Exploring the Concept of Using Lifts to Assist the Evacuation of Very Tall Buildings

Peter Sumner

WSP Parsons Brinckerhoff
One Queens Drive, Birmingham, B5 4PJ, UK

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Abstract: Evacuation times for very tall buildings, whether for planned evacuation, real fire or non-fire emergencies, can be extreme. This paper explores the concept of using lifts to assist the evacuation of tall buildings and discusses the major considerations for building designers.

As buildings are getting taller there is a need to consider the safety of occupants during evacuation. The physical exertion that is required to walk down 100+ flights of stairs and in some cases for times in excess of 2 hours can be very challenging for many people. This unexpected physical exertion added to the stress of evacuating a building during an emergency can lead to tiredness, physical or mental injury and fatality.

The design of buildings and complete lift systems to withstand the effects of fire, smoke, water and loss of power can be very expensive in terms of equipment and in the potential loss of rentable area. However, depending on the fire and life safety strategy of a given building, an emergency may not require the simultaneous evacuation of all the occupants, therefore, evacuation by lift may not be required from all levels of a building and may not require the use of all lifts.

1 INTRODUCTION

Evacuation times for very tall buildings, whether for planned evacuation, real fire or non-fire emergencies, can be extreme. Whilst designers are required to consider safe evacuation of occupants from all buildings, conventional stair evacuation of tall and very tall buildings can in itself be hazardous.

Designers have been considering the use of lifts to assist the evacuation of tall buildings for some time; firstly as a matter of code to enable safe egress of all persons including persons with disabilities and secondly as a means of reducing the overall evacuation time and risk of injury to evacuees.

The premise for most buildings is that lifts shall not be used in case of fire and that there shall be sufficient evacuation stairs to ensure a safe evacuation by all building occupants. The question is: does this current design model best serve the needs of occupants of very tall buildings?

There are two main issues with stair evacuation; does the number of flights of stairs cause undue physical stress to evacuees, considering their size, age and general ambulatory condition and; does the time required to evacuate by stair lead to fatigue and cause undue physical and mental stress.

Evacuation stairs will always be an essential requirement for the Life Safety design of buildings either as the sole means of evacuating the building or as a back-up to others means of evacuation. That said there are obvious benefits of using lifts to assist the evacuation when it is safe to do so.

If lifts are to be used to assist the safe evacuation of buildings, cooperation must be achieved between all persons responsible for the design of a building including, client, Architect and Engineers and consent will be required from the local fire authority or building control department.

Incorporating lifts into the evacuation strategy of a building should therefore begin in the early feasibility and concept design stages of the building. This paper considers the options available for the evacuation of very tall buildings by use of lifts and stairs and discusses the design issues, technical solutions and benefits, in terms of evacuation time and evacuee wellbeing.

2 BACKGROUND

As buildings have grown taller the need to consider efficient and assured access into and around buildings and egress from buildings at all times and for all persons including persons with disabilities has grown ever more important.

There have been technical discussions, specialist meetings, symposia and a vast number of papers written over the years that give an understanding of the problems to encounter and solutions to be found if lifts are ever going to be used to assist the general evacuation of buildings.

Throughout the 1990's, American Society of Mechanical Engineers (ASME), National Fire Protection Association (NFPA) and National Institute of Standards and Technology (NIST) all held workshops where papers were submitted to aid discussion on fire evacuation using lifts (Elevators). At that time the consensus was not generally in favour as there was a huge scepticism about the safety of users, mainly due to a number of well documented disasters where people had died while using lifts during building fires.

Most of the issues discussed were technical ones and included: machine failure, reliability of power supplies, lifts passing through fire and smoke zones, exposure to water and inadequate operation; all of which have since been addressed and can pose little or no problems for today's design Engineers.

One other major concern remained and a study by So, Lo, Chan and Liu in 1997 [1], considering the issue of human behaviour while evacuating from building fires, concluded that further research into the subject should be undertaken.

The unprecedented attack on the World Trade Centre in 2001 which led to the collapse of WTC1, WTC2 and WTC7 in less than 2 hours and to the death of 2,752 people has driven further studies into Human Behaviour in fire emergencies. It is unlikely that the disaster could have been prevented by enhanced design measures but the sheer length of time that it took evacuees to escape the building is a matter for life-safety design and has been the subject of many studies since the 2001 disaster.

Egan [2] discovered that fatigue would be experienced in about 5 minutes and Pauls [3] that the average speed of evacuation would be 1 floor per 16 seconds. Investigations into the evacuation of WTC2 have shown times in excess of 60 seconds per floor. One of the problems is that as fatigue sets in, evacuees will stop to rest and cause blockages in the escape stair thus causing increased evacuation times for all.

The behaviour of human beings under the stressful activity of evacuating buildings in real fire emergencies is something that it has been very difficult to model or to predict. However, the evacuation of the World Trade Centre complex following the events of 11th September 2001 has presented students and researchers with excellent insights into the factors that assist and hinder egress within the high-rise building environment.

There have been many research papers on the subject of human behaviour in fires and many that were commissioned following 9/11 and to address the issues raised by the evacuation of the WTC complex. Since 1998, the annual International Symposium on Human Behaviour in Fire has given students and researchers a platform to present their work and for delegates to debate the issues raised by research.

3 PROGRESS

Much progress has been made and more is now known on the behaviour of people in fire emergencies and on the likely behaviour of people during an evacuation. As such, more people are beginning to see the huge benefits that can be gained by designing lift systems to operate in fire emergencies and to assist the evacuation process.

It is a fact that the design and management of lifts will cost more in terms of capital expenditure for both the design and construction phases of a building but it can also lead to a reduction in income return due to a likely reduction in the net lettable area through additional space requirements of lifts, refuge spaces and the various other aspects of building design. As such, all parties involved with the design will need consent from both client and Architect if the concept of improved life-safety through reduced evacuation times is to become a reality.

Since 9/11, a number of buildings have been designed and constructed with the use of lifts to assist the evacuation strategy and many more have undergone changes to their original life-safety strategy to enable the use of lifts. One such development is Petronas Towers in Kuala Lumpur whose evacuation strategy has changed since the building first went into service. [4]

This paper investigates the evacuation strategy of a number of very tall buildings, including Petronas Towers and discusses the use of lifts to assist evacuation and life safety in those buildings. Finally, the paper sets out the general principles of design and issues to be overcome when using lifts to assist the evacuation of very tall buildings.

4 EXISTING BUILDING STUDY

Although evacuation by lift was not always a design priority, the use of lifts to assist the evacuation of buildings in fire and non-fire emergencies has become increasingly more common place in recent years.

There are a number of today's tall and very tall buildings that use lifts in some way to assist the evacuation process. A recent technical note by the National Institute of Standards and Technology (NIST) in the US explored the evacuation strategy of twelve high-rise buildings and provided an in-depth discussion of six of those buildings.

This study considers four of the buildings discussed in the NIST paper, three of which have held the title of 'world's tallest building'. All 4 buildings are over 450m tall and as such are classed as very tall buildings.

Table 1: Very tall buildings

Building	Location	Building height (m)	World's tallest building	Year opened
Petronas Towers	Kuala Lumpur, Malaysia	452	1997 – 2004	1998
Taipei 101	Taipei, Taiwan	509	2004 – 2009	2004
Shanghai World Finance Centre	Shanghai, China	492	No	2008
Burj Khalifa	Dubai, UAE	828	2009 – Present	2010

4.1 Petronas Towers

The construction of Petronas Towers, Kuala Lumpur was completed in 1998 and its height of 451.9m made it 'the world's tallest building' at that time. The buildings are primarily office space with a single tenant, Petronas chemical company occupying one tower and the other being let to multiple tenants. One unique feature of the towers is the adjoining bridge link at levels 41 & 42.

The fire and life safety strategy for the Petronas Towers was at the time, designed to meet British Standard Code of Practice BS 5588: Part 5. However, the Code of Practice that gave guidance on the means of escape for disabled people was BS 5588: Part 8 which has since been withdrawn in the UK but is often still referenced in other parts of the world. The COP recognised the use of lifts for evacuation of persons with disabilities and gave guidance on refuge spaces, evacuation strategies and lifts [13, 14].

The evacuation strategy for persons with disabilities is to wait in a designated refuge space adjacent to a firefighting lift (or other lift suitable for evacuation use) and/or an escape stair and await assisted evacuation by building management or the fire service.

The evacuation strategy for persons within disabilities within Petronas Towers is as described in BS 5588: Part 8 and provides refuge space on all levels. The fire-fighting lifts are then used to evacuate waiting persons with disabilities before the fire service arrive.

The evacuation strategy for able bodied people has changed since Petronas Towers first opened. At that time, the strategy required occupants below the bridge link (level 41) to use the escape stairs to safety and for those occupants above the bridge link to use the escape stairs to reach level 41 then to cross the bridge link and use the lifts in the adjacent tower to safety. At that time an incident requiring simultaneous evacuation of both towers was not considered.

Post 9/11, the strategy changed to account for the simultaneous evacuation of both towers. Today, occupants above the link bridge use stairs to reach level 41 & 42 where double deck shuttle lifts are available to transport evacuees to the ground and mezzanine floors and to safety. It is not known if the shuttle lifts have special design features that allow their use when the fire is local to the lifts or whether in this case the lifts shut down and evacuation reverts to either stairs or the other tower.

4.2 Taipei 101

Taipei 101 is an office building that also houses retail, a conference centre and restaurants. Construction was completed in 2004 at which time Taipei 101 became the latest building to claim the title of 'the world's tallest building'.

The designers of Taipei 101 originally planned for traditional stair evacuation but an evacuation which was conducted prior to completion took approximately two hours to complete. Aware of the research undertaken after 9/11, the authorities decided to try another evacuation but this time with the passenger lifts remaining in service. The evacuation using lifts and stairs took 57 minutes as opposed to 2 hours using the stairs alone. [5]

The decision to include evacuation by lift in the Taipei 101 evacuation strategy was made after the final design and construction stages and so only limited modifications could be made to enhance the reliability and safe operation of lifts.

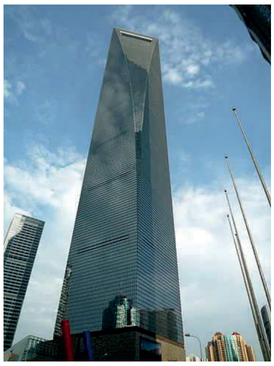
However, the enhanced features were only applied to special emergency/service lifts and to fire-fighting lifts [5].

The building was designed with special refuge areas every 8 floors to allow persons who could not use the stairs to wait in a fire-protected area to be evacuated by either the special emergency/service lifts or the fire-fighting lifts [4].

The fire-fighting lifts and special evacuation/service lifts are the only lifts used in a fire emergency and all other lifts, including the main passenger lifts are shut down. Although the full evacuation strategy is unknown, it is stated that refuge areas and lifts are available to assist the evacuation of all persons who cannot use the stairs which may be targeted at persons with disabilities but does not discount other occupants.

It is a fact that the designers considered the evacuation by lift for persons who have difficulties using the stairs although this strategy could not accurately quantify the number of persons who may need to use the refuge spaces and lifts.

4.3 Shanghai World Finance Centre



The World Finance Centre in Shanghai is a mixed use development mainly consisting of offices, a hotel and conference centre. Construction was complete in 2007 and although the design intent had been to construct a 510m high tower, due to restrictions on the height of the roof the building was constructed to a final height of 492m [4].

The Shanghai World Finance Centre was designed to surpass the 1995 Chinese code for the fire protection design of tall buildings (GB50045-95) which required a refuge floor every 15 floors. Shanghai World Finance Centre was designed with a refuge floor every 12 floors [6].

Two special lifts were originally designed to serve the observation deck at the top of the tower but were modified to support evacuation from each of the refuge floors in an emergency [6]. Occupants with disabilities and other occupants who cannot use the stairs to reach a refuge floor are required to wait adjacent to one of the fire-fighting lifts for evacuation by building management or the fire service [7].

The refuge areas serve two purposes, evacuees can wait and rest in a safe place before continuing their journey on foot or they can wait for a lift to transport them direct to the ground floor. Evacuation by lift is a managed strategy where priority is given to persons with disabilities and others who find it difficult to manage conventional stair evacuation [7].

4.4 Burj Khalifa

The Burj Khalifa is a mixed use tower in downtown Dubai, United Arab Emirates incorporating offices, a hotel and residential apartments. Construction of the tower was complete in 2009 and to a height of 828m which made it the world's tallest building from that date. The building was opened to the public in 2010.

The building was constructed to IBC: 2003 and to NFPA101 fire and life safety code and was designed for the use of some lifts to assist the evacuation process. A full building evacuation uses 10 of the 58 lifts installed in the building. [4]

Burj Khalifa has a total of 163 floors and has full fire protected and pressurised refuge spaces on levels 43, 76 and 123. Occupants are expected to leave the fire affected floors via the emergency stairs and walk to one of these refuge spaces where they will be transported via lifts to the exit floor and safety [4].

Design information states that total estimated evacuation time using a mixture of stairs and lifts is 90 minutes with 55% of the 19,000 occupants using stairs and 45% using lifts. [7]

4.5 Summary of existing building evacuation strategy

All of the above buildings use lifts to assist the evacuation strategy but each in a slightly different way.

The evacuation strategy for **Petronas** is different for occupants of the upper and lower zones of the building. Occupants of the lower floors are expected to use the stairs to reach the building exit while occupants of floors above level 42 use the stairs to reach level 42 before transferring to shuttle lifts.

Taipei 101 has special service / evacuation lifts to transport evacuees from refuge areas located every 8 floors to the main exit floor. The lifts were designed for the purpose of evacuation after the construction stages and so only limited modifications to enhance reliability could be made. As such it is unknown whether the available lifts provide sufficient capacity for the expected number of users.

Similar to Taipei 101, **Shanghai World Finance Centre** (SWFC) has special evacuation lifts to transport evacuees from refuge areas to the main exit but in this case the refuge areas are every 12 floors. SWFC has only 2 lifts designed to assist the evacuation so the evacuation strategy is unlikely to make provision for all occupants.

Burj Khalifa uses 10 lifts to assist the evacuation of the tower which operate between 3 specially designed refuge floors and the main exit. Occupants use the stairs to reach the nearest refuge floors where they wait to be evacuated by lift. The building design and evacuation lift configuration are unknown but the referenced paper states that 45% of the occupancy can be evacuated by lift which equates to 8,550 people.

5 DESIGN ISSUES

5.1 General

Irrespective of whether the building evacuation strategy makes provision for the evacuation of all occupants or for disabled and injured persons only, lifts that are used to assist the evacuation will have to be specially designed for the purpose and should be installed in a fire and smoke protected core.

5.2 Safe and Reliable Operation

Many previous studies have considered the design issues relating to the safe use of lifts in a fire emergency. One very early study in this regard was by So et al (1997) who listed a number of areas of concern needing further research if lifts were ever to be used as part of an evacuation plan [1]. The areas of concerned are discussed below:

The danger of machine failure can be brought about by: loss of power, non-fire related failure of equipment or fire related damage to equipment and can occur whether the lifts are in normal service or in firefighting or evacuation mode. With an unprotected lift there would certainly be an increased risk of failure during a building fire; the main issue here is to try to minimise the risk of failure through good design.

A building and lift installation that were designed and constructed in line with the requirements of BS 9999 (2008) and BS EN81-72 (2015) should have a reduced risk of loss of power or machine failure due to the effects of fire, smoke or water.

The above Code of Practice (COP) recommends that machine rooms be constructed within firefighting shafts, defining a firefighting shaft as “a protected enclosure containing a firefighting stair, firefighting lobbies and, if provided, a firefighting lift together with its machine room”. When considering the possible failure of the main power supply the COP recommends the use of a back-up power supply from an alternative source. Such a source could be either a separate substation or a generator driven supply.

Research shows that lifts have a likely breakdown rate of 1 every 62 ½ days, equating to one breakdown every 90,000 minutes [10]. The likelihood of a breakdown in a 10 minute evacuation period would therefore be considered as 9,000:1. Since this is a case of balancing the possibility of smoke breaking through to the firefighting shaft against that of the lift breaking down, two simple control measures could be put into place that would reduce the risk.

Firstly, the breakdown rate could be improved by employing a more rigorous maintenance program for lifts that may be used for evacuation and secondly, by monitoring for signs of smoke within the firefighting shaft, the lift could be forced to the evacuation floor and out of service at the first signs of danger [9]; in this case, evacuation would revert to stair only.

Obstruction of the fire service would only become an issue if the firefighting lifts were used as the main evacuation lifts. As previously discussed, firefighting lifts can be used before the fire service arrive on site to assist the evacuation of disabled persons. Once the fire service arrives, they would take control of the lift and the operation of assisting injured and disabled persons out of the building.

It is recommended that in line with the current COP, the evacuation strategy only consider the use of fire-fighting lifts for injured persons and for persons with disabilities. If the evacuation strategy requires the use of lifts for the evacuation of other occupants, then lifts designed for the specific purpose of evacuation should be used. In this case the risk of obstructing the fire service from going about their duty is reduced.

The evacuation of a building may require large numbers of people to be transported from specific floors of the building to an exit level in a very short space of time. Lift groups are not normally configured for this type of traffic and may have **inadequate lift configuration and operation** for this type of traffic.

For office buildings, the main passenger lifts are generally configured to provide acceptable performance during the morning or lunchtime peaks, up peak and two-way peak respectively. Lift systems for hotels and residential buildings may also be configured for acceptable performance during two-way peaks but at different times of day. In all cases, the lift configuration will be designed for a peak period of operation other than evacuation.

This does not mean that lifts cannot be configured with evacuation in mind or that the control system cannot incorporate adequate evacuation software. Whatever configuration of lifts is eventually used to assist the evacuation will require calculations to be performed to understand the likely evacuation time when using lifts.

Lifts used during a fire emergency could be exposed to the effects of the fire while **passing through zones of danger.** One solution for prevention of smoke entering the fire-protected core or lift shaft would be to pressurise the core and/or lift shaft. The need for and extent of pressurisation would depend on the evacuation strategy, building arrangement and lift configuration but in all cases, the evacuation lifts, lift lobbies and refuge areas should be protected against smoke and the effects of fire much the same as any other escape route or stair.

All lifts use electrical circuits, on the lift car, in the lift well and in the machine room and as such should be protected from **exposure to water**. Water from sprinkler systems and direct from fire service hose pipes could cause electrical failure if allowed to enter the lift well or machine room.

Firefighting lifts are designed to prevent water entering the lift shaft by ramps or gullies and to detect and remove any water that finds its way into the lift shaft by sump pumps or drains in the lift pit. In addition, wiring and equipment should be protected against the effects of water by being installed in a minimum of IPX3 rated enclosures. [16]

Generally, passenger lifts are not designed to operate in the presence of water and additional features should be installed to ensure that casual water from building fire prevention systems does not affect the reliability of lifts that are to be used for evacuation.

Consideration should be given to the design of fire protection systems that do not require sprinklers in lift shafts or lift lobbies and ramps and gullies should be installed at convenient locations to prevent water entering the lift lobby and lift shaft.

Preventing water entering the lift lobby and lift shaft would be a better solution than providing the water protection described above for firefighting lifts but it is unlikely that prevention methods can be assured so a level of protection will also be required to equipment to ensure continued reliable operation at all times.

One other non-technical point of concern was raised by So et al (1997), who foresaw problems relating to the **complex psychological reaction of the evacuees** to a building fire and a forced evacuation of the building. Evacuees may suffer an inability to understand and follow evacuation guidelines in the stressful environment of a fire emergency. Apart from the stress, anxiety and possible panic that evacuees may experience when the fire alarm is raised, they are likely to struggle to carry through any pre-planned evacuation routine.

There is a recognised theorem that people require information in order to prevent the onset of panic. Research in the field of human behaviour in fires has shown that panic is not inevitable and that clear and precise information can help people to remain calm. [11]

So et al (1997) were concerned about lift operation in an evacuation and made a suggestion that lift control systems with 'computer vision' would be better and that modern systems were more than capable of this type of operation. From this approach it would seem that the authors were advocating some type of crowd control by vision adjusted elevator control operation.

The above concept is not only possible but such equipment is available and adaptable for use on lift control systems. It is recommended that all evacuation control systems use a type of Information Fire Warning system (IFW's) to pass lift and evacuation status information to evacuees waiting at upper floors in an attempt to stop the onset of panic. [9]

This does not mean that evacuation operation should be by automatic control or any other type of control, just that the progress of the evacuation and lift operation should be made visually and audibly available for building occupants waiting to be evacuated.

6 LIFT CONFIGURATION

6.1 General

Each of the existing buildings presented in this report uses a different strategy for evacuation and each strategy requires a different number of lifts to meet the expected demand.

However, some of those buildings had a different evacuation strategy in place at the design stage than they have in place today and as such it is uncertain whether the lifts have sufficient design features to ensure reliable operation or to ensure their use in all types of emergency.

It is important that the strategy is set early in the design life of the building and it can be met by the existing lift configuration otherwise additional lifts may be required. Additional lifts mean less rentable area and could affect the viability of the project.

The right lift configuration to assist the evacuation of any given building may be inappropriate for another building and will depend on the type and use of the individual building and on the existing lift arrangement.

Earlier we discussed the design issues to be overcome if lifts are to provide safe and reliable operation during a building evacuation and touched on lift performance during evacuation mode. The right solution is one that provides sufficient lift capacity to meet the needs of the evacuation strategy and a robust design that ensures each of the design issues is met.

6.2 Theoretical Lift Performance

Diagram 1 depicts a lift arrangement for a typical tall building. High level calculations have been performed to determine how many and what type of lifts are required to meet the expected demand given the occupancy in the table.

The low, mid and high zones are served by Double Deck lifts, the sky lobby by Double Deck shuttle lifts and super high rise zones by Single Deck lifts.

Table 1, contains high level results for the stated typical building arrangement and for an assumed 12% demand during an up peak period.

Diagram 1: Typical tall building arrangement

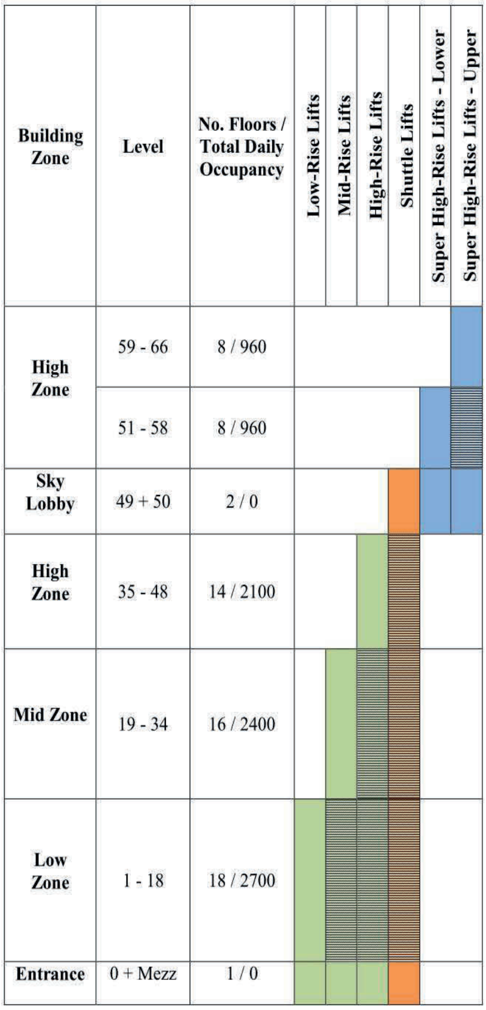


Table 1: Lift Arrangement

Building Zone	Lift arrangement	Arrival Rate (%)	Interval (s)	Capacity Factor (%)
Super high rise - Upper	6 x 1275kg SD	12	21.0	52.6
Super high rise - Lower	6 x 1275kg SD	12	23.3	58.2
Sky lobby	4 x 1600kg DD	12	29.9	60.9
High rise	8 x 1275kg DD	12	24.7	67.7
Mid rise	8 x 1600kg DD	12	26.1	66.5
Low rise	8 x 1600kg DD	12	25.8	73.8

Assuming the lifts for the above typical tall building meet the performance requirements for 'Up' and 'Two-way' peak traffic, it is almost certain that they will provide sufficient capacity for 'Down' peak traffic; evacuation can be considered a form of down peak demand.

A potential evacuation strategy for the above building would be for all persons below the sky lobby to use the stairs and for all occupants of the super high rise zone to use the stairs to the sky lobby at levels 49 & 50, and from there use the shuttle lifts to exit the building.

If we assume a worst case of a total evacuation (1,920 persons) of the super high rise zone and that the evacuation demand will be 100% down traffic, then the Round Trip Time (RTT) and Handling Capacity of a given lift arrangement can be determined by calculation.

$$RTT\ (Barney, 2003) = (2Ht_v) + \left(S\left(2 - \frac{S}{N}\right) + 1\right)t_s + Pt_p + P\left(2 - \frac{S}{N}\right)t_p \qquad (1)$$

The above RTT equation (1) presented by Barney [8] is for a Double Deck lift with multiple stops. However, if we assume the shuttle lifts will travel between 2 set stops then, we can state that each trip would include one stop only, with one period of loading, one period of unloading and two high speed journeys between the ground floor and the sky lobby. The RTT equation can be simplified for the proposed manual evacuation and would become as equation (2) below.

$$RTT\ (Sky\ Lobby\ Shuttle) = (2t_T) + (S + 1)(t_s) + 2Pt_p \qquad (2)$$

Where,

S = Average number of stops

P = Average number of passengers

t_T = Single journey travel time which can be calculated by kinematics for each journey to and from the sky lobby.

t_s = Time, associated with each stop: Door Open time + Door Close time + Start Delay

t_P = Period of time for a single passenger to enter or leave the car

Table 2: Kinematics

Lift Group	Rated Speed V (m/s)	Acceleration A (m/s^2)	Jerk J (m/s^3)	Travel distance H (m)	Travel time t_T (s)
Shuttle Lifts	**6**	**1.0**	**1.4**	**200**	**40.0**

$$Rated\ Capacity\ (per\ car), CC = 24\ persons$$

$$Average\ number\ of\ passengers\ (per\ car), P = 24 \times 0.8 = 19.2$$

$$Passenger\ average\ transfer\ time, t_p = 0.8\ seconds$$

$$RTT\ (Sky\ Lobby) = (2t_T) + (S + 1)(t_s) + 2Pt_p \qquad (2)$$

$$RTT\ (Sky\ Lobby) = (2 \times 40.0) + (1 + 1)(1.9 + 2.9 + 0.5) + (2 \times 19.2 \times 0.8)$$

$$RTT\ (Sky\ Lobby) = 121.32\ seconds$$

$$INT\ (Sky\ Lobby) = RTT/No\ Lifts = 121.32/4 = 30.33\ seconds$$

$$No.Journeys = Super\ High\ Rise\ occupancy\ /Persons\ per\ trip\ (2P) = 1920/38.4 = 50$$

$$Evacuation\ time\ (Super\ High\ Rise\ Zone) = {(INT \times No.trips)}/{60}$$

$$Evacuation\ time\ (Super\ High\ Rise\ Zone) = {(30.33 \times 50)}/{60} = 25.275\ minutes$$

The above calculation is very simplistic but gives an idea of the possibilities of using lifts for evacuation. The example lifts are shuttle lifts designed to meet performance targets for the morning up peak and could theoretically evacuate the total super high rise zone in approx. 25 minutes.

The above example tall building may have an evacuation strategy that also requires the use of lifts for persons in the mid or high rise zones for which there would be numerous options to execute the evacuation. Each option would require consideration for the design of lifts, the building environment in which the lifts operate and the performance of the group in evacuation mode.

7 LIFT DESIGN

7.1 Control

A decision needs to be made if the lifts are to operate on normal control, under management control or with some special bespoke evacuation control.

The current Code of Practice for reference to means of escape for disabled people is BS 9999 (2008), the Code of Practice for the design, management and use of buildings. The COP recommends to adopt a management strategy for evacuation and suggests that lifts used to assist the evacuation of disabled people should be operated under the direction and control of the fire safety manager. [15]

The previous, now withdrawn Code of Practice for means of escape for disabled people, BS 5588: Part 8, also recommended to adopt a management strategy for evacuation and to avoid automatic operation of lifts. [14]

7.2 Lift Lobbies

Lift lobbies and refuge areas should be considered fire protected cores with access to escape stairs and with minimal risk of fire and smoke infiltration. Information Fire Warning systems should be incorporated into the refuge areas and lift lobbies to provide up to date information on lift arrival and departure status and to keep the evacuees informed as to the progress of the evacuation. [9]

7.3 Structural Implications

As discussed, the lift shafts should be designed with a minimal risk of smoke infiltration by considering the fire loads of the lower ground and mezzanine floors and by avoiding the need for pressure release holes in lift shafts.

Sky lobby lift lobbies should be designed without sprinkler systems or provided with a means to prevent water entering the lift lobbies and lift shafts.

7.4 Building design implications

Every solution is different but in this case, the only implication on building design is the requirement for a refuge area at the sky lobby level which will reduce the rentable area and increase the design cost.

7.5 Lift design implications

The shuttle lifts should have additional features to enable safe and reliable use in fire or non-fire emergency evacuation.

7.6 Building Services Implications

Normally only fire-fighting lifts require emergency power supplies but in this case an additional supply would be required for the four double deck lifts serving the sky lobby.

In addition, there may be a need to pressurise the shuttle lift lobbies although it may be possible to achieve this through natural means.

7.7 Evacuation strategy

The evacuation strategy for a design similar to the above example would require management control of the evacuation, emergency telephones at the lift lobbies, refuge areas and emergency command centre and a number of trained staff located in the refuge areas and lift lobbies.

8 DISCUSSION

The intent of this paper was to discuss the implications of using lifts to assist the evacuation of tall and very tall buildings. The paper investigated the evacuation strategies of four existing tall buildings including three that have held the title of 'The World's Tallest Building'.

With reference to previous papers on the subject, the main design issues were discussed and solutions presented for design requirements that would ensure safe and reliable use of lifts during evacuation.

A typical building was presented as an example, showing that generally, lifts configured to meet performance requirements during a main traffic peak would normally provide acceptable performance during evacuation mode. In this case, shuttle lifts that were designed to transport 12% occupants of a super high rise zone in 5 minutes during a morning up peak, were capable of evacuating the entire super high rise zone in <25 minutes.

It is important that if lifts are to be used to assist the evacuation of a building that they are part of the overall life safety strategy for the building. Many modern buildings have compartmentalised construction and employ phased evacuation where only floors immediately adjacent to the fire floor are evacuated. However, in cases where the fire spreads and the phased evacuation is escalated, it may become necessary to evacuate a complete zone or even complete building. For this reason, a total evacuation should always be modelled.

Every building is different but if consideration is given to the design of lift systems to assist the evacuation strategy at the building concept stage then all parties to the design process can have an input. The use of lifts to assist either a full or partial evacuation of any building is possible but depends on early cooperation between client, architect and design engineers. There will always be sufficient lifts in a building to evacuate the total occupancy in a reasonable time, the question is can the building afford a design that would make it safe to use the lifts.

A number of buildings currently under design have accepted principles of design that will enable lifts to be used to assist evacuation and it is hoped that presentation of case studies for these buildings will be possible at future symposium.

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BIOGRAPHICAL DETAILS

Peter Sumner is currently an Associate Director with WSP | Parsons Brinkerhoff working as an engineering consultant in the Vertical Transportation team. Peter has been in the lift industry for 34 years and before entering consultancy had previously worked in all sectors of the business from maintenance engineer to International Technical support engineer with ThyssenKrupp Elevator.

In 2003, Peter earned an MSc in Lift Engineering at the University of Northampton, gaining a distinction and a Professional Engineering Institute award for his dissertation on Fire-fighting and evacuation lifts. He was appointed to the Board of Studies at University of Northampton in support of Undergraduate Degree and MSc courses in Lift Technology and currently provides support to the School of Science and Technology on lift traffic design.