ALTERNATIVE EVACUATION DESIGN SOLUTIONS FOR HIGH-RISE BUILDINGS

SIMON LAY
WSP, Manchester, UK

SUMMARY
There have been many proposals for novel and innovative evacuation solutions for high-rise buildings, particularly since 11 September 2001. There has been much confusion with regard 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 key drivers for alternative evacuation design are discussed and guidelines for the practicalities of modern high-rise evacuation design are presented. Copyright © 2007 John Wiley & Sons, Ltd.

1. THE CASE FOR STAIRS
Humans are almost uniquely capable of crossing any of the terrain which planet earth can offer. Our evolution as bipeds led to the development of elevators as a means of vertical access in tall buildings, although stairs remain the primary means of vertical escape in buildings. As any parent who has had to hastily erect a stair gate in their house knows, negotiating stairs is something which even the youngest child appears to be achieve with somewhat surprising ease.

In even the most extreme of cases, such as the destruction of the Word Trade Center, stairs have been shown to perform extremely well as a means of egress. So if we are so good at using stairs, why try to overturn millions of years of evolutionary design and seek out alternative means of vertical escape in buildings?

This paper considers some of the drivers behind alternative escape solutions and practical design issues associated with the emerging trends.

2. THE DRIVERS FOR CHANGE
2.1 Mobility-impaired person
While the human biped form evolved as a design which can use stairs, society has moved on from the notion that mobility-impaired persons (MIPs) should be restricted to a life at ground level, or that MIPs should be reliant on assistance to carry out day-to-day tasks.

If we value the notion of freedom, independence and equality of movement that means we must cater for the needs of MIPs. While the traditional focus of MIP design has been focused on wheelchair users, this does not recognize that many persons who live the majority of their lives without any
mobility impairment may at some point become impaired for a transient period (e.g., during pregnancy or following a sports injury). Also, in very large buildings, the benchmark for what constitutes mobility impairment may need to be reconsidered. With an aging workforce which is also showing trends towards obesity, there are more and more people who may be unable to use very long stair runs in buildings.

It is important to create inclusive building designs which cater for the needs of all occupants and stairs are not readily able to provide an evacuation provision for many MIPs. While there may be bolt-on solutions for short flights of stairs, in a high-rise scheme stair lifts or similar devices are not appropriate.

2.2 Increased building height

It may seem obvious to suggest that because we have many more tall buildings, and some current schemes in design or early construction are now reaching towards or even well beyond the 1000 m mark, we must consider alternatives to stairs. There is some justification for this as the increased vertical travel can change the benchmark for what constitutes an MIP in the context of individual buildings.

Evidence from very tall building evacuations (NIST, 2006) suggests that stairs have proved effective for the overwhelming majority of occupants at heights up to or in excess of 90 office floors (c. 350 m). The majority of tall buildings are well under this height and care should be taken when seeking to apply alternative evacuation solutions to buildings which have a good track record of safety using stairs.

2.3 Building efficiency

A key driver in the economics of tall building design is the need to achieve efficiency in the ratio of gross floor plate to lettable area (the net: gross ratio). For a given building form, this ratio, the cost per square foot and the value per square foot of leased area form the backbone in the appraisal of the viability of a high-rise building design.

The repetition that occurs in a tall building ensures that losing a small amount of floor area on one floor can make a building unviable when taken over multiple floors. There is therefore an economic driver to seek out design solutions which may offer the ability to evacuate occupants using less floor area. Recent proposals for the International Building Code (NIST, 2007) to impose a requirement for a minimum of three stair cores in high-rise buildings will make some alternative design options even more attractive.

2.4 Changing threat profiles

The stair has served well for providing means of escape in fire. However, there is an increasing desire that other extreme events be considered when evaluating vertical escape routes from a building.

That we should consider evacuation under non-fire events will not come as a surprise to designers in countries such as Japan (Building Standard Law of Japan, 2004), where the need to consider earthquakes as an evacuation mode is common. However, the key change in threat profile is that of terrorist alerts.

Whether building design should try to respond to an assault of the magnitude of the World Trade Center attack is a matter for much debate and many consider that such large-scale events are best addressed by counter-terror measures from intelligence gathering to air defence solutions.
There is, however, a growing recognition (or remembrance) that terror attacks have traditionally been much smaller events than the World Trade Center attack, or may include more sophisticated means of assault such as chemical or gas attacks. There is also recognition that the standard guidance for occupants in most terror alert situations is that they should remain in their building and limit their exposure to flying debris.

Our understanding of the terror threat constantly changes. Unlike a system administrator who can modify the software and hardware of a computer to respond to the threat from ever-evolving and changing computer viruses, the fire safety engineer is basically left with understanding what can be done with the fixed architecture, typically through changes to the fire safety management ‘software’ of the building. As a result of this, some innovative evacuation strategies have emerged to address the emerging threats.

2.5 Alternative evacuation design options

Emergency egress solutions can be defined by two primary differentiating variables:

(1) evacuation philosophy; and
(2) mechanics applied to achieve evacuation.

The reason for evacuating (for example fire scenario or terror alert) could be considered as a third variable, but in practice the differentiation between different evacuation philosophies already encompasses this variable.

The evacuation philosophy is fundamentally either a simultaneous or a phased evacuation approach. As discussed below, there are further distinctions 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.

3. EVACUATION PHILOSOPHIES

3.1 Simultaneous evacuation

The standard design basis for buildings is simultaneous evacuation. 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. Phased evacuation has evolved to address these issues.

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.

A possible disadvantage of simultaneous evacuation in buildings design with pressurization systems is that the system can be overcome by the additional leakage introduced during an extended evacuation period (this may also be an issue for the interaction between pressurization systems and other evacuation philosophies and is not discussed further in this paper).

It is possible to evaluate the time for occupants to flow into stairs (assuming that the stairs are adequately sized) using simple flow rate calculations. This approach is not appropriate if the stairs are not sufficiently sized to contain all occupants simultaneously as congestion on the stair may prevent occupants from reaching the safety of the stair core.
There are a number of different ways of defining what the capacity of a stair is to accommodate all occupants of a building. For example (NFPA, 2006; UKDCLG, 2006):

**NFPA 101**: Allow 5 mm per person

**UK Approved Document B**: 

\[ P = 200w + 50(w - 0.3)(n - 1) \]

\((P)\) is the number of occupants that can be served
\((w)\) is the width of the stair, in metres
\((n)\) is the number of storeys served

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 approach is often used to test what would happen in a building designed for phased evacuation, when the management regime fails (see below). However, it is recognized that 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 calculations 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.

It is possible (and increasingly common) to evaluate how smoke and fire conditions may develop on the floor of fire origin and hence this can define how long occupants should have to gain access to a stair. This increasingly uses computational fluid dynamics (CFD) to provide accurate smoke development data (Figure 2).

Figure 1. Typical computational evacuation model (CEM) for a high-rise study using the STEPS Evacuation software (© WSP Fire Engineering)
In the absence of a more complex study, it is generally accepted that to achieve an acceptable egress into the core from the floor plate, evacuation should take no more than c. 2.5 minutes. This period is based on the assumptions inherent within the standard UK guidance (the Approved Document B). The acceptable time to enter the core does not vary with building height. However, there should be variation due to height in the acceptable maximum time for completed simultaneous evacuation (all persons from all floors to a final exit from the escape cores).

There is limited published data on what constitutes an acceptable total evacuation time for simultaneous evacuation to final exits in a high rise building. It is considered by the author that a reasonable design basis could be formed as shown in Table 1.

In deriving the proposed maxima 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. While 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.

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.

3.2 Phased evacuation, Defend in Place and In-Vac

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 Approved Document B to the Building Regulations:

**UK Approved Document B:** \( w = (P \times 10) - 100 \)

- \( P \) is the number of occupants per storey that can be served
- \( w \) is the width of the stair (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, while a phased evacuation design would require only 2 no. 1200 mm 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 led 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 Center 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 has suggested that concerns over the obedience of occupants can be tempered as time passes.

However, concerns over the robustness of phased evacuation have led to detailed studies being carried out to test the implications of simultaneous evacuation on schemes originally designed for phased evacuation (as discussed above). It has also been noted that many large hotel operators who may have previously worked on the basis of phased evacuation design in a high-rise hotel (to reduce business interruption from false alarms) have switched to a simultaneous evacuation philosophy.

While 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 be avoided in the cores of high-rise buildings which employ phased evacuation philosophies. Instead, either concrete cores or a concrete filled, permanent steel shutter type system should be used.

The process described above is perhaps the philosophy most understood as phased evacuation. However, there are other forms of phased evacuation.

There is a growing interest in the philosophy of ‘In-Vac’. This is not normally applied for fire evacuation but is an anti-terror strategy. It is recognized that in a bomb threat scenario sending occupants from the building may be as dangerous as leaving them in the building and that perhaps the primary hazard from even a small bomb may well be flying glass and debris. To counter this, if a robust core design is adopted, the cores can be considered to be a place where occupants can shelter until the all-clear is given. Protecting the occupants within the core (without moving them from the core) is known as ‘In-Vac’.

When a core is used for In-Vac, occupants are not expected to walk down the stairs and, instead, they will remain in the core, allowing a much higher density of persons to be achieved within the core.
(a floor space factor as low as 0.3 m² per person may be tolerable). An approximation of the core occupancies that can be achieved using In-Vac has been made by the author using the following:

\[ P = n(6w + 4w^2)/0.3 \]

- \( P \) is the number of occupants that can be served
- \( w \) is the width of the stair, in metres
- \( n \) is the number of storeys served

The above analysis applies only to the stair part of the core and some core designs enable a lobby to also be used as part of the In-Vac design. This can increase the occupancy that can be held within the protected core.

It is noted that for In-Vac to be successful training is required, so it is probably only suitable for occupancies such as commercial offices. Also, specific threat information may be required. Consider, for example, the consequences of adopting an In-Vac strategy for an expected bomb-blast only for the attack to be a chemical or gas device (as the cores are likely to act as chimneys).

The movement of fire-fighters during a phased evacuation should be considered and if stairs are narrow (<1200 mm is a suggested limit) additional provisions may be necessary to take into account the blockage of stairs by occupants which could restrict fire-fighter mobility. This may require additional stairs in an extreme situation or confirmatory studies using CEM techniques to demonstrate that fire-fighters can move up the stairs when occupants are descending.

It is also noted that In-Vac is not appropriate when fire-fighters might need to use stairs to gain access to the building. The very low floor space factors achieved within stairs and lobbies when using In-Vac could prohibit fire-fighter travel through the stair and lobby network.

A further common variant of the phased evacuation philosophy is that of Defend in Place. This is typically when the phasing of the evacuation is taken to a higher level of detail, with some occupants on the same floor as the fire remaining in the building. This approach often raises concerns with practitioners who are not familiar with the approach. In the UK (also Australasia and Scandinavia), this approach is the cornerstone of residential evacuation, where only those occupants in the apartment which has caught fire evacuate. Other occupants are not only kept in the building, but are deliberately not made aware of the fire incident. The basis for this approach lies in understanding the evacuation process for occupants who are not confronted with fire cues.

If you are in an apartment which is on fire, you are aware of the risk and will quickly get out, most likely before the fire service arrives and before conditions in the common areas of the building are compromised. However, if you are in a neighbouring apartment and the alarm sounds, you will have no other clue as to the likely risk and you will take a long time to gather together clothing, possessions and loved ones, before evacuating. This delay may give the fire a chance to compromise common areas, or the fire service may be in attendance, which is likely to lead to common areas being compromised, at least during fire-fighter operations. However, if you stay in your apartment you can open a window for fresh air; you are in a sealed compartment away from the fire such that the risk to your life will be very low indeed. To augment this, common corridor spaces should also be ventilated.

It is considered that Defend in Place can provide a possible solution for residential and hotel type occupancies, and there is some significant data supporting this. For example, consider that over 50% of occupants who died in the MGM fire in Las Vegas (CCFD, 1980) died trying to use the escape routes. Had they stayed in their rooms, and the corridors had been protected to act as a buffer zone, many of these deaths might have been avoided.

The Defend in Place approach has a significant impact on the design of stair cores. In the UK, by adopting a Defend in Place approach no specific limit is imposed within the guidance of the UK Approved Document B for single-stair residential towers. However, for very tall buildings, it may be appropriate to take into account other factors.
4. ALTERNATIVE EVACUATION MECHANICS

In addition to evacuation philosophy, the other differentiating variable for evacuation strategies is the physical process applied to move occupants vertically. While 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 recognized 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.

It should be noted that Table 2 is not intended to reflect the benefits of elevator evacuation for MIPs. It is considered that in any scheme over three storeys in height elevators could have a real benefit in supporting MIP evacuation and in schemes over six storeys in height may be essential.

4.1 Practicalities of elevator evacuation

There are some design standards for evacuation elevators, such the guidance provided in the British Standard BS 5588-8 (1999), although these are primarily derived for the evacuation of MIPs, 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.

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

<table>
<thead>
<tr>
<th>Building height</th>
<th>Building use</th>
<th>Elevators used in evacuations</th>
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</thead>
<tbody>
<tr>
<td>Up to 50 storeys</td>
<td>Offices</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Hotel</td>
<td>–</td>
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<tr>
<td></td>
<td>Residential</td>
<td>–</td>
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<tr>
<td></td>
<td>Public space</td>
<td>○</td>
</tr>
<tr>
<td>50–70 storeys</td>
<td>Offices</td>
<td>○</td>
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<tr>
<td></td>
<td>Hotel</td>
<td>○</td>
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<tr>
<td></td>
<td>Residential</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Public space</td>
<td>●</td>
</tr>
<tr>
<td>70–100 storeys</td>
<td>Offices</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>Hotel</td>
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<td>Residential</td>
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<td></td>
<td>Public space</td>
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</tr>
<tr>
<td>Over 100 storeys</td>
<td>Offices</td>
<td>●</td>
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<td></td>
<td>Hotel</td>
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<td></td>
<td>Public space</td>
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</tbody>
</table>

– Elevators considered to be of limited benefit.
○ Elevators considered useful to support evacuation.
● Elevators considered essential component of evacuation.
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, 2003). This will introduce requirements for standby power provisions, waterproofing of systems and advanced control mechanisms.

While 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 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 m² per 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 pressurization 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 m² per person limit, the above conditions take 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 m² per person is presented in the UK Approved Document B as a typical bar occupancy level (although not the crush space around a bar, which can reach 0.3 m² per 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:

\[ \Sigma P_{\text{net}} = P_{\text{arr}} - (P_{\text{elv}} + P_{\text{str}}) \]

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

This calculation should be carried out over a series of time-steps 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.

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 recognize 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.
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. While 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 micro-switches 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 recognize the flexing of the elevator cables.

If an elevator system can recognize 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 lobby using the day-to-day elevator lobby to accommodate occupants during an evacuation. This may therefore require an 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 recognize 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

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**Case A:** The refuge space is too small to prevent the occupancy space falling below 0.5 m² / person whilst waiting for elevator evacuation.

**Case B:** A second evacuation elevator has been introduced to increase the frequency of evacuation and elevator speed increased. Floor space now stays above 0.5 m² / person.

Figure 3. Evacuation refuge capacity study (© WSP Fire Engineering)
public have access, it will be necessary to have trained staff to direct evacuation. These staff may require significant training and it is recognized 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.

4.2 Elevators as primary evacuation routes

Provided that elevators and refuge 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 and is suited to this approach as:

- the number of occupants being moved is small in relation to the footprint 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 as the use of elevators. 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, 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 may be possible with appropriate due care, provided that the occupancy rate on the floor plate was small. This may make the approach appropriate for the small office space often found towards the top of a very tall building and could also apply to public viewing spaces at the top of very tall buildings.

4.3 Advanced stair options

There is great interest in the use of elevators for evacuation. However, as noted at the start of this paper, humans are generally well adapted to using stairs and, as identified in Table 2, elevator evacuation may not be appropriate in buildings up to c. 50 storeys (which is probably the most common range of tall building heights). It is therefore necessary to consider some alternative stair configurations.

Mixed-use buildings provide a good example of where advanced stair options can be considered. The different evacuation modes employed in separate parts of a mixed-use high-rise scheme may require different egress options which will need to be brought together.

A good example of this challenge is a high-rise which combines either commercial offices or a hotel on the lower floors, with a residential element to the upper floors. In this case, based on the phased or simultaneous evacuation of the hotel/office floors and the Defend in Place strategy for residential, 2 no. stairs would be required for the lower floors, but a single stair may be sufficient for the upper floor. Recognizing this enables an enhanced net:gross ratio to be achieved.

A configuration for achieving a strategy for mixing a single stair at the top of a building with multiple stairs at the lower levels is shown in Figure 4. The building depicted in Figure 4 is the Beetham
Figure 4. Efficient stair design at the Beetham Hilton Tower (plans reproduced with kind permission of Ian Simpson Architects and the Beetham Organization)

Figure 5. ‘Delta’ stair configuration for mixed-use high-rise tower design (© WSP Fire Engineering)
Hilton Tower in Manchester, England (completed and occupied in 2007). It is 48 storeys in height, with the lower 23 floors as a hotel and the upper 25 floors as residential. A pair of stairs serves the hotel levels as far as the bar level at Level 23, but only one stair core continues after this point.

The hotel in this design case is sprinklered, and ancillary hotel accommodation (kitchens, function rooms, etc.) are located in a podium structure to the side of the main tower (which contains only residential apartments and hotel bedrooms). The building is a concrete frame with concrete cores and each pair of hotel rooms and every apartment forms a separate fire compartment. On the basis of this, an advanced stair strategy was considered acceptable.

The single stair in the residential part can generate one additional challenge as the approach described above can lead to the single core being offset towards one end of the building. This generates a long travel distance from an apartment to the stair core. To address this, such buildings employ an enhanced smoke ventilation system to compensate for the extended travel. This has the advantage of enhancing conditions for occupants and fire-fighters (to a level much improved over the standard conditions which could occur in a prescriptive code compliant design).

It is also possible to apply the above design logic in reverse, providing multiple stairs to the top of a building with a single stair below. This approach can only work when one has a relatively small occupancy using the lower parts of the stairs. A good example of such a design is where there is a bar/public viewing area at the top of a high-rise residential scheme. A small occupancy in the bar/public viewing area could be readily accommodated without a second egress stair, but if a significant occupancy is necessary (for example, 200–300 persons) then a second stair could serve just the upper levels, and then feed into the single stair serving the lower floors of the building. This is designated by the author as a ‘2-into-1’ design.

To limit the potential for crowding on the stair, the author proposes the following approach to create a practical 2-into-1 stair design. One of the stairs serving the top of the building is a scissor flight within the main core and then this stair is itself split into further scissor flights which feed into the single stair at different levels. This is not a simple arrangement and is best described visually, as shown in Figure 5. This approach has been designated by the author as a ‘Delta’ arrangement and requires detailed analyses, but in principle enables a high occupancy to feed into a single stair core in a controlled manner which limits the potential for overcrowding at the single stair. While care should be taken to ensure effective wayfinding for occupants and fire-fighters, this approach does mean that occupancies which may require two stairs can be placed at the top of a building, without needing to sacrifice the space for a second stair throughout the entire tower.

5. CONCLUSIONS

This paper has not considered some of the more strange and novel evacuation solutions being put forward. These include systems ranging from helicopter rescue, personal rockets and ejection systems, to rapid slide and rail solutions or zip wires to neighbouring buildings and large rescue towers to be brought alongside the building. These systems have not been discussed because they are considered unlikely to play a significant role in the evacuation of occupants in real buildings.

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.

Careful design of the evacuation systems in a building, exploiting those systems which are already reliable due to their need for day-to-day operation of a tall building is considered to be a more appropriate approach and will lead to a more efficient design.
It is clear that to achieve an effective and efficient evacuation solution it is necessary to take into account the evacuation options from the earliest space planning stages of a project, then develop concepts into detailed design solutions and comprehensive system specifications. It is then necessary to ensure that the final construction satisfies the detailed design intent and also that the operational procedures of the building reflect the design.

There is a future for the use of elevators for evacuation and we have the tools available today to enable us to design solutions that use elevators for evacuation. However, the traditional stair is not dead just yet and is still proving itself to be adequate in many high-rise designs.

REFERENCES


CCFD. 1980. Official Investigation in to the fire at the MGM Grand Hotel, 21 November 1980. Fire Department, Clark County, NV.


