Vertical Transportation in Tall Buildings

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Abstract
Part 1 of this paper[1] reviews how lift service is provided in buildings from low rise to mega high buildings. Examples are briefly described. Having transported passengers to their destination floors, Part 2 discusses how lifts behave and are used during a fire and for an evacuation during an emergency. The final part debates whether buildings need be so tall and why lifts need to be so fast.

1 TALL BUILDINGS

1.1 Definitions

A low rise building might be described as one where the able bodied do not need a lift to reach their floor, but if one is available they invariably use it. This would imply a building of 3-5 floors. A mid rise building is one where there may be 8-10 floors and the lift becomes essential, in order for occupants to use the building. A high rise building might be one which contains 15-16 floors and maybe equipped with lifts serving two zones. Low, mid and high rise buildings describe the majority of the building stock of the UK.

Tall buildings might be defined as those buildings over 30/40 stories high. This height can be related to nature, as the tallest tree[2] ever measured was 132.6 m. Generally, if service can be provided from the access level (main terminal floor) to every floor in the building, this is a tall building.

A building could be called very tall, once shuttle lifts serving sky lobbies are required. Fortune (1997) defines a tall building as a `skyscraper', ie: “A high rise building with more than one zone of elevators.” and a very tall building as a `Mega High Rise building', ie: “A building with one or more sky lobbies and in excess of 75 floors.”.

As a general rule, about 60 floors can be served from a main terminal lobby at ground level, by up to four groups of lifts (a practical limit). If double deck lifts are used, this permits up to 80 floors to be served from a main terminal lobby. Buildings with more than 80 floors require sky lobbies with shuttle lifts to serve them. This permits buildings of 120/160 floors with one sky lobby and buildings of 180/240 floors with two sky lobbies with single/double deck lifts. Remember the maximum practical number of lifts that can be grouped together is eight cars with four facing four.

The Council on Tall Buildings and Urban Habitat survey of the 100 tallest buildings in 1999 (reported in Elevator World, 1999) indicated 63 were in North America, 30 around the rest of the Pacific Rim, four in Europe (one in London) and three others. The heights of the top 50 ranged from 260-450 m, a 190 m range, whilst the bottom 50 ranged from 230-260 m, a 30 m range. There must be hundreds of buildings between 130 m (the highest tree) and 230 m.

Very tall buildings sometimes described as `monumental' buildings are few in number compared to the totality of buildings world wide and their traffic design requires expert consideration. The traffic design of such buildings employs many techniques such as stacked

[1] A printed copy of this paper can be obtained by sending your business card and a stamped, addressed, A4 sized, envelope to PO Box 7, Sedbergh, LA10 5GE.

[2] *Eucalyptus Regnans*, Watts River, Victoria, Australia in 1872 was 132.6 m high [Guiness Book of records].

zones, shuttle lifts and sky lobbies, transfer floors, double deck lifts and "top/down" service.

1.2 Zoning

In modern high rise buildings each lift is not usually required to service every level, as this would imply a large number of stops during each trip. The effect is to increase the round trip time, which in turn increases the interval and the passenger waiting time and the passengers have to endure long journey times.

The solution is to limit the number of floors served by the lifts. A rule of thumb is to serve a maximum of 15-16 floors with a lift, or a group of lifts. This introduces the concept of zoning. Zoning is where a building is divided so that a lift or group of lifts is constrained to only serve a designated set of floors. There are two forms of zoning: interleaved and stacked.

An interleaved zone is where the whole building is served by lifts, which are arranged to serve either the even floors or the odd floors. This has been a common practice in public housing and has been used in some office buildings. So for example in a 16 floor residential building one lift may serve: G,1,3,5,7,9,11,13,15, whilst another lift serves: G,2,4,6,8,10,12,14,16.

The effect is to reduce the number of stops a lift makes because there are fewer floors to be served. This also reduces the capital costs because there are fewer openings and landing doors to install. The service to passengers, however, is poorer than with a duplex serving all floors, because there is only one lift to take them to their floor. Tenants tend to solve this by calling both cars at the main terminal and if it is the `wrong' one, walking a flight of stairs to their floor (if they are able). Thus cars are unnecessarily brought to the main terminal. Interleaved zoning is not recommended " (a)... proven disaster in the US." (Strakosch, 1988).

A stacked zone building is where a tall building is divided into horizontal layers, in effect, stacking several buildings on top of each other, with a common `footprint' in order to save ground space. It is a recommended practice for office and institutional buildings.

Each zone can be treated differently with regard to shared or separate lobby arrangements, grade of service, etc. The floors served are usually adjacent, although some buildings may have split subzones, where the occupants of each subzone are associated with each other and can be expected to generate some interfloor movements. The number of floors in a zone, the number of lifts serving a zone and the length of the express jump all affect the service times.

1.3 Shuttle Lifts (with sky lobbies)

Many tall buildings are divided into several zones: low zone, mid zone, high zone, etc. with service direct from the main terminal floor, situated at ground level. These are called `local' zones. This becomes impractical with very tall buildings and shuttle lifts are employed to take passengers from the ground level main lobby to a `sky lobby'. This could be 200 m (Petronas Towers, Kuala Lumpur, Malaysia).

Passengers disembark at the sky lobby and service is then provided to further low, mid, high zones, etc. using the sky lobby as an upper main terminal floor. The advantage is that the core efficiency is improved, as the hoistways extend the whole height of the building (except for the intervening equipment spaces) and occupy the same hoistway `footprint'. Shuttle lifts are usually quite large and fast and provide an excellent service to the sky lobby. Their main disadvantage is that the passengers must change lifts mid journey, hence increasing their total journey time. When a traffic design involves a change of lift, the two journey times are best quoted separately. Sometimes passengers travel down from the sky lobby as well as up (Fortune, 1986). Most shuttle lifts are single deck, but there are a number of double deck installations.

Schroeder (1989a) defines four basic sky lobby configurations:

1. Single deck shuttles, single deck locals, eg: World Trade Center, USA.
2. Double deck shuttles, single deck locals, eg: Sears Tower, USA.
3. Double deck shuttles, double deck locals, eg: Petronas Towers, Malaysia.
4. Single deck shuttles, single deck top/down locals, eg: none.

Configuration 4 would be difficult to engineer, as offset lobbies would be required. A configuration Schroeder did not consider should be added:

5. Double deck shuttles, single deck top/down locals, eg: UOB Plaza, Singapore.

Generally shuttle lifts serve between two stops only, hence the term `shuttle', but sometimes they serve three stops, ie: with two sky lobbies (Sears Tower, USA).

The number of shuttle lifts that are installed world wide is not large. Their traffic design is relatively simple, but their application in a building requires expert consideration.

1.4 Double Decker Lifts

Double deck lifts comprise two passenger cars one above the other connected to one suspension/drive system. The upper and lower decks can thus serve two adjacent floors simultaneously. During peak periods the decks are arranged to serve `even' and `odd' floors respectively with passengers guided into the appropriate deck for their destination. Special arrangements are made at the lobby for passengers to walk up/down a half flight of stairs/escalators to reach the lower or upper main lobby.

Double deck lifts, which are common in the USA and elsewhere, but unusual in Europe, are used in very tall buildings. Fortune (1996) indicated 465 double deck lifts in 34 buildings across the world (see Table 1).

Table 1 World wide location of double deck lifts

Location	Number	Buildings
N. America	317	17
Singapore	55	5
Malaysia	29	1
Japan	17	3
Spain	15	3
Taiwan	12	1
Australia	11	1
England	4	1
Hong Kong	4	1
China	1	1
Total	465	34

There are many advantages and disadvantages to double deck operation and special care has to be taken with the lobby arrangements. One advantage for double deck lifts is that the `hoistway' handling capacity is improved, as effectively there are two lifts in each shaft. A disadvantage for passengers during off peak periods is when one deck may stop for a call with no coincident landing, or car call, required in the other deck. Special traffic control systems, available during off peak periods, attempt to overcome this problem.

Fortune (1996) expounds the advantages of double deck installations as:

1. Fewer lifts
2. Smaller car sizes
3. Lower rated speeds
4. Fewer stops
5. Increased zone size
6. Quicker passenger transit times
7. 30% less core space
8. Taller buildings on same footprint
9. Smaller lobbies
10. Fewer entrances
11. Faster installation
12. Reduced maintenance costs

and the disadvantages as:

1. One significant supplier
2. Passenger misuse
3. Zone populations must be large
4. Balanced demand from even and odd floors
5. Interfloor distance must be regular
6. Slightly larger hoistways
7. Increased pit and machine room loadings
8. Lobby exits need to be larger
9. Special facilities for disabled access to "other" floor

1.5 Transfer Floors

Most tall and very tall buildings provide some means to travel between zones and stacks. This is sometimes achieved by overlapping zones (Petronas Towers), introducing extra stops (Sears Tower) or shuttle lifts (World Trade Center). A common served floor (other than the Main Terminal or Sky Lobby) is important, where there are common facilities to be accessed, eg: restaurant, travel bureau, banking, sports facilities, post room, reprographics, etc.

The effect on traffic handling can be disruptive. In general it is important to restrict access to such floors during uppeak and down peak, although the purpose of such a floor would be defeated at other times, ie: at the mid day break or during interfloor traffic.

1.6 Top/Down Service

A top/down lift installation is where a sky lobby is used to serve building zones or stacks both in the conventional up direction, but also in the down direction. This does mean that passengers may (psychologically) be concerned that they have travelled up a building only to be then required to travel down to their destination. This technique has only been applied in a few buildings.

The concept is illustrated in Figure 1. This shows a low zone served from the Main Terminal floor at ground level. A sky lobby is positioned two thirds of the way up the building. From the sky lobby a conventional group of lifts serve the high above the sky lobby and another group serve the mid zone below the sky lobby.

Although top/down is more expensive in equipment terms and may complicate the machine room and overtravel arrangements, the technique does allow a small footprint building to provide a larger rentable space.

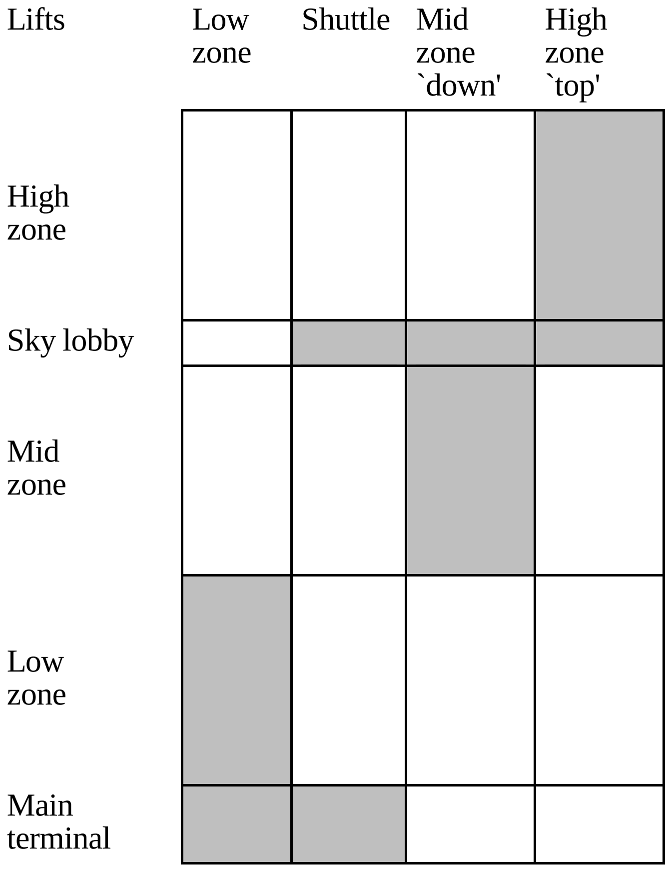

Figure 1 Illustration of concept of top/down sky lobby

1.7 Examples of Very Tall Buildings

The techniques are best visualised by considering four of the tallest buildings in the world. A simple presentation is given only and no conclusions are drawn. Goods lifts, firefighting lifts and other lift services are not indicated.

(a) Double Deck Shuttles to Double Deck Locals

Petronas Towers, Kuala Lumpur, Malaysia (1996).

The two Petronas Towers are 452 m high with 88 stories above ground. The building is divided into two stacks.

Stack 1 has 2 groups of 6 double deck lifts serving Main Terminal and Floors 8-23 at 4 m/s and Main Terminal and Floors 23-37 at 5 m/s. Floor 23 acts as a transfer floor.

Stack 2 is served by a group of 5 double deck shuttle lifts at 6 m/s to sky lobbies at Floors 41/42. From the sky lobbies there are 3 groups of 6 double deck lifts serving 3 zones: Floors 44-61 at 3.5 m/s; Floors 61-73 7 m/s; Floors 61/62 and 69-83 at 7 m/s. Floors 61 and 62 act as transfer floors.

There are 2 lifts linking Stack 1 to Stack 2 serving Floors 36-37, 40-43 at 1.6 m/s.

There are escalators between the upper and lower Main Terminal (0/1) levels and between Floors 41 and 42.

(b) Double Deck Shuttles to Single Deck Locals

The Sears Tower, Chicago, USA (1974).

The Sears Tower is 436 m high and has 103 stories above ground. The building is divided into three stacks.

Stack 1 has 3 groups of 6 single deck lifts serving Main Terminal and Floors 5-10 at 2.5 m/s; Main Terminal and Floors 10-17 at 3.5 m/s; Main Terminal and Floors 17-23 at 4 m/s and one group of 5 lifts serving Main Terminal and Floors 23-28 at 5 m/s.

Stack 2 has sky lobbies at Floors 33/34 served by 8 double deck shuttle lifts at 7 m/s. From the sky lobbies there are 3 groups of 6 single deck lifts serving Floor 33 and Floors 35-42 at 2.5 m/s; Floor 33 and Floors 42-49 (2 lifts also serve Floor 27) at 3.5 m/s; Floor 34 and Floors 49-57 at 4 m/s and one group of 5 lifts serving Floor 34 and Floors 58-63 at 5 m/s.

Stack 3 has sky lobbies at Floors 66/67 served by 6 double deck shuttle lifts at 8 m/s, which also can stop at Floors 33/34 for service to Stack 2. From the upper sky lobby there are 3 groups of 4 single deck lifts serving Floor 66 and Floors 68-74 (2 lifts also serve Floor 63) at 2.5 m/s; Floor 66 and Floors 75-81 at 3.5 m/s; Floor 67 and Floors 82-87 at 4 m/s and one group of 5 single deck lifts serving Floor 67 and Floors 88-102 at 5 m/s.

In addition there are two observation lifts serving Main Terminal and Floor 103 at 9 m/s.

(c) Single Deck Shuttles to Single Deck Locals

The World Trade Center, New York, USA (1972, destroyed by terrorists, 11 September 2001)

The World Trade Center comprised two towers of 110 floors and was 416 m high. It was divided into three stacks.

Stack 1 had 4 groups of 6 single deck lifts serving: Main Terminal and Floors 9-16 at 4 m/s; Main Terminal and Floors 17-24 at 5 m/s; Main Terminal and Floors 25-32 at 6 m/s; and Main Terminal and Floors 33-40 at 7 m/s.

Stack 2 had a sky lobby at Floor 44 served by 8 single deck shuttle lifts at 8 m/s. From the sky lobby there were 4 groups of 6 single deck lifts serving: Floors 46-54 at 2.5 m/s; and Floors 55-61 at 4 m/s; Floors 62-67 at 4 m/s; and Floors 68-74 at 5 m/s.

Stack 3 had a sky lobby at Floor 78 served by 8 single deck shuttle lifts at 8 m/s. From the sky lobby there were 4 groups of 6 single deck lifts serving: 78 and Floors 80-86 at 2.5 m/s; 78 and Floors 87-93 at 4 m/s; 78 and Floors 94-99 at 4 m/s; 78 and Floors 100-107 at 5 m/s.

In addition there were a group of 3 single deck interzone shuttles between Floors 44 and 78 at 8 m/s.

(d) Top/Down Service

United Overseas Bank, Singapore (1992)

This is a 66 storey building, 280 m high, divided into three stacks.

Stack 1 has a group of 6 single deck lifts serving Main Terminal and Floors 7-20.

Stack 2 has a sky lobby at Floor 37 served by the lower deck of 6 double deck shuttles. From the sky lobby a group of 6 single deck lifts serve (down) Floors 20, 23-36.

Stack 3 has a sky lobby at Floor 38 served by the upper deck of 6 double deck shuttles. From the sky lobby a group of 6 single deck lifts serve (up) Floors 41-59

There is a transfer floor at Floor 20 for Stack 1 and 2 interchanges.

This building can be categorised as double deck shuttles to single deck locals.

1.7 Very Tall Buildings: a Postscript

Frank Lloyd Wright proposed a mile high building (1,600 m) in 1956 to be built in Chicago, USA. This building would have 528 storeys and would have accommodated 130,000 occupants. Wright proposed to install 76 quintuple (5) deck lifts, although estimates today suggest that more than twice that number would have been needed to obtain current performance standards. This building would have been four times higher than the world's current tallest building the Petronas Towers described above. It was never built.

2 PEOPLE PROTECTION IN BUILDINGS

2.1 Behaviour of Lifts during a Fire

When a fire breaks out there may be passengers travelling in a lift or a lift may be empty, but in motion. What should happen to the lift ? Ideally the lift should be sent to a designated floor, open its doors to allow passengers to exit, close its doors and go out of service.

The best source of good practice is prEN81-73 "Behaviour of lifts in the event of fire". This is a provisional harmonised European standard. It contains a flow diagram, reproduced as Figure 2, indicating the complexity of the possible behaviours. The main obstacle to dealing with the behaviour of lifts in the event of fire is that only a very small percentage of buildings are technologically sophisticated (intelligent buildings) to be able to send the necessary signals to the lift system.

Until all buildings install the technology, and lifts can be designed and installed to remain in use during a fire, all persons should be discouraged from using a lift by the words:

"**DO NOT USE THE LIFT IN THE EVENT OF FIRE !**"

2.2 Firefighting Lifts

Firefighting lifts are discussed by Smith in Section 6 of the CIBSE Guide D: 2000, which provides an extensive list of further references. A wide range of regulations apply across the world, but the most comprehensive is prEN81-72 "Firefighters lifts", which repeats much of BS5588: Part 5. (prEN81-72 is another provisional harmonised European standard.) All regulations apply at the discretion of the local Fire Authorities. Generally firefighting lifts are required in buildings, which have occupiable space more than 18 m above and/or 9 m below the fire access level for every 900 m^2 of building footprint or part thereof. They must serve all occupiable levels, have at least a 630 kg rated load and be capable of reaching the highest (or lowest) level served in less that 60 s. They must not be used for the transportation of goods and must be unobstructed at all times.

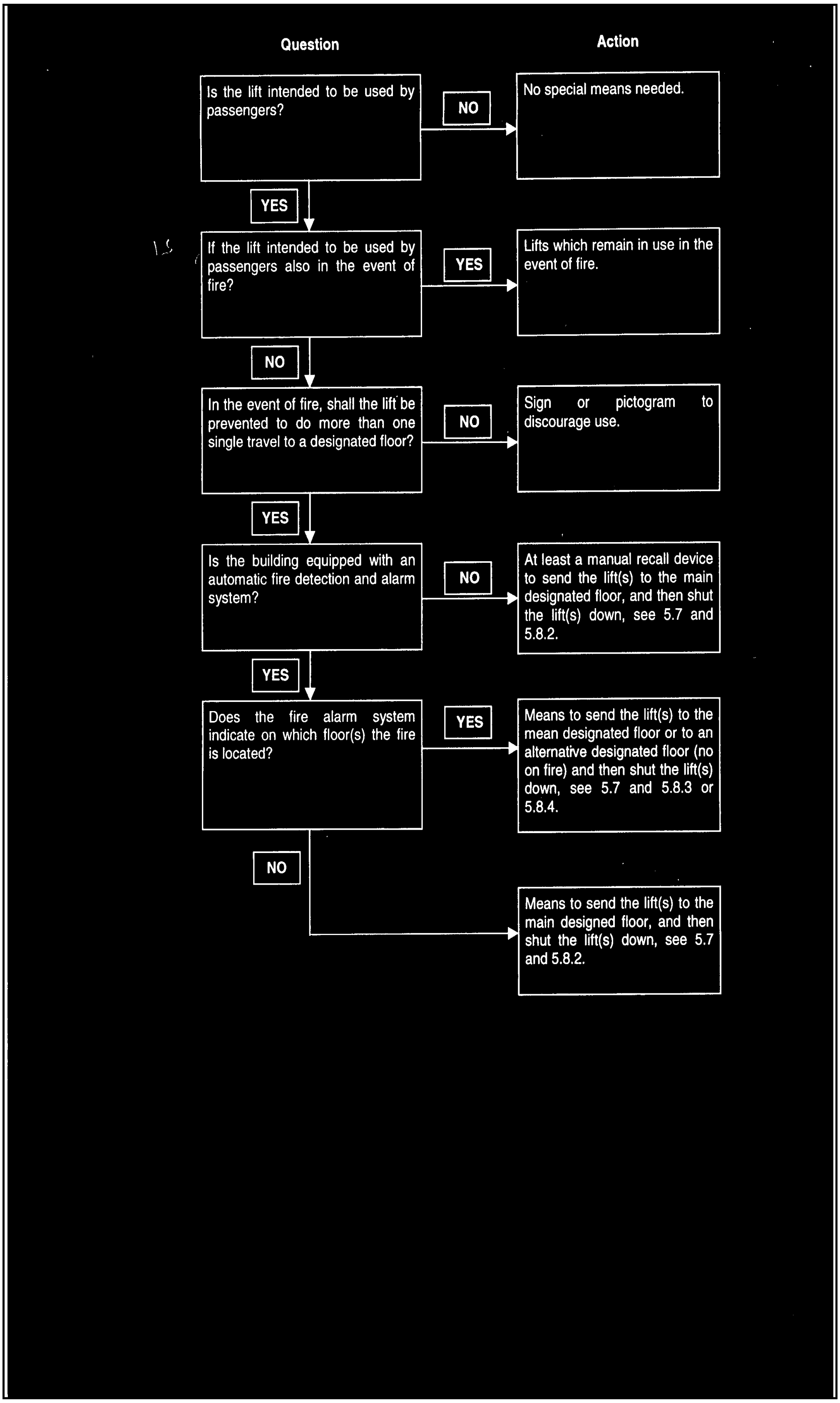

Figure 2 Flow chart of lift scenarios
(from prEN81-73)

Firefighting lifts are often single lifts situated around the floor plate. Their size is often the lowest possible permitted (630 kg), and their speed is often the lowest possible to reach the highest floor served in 60 s. The handling capacity is therefore low and as usually only a single lift is present at each location, the interval is equal to the round trip time. Firefighting lifts should not generally be considered as part of the vertical transportation provision, but they do provide a useful addition to the vertical transportation services of a building. For instance in a building with a large floor plate, occupants may be much nearer to a firefighting lift than the main group and may use it in preference, despite its poorer performance.

Sometimes a firefighting lift is part of a group and extra precautions are necessary to ensure its fire integrity, *viz*: protected stairways, additional doors, etc (prEN81-72). These precautions may affect the traffic circulation to these lifts and should be taken into account when calculating the handling capacity of such a group. In particular the firefighting lift may be smaller than the other passenger lifts and may be equipped with additional doors and car operating panels.

The main requirements are:

- Buildings more than 18 m high and/or 9 m deep from main access level require FF lifts
- One FF lift for every 900 m^2 of occupiable space
- Must have a protected lobby with protected stairs
- FF lifts must serve all habitable levels
- Capture switch at main floor
- 2nd protected power supply
- Communication system
- Attendant control
- Escape hatch

2.3 Evacuation Lifts

Evacuation lifts are also discussed in Section 6 of the CIBSE Guide D: 2000. In the UK BS5588: Part 8: 1991 “Code of practice for the means of escape for disabled people” applies, until BS9999 becomes available. In general, the requirements for an evacuation lift are the same as those for a firefighting lift, except that the operation and communication arrangements are different. However, although a fire fighting lift can be used as an evacuation lift, an evacuation lift cannot be used as a firefighting lift.

Evacuation lifts are provided to facilitate the egress of persons with impaired mobility in the event of a fire or other incident. The evacuation is always supervised and persons are not to attempt self rescue.

“**DO NOT USE THE LIFT IN THE EVENT OF FIRE UNLESS SUPERVISED !**”

3 WHY SO FAST, WHY SO TALL ?

3.1 Fast

There is a tendency for lift companies to offer faster and faster lifts to owners of haughty disposition, who follow the fashion. But what is gained by faster and faster lifts ?

A lift leaving a floor starts from rest, accelerates, travels at its top speed (rated speed), decelerates, levels and stops at the next floor. In practice all, but the slowest, lifts need a long travel distance, in order to reach their rated speed. What is this distance ? School physics provided a basic equation of motion:

$$v^2 = u^2 + 2as \quad \text{... (1)}$$

The initial velocity (u) is zero, so Equation (1) becomes:

$$s = v^2/2a \quad \text{... (2)}$$

The travel distance (s) to reach rated speed (v) between stops will be twice the value obtained from Equation (1). Column 2 of Table 2 indicates the travel distances required for a lift with an acceleration of 1.0 m/s^2 (chosen for simplicity) to reach the rated speed during the trip.

Table 2: Travel distances to reach rated speed

Rated speed (m/s)	Travel distance to reach rated speed (m)	Time to travel 200 m (s)	Time to travel 400 m (s)
1	1.0	202	402
2	4.0	102	202
5	25.0	45	85
10	100	29	49
20	400	27	37

The table shows that a slow speed lift (1 m/s) can reach the rated speed in a distance of 1.0 m. A lift with a rated speed of 20 m/s (one manufacturer has a product at 17.5 m/s) takes a distance of 400 m ! This is the height of the current tallest buildings !

Equation (2) assumes that the rate of change of acceleration (a) [called jerk j] is infinite, which it cannot be. If jerk is considered then Equation (1) becomes:

$$s = v^2/a + va/j \quad \text{... (3)}$$

and has the effect of increasing the distance value.

How much is the travel time (t) reduced by using faster lifts ? Considering lifts with an acceleration of 1.2 m/s^2 and a jerk of 1.8 m/s^3 (more likely values), columns 3 and 4 of Table 2 show that for a travel of 200 m, a 5 m/s lift takes 45 seconds and a 10 m/s lift takes 29 seconds. This is 16 seconds slower. The faster lifts will have to be aerodynamically profiled to reduce wind noise and buffeting and the guide rails will have to be installed to very, very, close tolerances, if the ride quality is to be acceptable. All for a small time difference of 16 seconds.

In general, lifts with rated speeds up to 6 m/s can be installed under conventional arrangements. This may be as fast, as can be sustained.

3.2 Tall

The theme of the 2002 CIBSE National Technical Conference is "Education and Sustainability". The earlier parts of this paper are educational. Turning now to sustainability. The taller a building, the more energy is expended in moving people to its top. The potential energy is mgh, where h is the building's height. If the lifts are required to have higher rated speeds then they will use more kinetic energy. The kinetic energy is $\frac{1}{2}mv^2$, where v is the rated speed discussed in Section 3.1. Can society continue to "sustain" these energy costs ?

The sociological situation becomes more difficult as people are forced to work and live closer together. In the London and South East, the transport system and other infrastructure facilities are unable to cope and the cost of housing makes it difficult for artisans, skilled and professional people alike to afford to live in the area. The dinosaur became extinct because it became too big. There is a case to build as high as the tallest tree, but no higher. Can society continue to "sustain" these resources ? Another factor is do people wish to work (or live) high in the sky ? There is already a reported trend to move "up town" and down.

4 CONCLUSIONS

This paper has given an overview of how the vertical transportation services required in tall and very tall buildings, might be provided. Of necessity the discussion is brief. The traffic design of vertical transportation is a specialist activity and owners, developers and especially architects are not qualified to provide a design. Impartial designs can be obtained from specialist consultants and partisan designs from lift companies. Barney discusses basic traffic design principles in Section 3 of CIBSE Guide D: 2000. More advanced guidance can be found in specialists texts (Barney, 2002, Strakosch, 1998). Tall buildings up to 40/50 storeys are ethically sustainable. A proposal to build four 50 storey buildings on the site of the New York World Trade Center, if implemented, indicates a trend in the right direction.

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