should be recognised that all schemes are individual projects and the process of considering the practicalities, positive and negative aspects of the use of elevators in evacuation should be considered for all high-rise schemes.

Building Height	Building Use	Elevators used in evacuations
Up to 50 storeys	Offices	○
	Hotel	-
	Residential	-
	Public Space	○
50 – 70 storeys	Offices	○
	Hotel	○
	Residential	○
	Public Space	●
70 - 100 storeys	Offices	○
	Hotel	○
	Residential	●
	Public Space	●
Over 100 storeys	Offices	●
	Hotel	●
	Residential	●
	Public Space	●

- Elevators considered to be of *limited* benefit
○ Elevators considered *useful* to support evacuation
● Elevators considered *essential* for evacuation

Table 2: Proposed guidance on the use of elevators in evacuation

It should be noted that Table 2 is not intended to reflect the benefits of elevator evacuation for mobility impaired persons. It is considered that in any scheme over 3 storeys in height, elevators could have a real benefit in supporting the evacuation of mobility impaired persons and in schemes over 6 storeys in height may be essential.

Practicalities of Elevator Evacuation

There are some design standards for evacuation elevators, such as the guidance provided in the British Standard BS 5588:Part 8 , although these are primarily derived for the evacuation of mobility impaired persons which is likely to be a less complex process than the use of elevators for general building evacuation. It is also noted that in a very tall building, elevators may need to function for the entire evacuation period.

To protect the elevators in an evacuation, it is considered that the elevator cores should be of concrete construction (or concrete filled, permanent steel shuttering systems) where the elevators are used for general evacuation. The design of the elevator system should follow the guidance for fire fighter elevators (such as the British Standard BSEN 81-72). This will introduce requirements for standby power provisions, waterproofing of systems and advanced control mechanisms.

Whilst elevators can be used to more quickly evacuate occupants from high level in a tall building, the time for occupants to reach a place of relative safety from an occupied floor plate can be longer due to the cyclic 'batch' nature of the elevator process as against the continuous nature of a stair evacuation. This requires a refuge space to be formed where occupants can wait in safety for the elevator to arrive.

The design of refuge spaces can be a complex matter. They need to be sufficiently large enough to make occupants feel comfortable and to enable them to move within the space (for example if they decide to use the stair rather than wait for an elevator). The following is considered to form a sensible design basis:

- The maximum tolerable space per occupant should be limited to no less than 0.5 m^2 / person.
- The refuge should be separated by 120 minutes fire resistance from the fire floor (doors to the lobby can be 60 minute doors with smoke seals – FD60S).
- The refuge should be provided with smoke ventilation (either pressurisation or an air exchange 'flushing' system).
- The refuge should include a communication system for occupants to talk to the fire building fire control centre.
- The refuge should connect to both evacuation elevators and a stair core.
- The refuge should be well lit to a typical day to day standard.

In setting a 0.5 m^2/person limit, the above conditions are taking into account the need to avoid panic, allow occupants to move within the refuge and enable fire fighters to exit through the lobby if required. The figure of 0.5 m^2/person is presented in the UK Approved Documenty B as a typical bar occupancy level (although not the crush space around a bar which can reach 0.3 m^2/person and would be unacceptable for an escape refuge).

In calculating the net occupancy at any one time in the elevator refuge, a calculation based on the following is required:

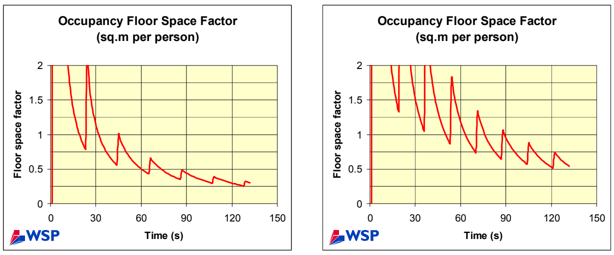
$$\sum P_{net} = P_{arr} - (P_{elv} + P_{str})$$

(P_{net}) is the net flow of occupants into the refuge space.
(P_{arr}) is the number of occupants entering the refuge space from the accommodation.
(P_{elv}) is the number of occupants leaving by elevator.
(P_{str}) is the number of occupants by stairs.

This calculation should be carried out over a series of timesteps that takes into account the cycle of the elevator operation. It is not acceptable to take average inflow and outflow rates to the refuge space, as this will not reflect the peak occupancy at any one time. It may also be necessary for the analysis to take into account the fact that the changing occupancy (and occupancy density) in the refuge space will itself change the flow of occupants through the refuge. As a result of this, non-linear modelling techniques may be needed for complex studies.

The results of a refuge space analysis are presented in Figure 3. This analysis is taken from a generic study by the author. The elevator cycle needs to take into account the charging and discharging period, travel to and from the evacuation floor to the ground floor and also recognise delays such as door closing times and a factor to account for overcrowding, leading to doors failing to close.

Simple analyses may be appropriate for initial design studies, but it is considered that as part of a formal design development and approval process, a complete computational model for the building evacuation using elevators should be developed.



Case A: The refuge space is too small to prevent the

Case B: A second evacuation elevator has been introduced

Figure 3: Evacuation Refuge Capacity Study
(© WSP Fire Engineering)

It has been noted that in some elevator systems, the rate of acceleration is limited during normal operation, but could be increased in an evacuation situation. Whilst there may be some benefits in evacuation period for this approach, it is considered that in practice such a solution could raise significant challenges, particularly over long travel periods. An important challenge is that the sensors and microswitches that tell an elevator when and where to stop (and which control when doors will or will not open) are tuned to take into account the acceleration and deceleration of the elevator under normal operating conditions and also to recognise the flexing of the elevator cables.

If an elevator system can recognise the change in operational parameters in an evacuation mode, then changes to the elevator speed and acceleration could be considered, but great care should be taken in the design and specification of the system as one could end up with an elevator system which overshoots the target floor, preventing the doors from opening.

In many situations it can be difficult to engineer a sufficiently large enough lobby using the day to day elevator lobby to accommodate occupants during an evacuation. This may therefore require additional lettable area to be set aside for what is an unlikely event. Some use can be made of sanitary accommodation attached to elevator lobbies, but a more common solution is to use stairs to move occupants to a floor below the fire floor and then, once in a place of relative safety, occupants can use the general office space or circulation areas to wait for elevator escape in safety.

A natural extension of using lower floors as a refuge is to consider the use of sky-lobbies in very tall buildings. Schemes in excess of c. 70 storeys typically include a sky lobby design as part of the mechanical and electrical plant and elevator network design. This may require occupants to walk down up to c. 35 storeys, but this is commensurate with the guidance in Table 2 and is an effective strategy for many buildings.

It is also noted that in designing for elevator evacuation, care should be taken to recognise that the general public have been trained not to use elevators in the event of a fire. This is the normal situation. In an office building, staff training can overcome this challenge. However, in buildings where the public have access, it will be necessary to have trained staff to direct evacuation. These staff may require significant training and it is recognised that they will be remaining with occupants in the building for a significant period of time, which may have staff insurance implications. Responsible staff will also require mobile and fixed communication systems to communicate with a control centre for the building (who will need to manage the evacuation) and may require additional safety equipment such as lights, fluorescent tabards and megaphones.

Elevators as Primary Evacuation Routes

Provided that elevators and refuges spaces are designed in accordance with the standards described above, it is considered that there is no reason to preclude the use of elevators in an evacuation as one of the primary evacuation routes. This approach is being investigated for a number of very tall residential buildings which are suited to this approach as:

- The number of occupants being moved is small in relation to the foot print of the building.
- Occupants are familiar with the elevators as their day to day access route for the building.
- There is a natural refuge space available in the form of the common residential corridor, which is large in relation to the typical occupancy.

It is natural to pursue this approach in the UK or Australasia. These regions allow single stair residential buildings of considerable height and the adoption of elevators as primary escape routes will enable the standard guidance to be extended to single stair buildings of any height, preserving the critical net:gross floor ratios that make such buildings viable. However, the basic principle of using elevators as primary escape routes is technically and practicably sound and as such, through a performance based design solution, it should be possible in any region, no matter what the standard prescriptive guidance dictates.

The use of elevators as primary evacuation routes, in place of some stairs in non-residential buildings is a more controversial approach, but following the same premise as the residential approach, it is considered that this could be considered, provided that the occupancy rate on the floor plate was small. This may make the approach appropriate for small office foot plates and would also apply to public viewing spaces at the top of very tall buildings.

Conclusions

The elevators and stairs provided in buildings today are commercially tolerable and can provide adequate means of egress under fire and other emergency conditions, without resorting to design solutions which are not fully tested and would be potentially confusing to occupants. There are also likely to be concerns relating to the cost and reliability of novel solutions and such designs may also take up additional space in a building.

There is a future for the use of elevators for evacuation and we have the tools available today to enable us to exploit such design solutions.

References

Reports

NIST NCSTAR 1: Federal Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report of the National Construction Safety Team on the Collapses of the World Trade Center Tower. NIST 2006.

Approved Document B to the Building Regulations. Volume 2 – Buildings Other Than Dwellinghouses. NBS 2006.

BS 5588-8:1999. *Fire precautions in the design, construction and use of buildings. Part 8: Code of practice for means of escape for disabled people*. BSI 1999.

BS EN 1991-1.2:2002. *Eurocode 1: actions on structures general actions : actions on structures exposed to fire.* BSI 2002.

BS EN 81-72:2003. *Safety rules for construction and installation of lifts : particular applications for passenger and goods passenger lifts firefighters lifts*. BSI 2003.