

Elevator planning for high-rise buildings



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High-rise buildings exist by the grace of elevators, and not vice versa. In a functional context, a tower's elevator core is the building's main artery, and in a constructional context, its spine. When Elijah Graves Otis invented the over speed governor and safety brake in 1854, elevators suddenly became a safe and viable option for transporting people and were no longer the limiting factor in the construction of high-rise buildings. Since then, high-rise construction has spread like wildfire across the globe. Principally in North America but increasingly in Asia, the limits are being pushed ever higher. The Taipei 101 measuring 509 m (1,670 ft) is currently the world's tallest finished building, but this year, the first tower measuring over 800 m (2,625 ft) will be completed in Dubai.

REGIONAL LIMITATIONS

Various issues determine the practical limitations for high-rise construction around the world. These include:

- financial considerations (labour and ground costs)
- construction time
(phases, investment risk and permitted daily work hours)
- soil conditions (foundations)
- seismic/wind hazards
- accessibility/mobility at ground level
- regulations (construction, daylight access)
- energy consumption and efficiency
- prestige



Millenniumtoren Rotterdam (132 m)

The feasibility of high-rise construction plans in the Netherlands is most often restricted by soil conditions, investment risks associated with such large-scale projects and reticence among future tenants to commit to projects ahead of construction. In the Netherlands, buildings taller than 150 m (490 ft) are purely showcase projects. Project developers interested in a return on their investment generally turn to other types of development.

TALL, TALLER, TALLEST

There are several plans in the pipeline to top the current Dutch high-rise record holder, the Montevideo residential tower block in Rotterdam, that was built in 2005 and measures 152 m (499 ft). The Maastoren building is currently under construction in Rotterdam that will measure 164 m (538 ft), and preliminary plans have been discussed for the construction of a tower block in Utrecht, called the Belle van Zuylen, that would measure 242 m (794 ft).

Elsewhere in Europe, restrictions are different, especially in London, Frankfurt and Moscow where buildings are 50–100% taller than those in the Netherlands. One Canada Square at Canary Wharf in London measures 235 m (771 ft) and various plans have been approved for the construction of tower blocks measuring 250 to 300 m (820 to 985 ft) over the next ten years. The tallest building in Frankfurt is the Commerzbank at 259 m (850 ft), but the Millennium Tower that is still in its planning phase will be 369 m (1,211 ft) tall. The tallest building in Europe is in Moscow, the Triumph Palace measuring 264 m (866 ft). Within the next two years, a further four buildings topping 300 m (984 ft) will be completed including the 380 m (1,247 ft) tall Mercury City Tower. The tallest European project currently under construction is also in Moscow, the Russia Tower. This building will be 612 m (2,008 ft) tall.

In North America and Australia, construction companies have many years of experience building high-rises above the 250 m (820 ft) mark. Since 9/11, the Sears Tower in Chicago is the tallest skyscraper in North America measuring 442 m (1,450 ft). The WTC in New York City used to measure 508 m (1,867 ft). In New York City, the Empire State Building is now the tallest skyscraper at 381 m (1,250 ft), but the Freedom Tower (currently under construction on the site of the former WTC) will reclaim the title for the continent's tallest tower block at 541 m (1,775 ft). Throughout New York, Chicago and Toronto, there are dozens of buildings topping the 250 m (820 ft) mark.

In Australia, the maximum height for skyscrapers lies between 250 and 300 m (820 and 985 ft) with one solitary exception, the Q1 residential tower block in Gold Coast City measuring 323 m (1,060 ft).

In recent years, Asia has taken a clear international lead in field of high-rise construction. Eight of the ten world's tallest buildings are currently situated in Southeast Asia. Predominantly in Dubai and China, ultra-high-rise towers appear to be sprouting out the ground like mushrooms. Buildings measuring between 300 and 400 m (985 and 1,312 ft) are the norm in certain areas of Southeast Asia, and the world's three largest finished buildings can also be found there, the Taipei 101 at 509 m (1,667 ft) and the Petronas Twin Towers in Kuala Lumpur at 492 m (1,614 ft). There are currently an additional four towers of between 450 and 600 m (1,475 and 1,970 ft) under construction and another dozen

of between 500 and 600 m (1,640 and 1,970 ft) on the drawing board.

Despite these valiant Southeast Asian efforts, the tallest building in the world will soon be standing in the Middle East – the 818 m (2,651 ft) tall Burj Dubai building currently under construction in Dubai and due for completion in 2008. This frenzied hotbed of high-rise construction will see an additional twenty tower blocks measuring between 350 and 500 m (1,150 and 1,640 ft) before 2010. However, Kuwait and Dubai are pushing the envelope even further with proposals for 1000 to 1200 m (3280 to 3940 ft) high...

ELEVATOR PLANNING

Building access plays a crucial role in the development and feasibility of high-rise construction plans. Internal transportation systems function as the building's main artery, determining the functionality and quality of life within the tower block, yet they also result in a considerable loss of rentable floor space on each level. Moreover, the elevator core is often the building's support structure, especially in narrower constructions. For this reason, it is very important that a traffic flow specialist be involved in the initial orientation phases of a high-rise construction project, as well as the developer, architect and structural engineer. Specifications for internal transportation must be drawn up whereby routing and usage remain logical, while occupying as little space as possible. Above all, the capacity required for stairs, elevators and shafts need to be determined.

CAPACITY AND WAITING TIME ANALYSIS

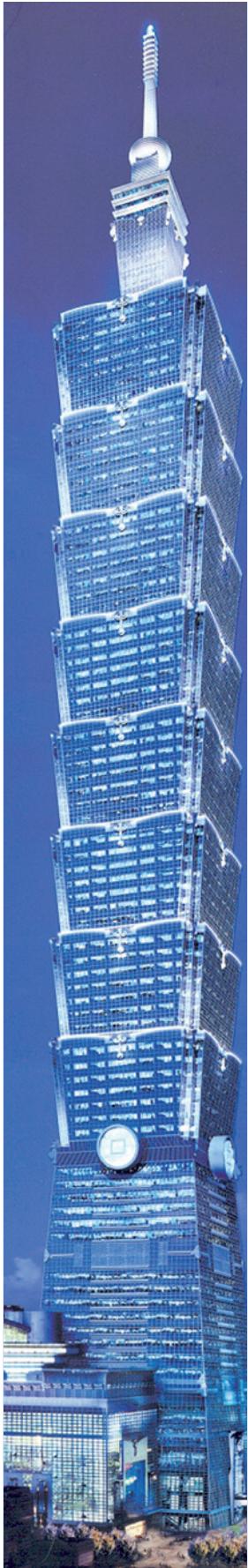
When designing an elevator system for either low-rise or high-rise buildings, the same initial estimates can theoretically be applied to its usage and function as for any other project. The building's function (office space, residential, hotel or a combination of these), the probable population and peak demand (either the up-peak, down-peak or lunch-peak) form the determining factors. The following parameters need to be determined in



Skyline Chicago

Traffic Flow Intensity Parameters			
Function	Population	Occupancy	Peak Demand
Office Space	1 x workplace per 18-25 m ² (190 270 sq ft) GFA, or 1 x workplace per 10-15 m ² (110 160 sq ft) NFA	60-85% enter in the morning up-peak	The up-peak is generally always indicative (12.5-18% per five minutes), unless the restaurant is not located on the ground floor.
Hotel	1.2-1.5 persons per room	90% room occupancy	The morning down-peak is determinant. Descending and ascending breakfast traffic plus downwards checkout traffic, together 14-18% per five minutes.
Residential	Based on the Dutch NEN 5080 (comparable with CIBSE), dependent on the number of rooms per apartment: 1.25 persons in a 1 or 2-room apt. 2.00 persons in a 3-room apt. 2.75 persons in a 4-room apt. 3.50 persons in a 5 or more-room apt.	40-60% leave in the morning down-peak	The down-peak is indicative (3-6% per five minutes).
Educational	1 x person per 4-7 m ² (45-75 sq ft) NFA	45-75% arrive during the first or second lesson period	The up-peak and/or the peak during lesson changeovers are indicative (15-25% per five minutes).

Table 1: Indication of population, occupancy and peak demand for various building functions (Europe).



Taipei 101 Elevator Technology

The tallest building in the world is currently the Taipei 101 measuring 509 m (1,670 ft). This office block houses fifty elevators of which thirty-four are double-deckers and two are the fastest elevators in the world. Total investment in elevator technology for this building totalled approximately US\$85 million.

The tower has two shuttle elevators for public access to the observation deck on the 89th floor. These elevators have been officially recognized by the Guinness Book of Records as the fastest elevators in the world. With full loads, the ascent speed reaches a maximum of 16.8 m/s (55 ft/sec) or nearly 60 km/h (37 mph). Descent speeds measure 10.0 m/s (33 ft/sec) or 37 km/h (23 mph). In comparison, the fastest elevators in the Netherlands travel at 6.0 m/s (19.5 ft/sec). These are located in the Delftse Poort (Rotterdam), the Rembrandtoren (Amsterdam), the Hoftoren (The Hague) and the WTC (Amsterdam).

Elevator cars in these shuttles are fitted out as airtight pressure cabins and equipped with pressure regulation systems similar to those used in aircraft. This allows for a gradual change in pressure over the elevator's height to alleviate the pain that can be caused to passengers' ears. Pressurization on descent is also the reason why the elevators descend more slowly than they ascend. (Pressurization is more painful for the ears than the depressurization that occurs on ascent). Elevator cars are fitted with upper and lower capsule-shaped spoilers to provide aerodynamic streamlining. These ensure that the air stream flows smoothly around the moving elevator car saving energy and reducing interior shaft airflow-induced noise levels.

Vibration within the car has virtually been eliminated by implementing a tri-axial, active-control roller guidance system for suspending cars in their tracks. Active mass damping has also been fitted to each elevator to minimize lateral movement. Car movement experienced as two elevators pass one another in opposite directions at full speed has virtually been eliminated. Thanks to these measures, comfort levels can only be described as phenomenal, certainly given their exceptional speeds. The safety braking system, that operates in the event that the car exceeds nominal speeds by more than 10% for whatever reason (e.g. a broken cable or driveshaft, or traction failure), is fitted with brake pads made of a silicon nitride ceramic compound that brings the car to a standstill swiftly and safely.

The office block (floors 9 through 84) is accessed as though it were made up of three individual building segments each of 112 m (367 ft) stacked one on top of the other. Transportation to and from the sky lobbies on the 35th and 59th floors is provided by ten high-speed, double-deck elevators (weighing 4,080 kg (8,995 lb) and holding up to twenty-seven passengers per car) that shuttle their passengers non-stop to their transfer levels. Each of the three sub-segments is fitted with its own local double-deck elevator system (weighing 2,700 kg (5,952 lb) and holding up to eighteen passengers per car) of which four are low-rise and four are high-rise systems. The use of double-deck elevators doubles the transportation capacity per shaft, especially to and from the sky lobbies. These double-deck elevator cars also incorporate a technological innovation. The two cars are suspended independently of one another in a frame to allow for inter-dependent movement, which compensates for local floor height differences.

In addition to the public shuttle elevators to the observation deck on the 89th floor and the double-deck elevators to the sky lobbies, the Taipei 101 also houses four exclusive passenger elevators to the sky restaurant and executive club, four general-purpose goods and fire fighting elevators, six car park elevators, eleven passenger elevators at the base for commercial purposes and fifty escalators.

sequence for the anticipated traffic flow, given the building's envisaged function:

- population (number of employees and/or residents)
- occupancy (presence/simultaneousness)
- peak demand (indicative traffic flow peak)

where, required capacity = population x occupancy x peak demand (expressed as a % of the occupancy per 5 minutes)

Table 1 shows guidelines for population, occupancy and peak demand values for various building functions. These are based on European conditions, however regional differences can be significant. It is essential that a project-specific estimate be made of these parameters based on the project's individual characteristics, conditions and ambitions.

The building should be examined to establish the following criteria, which should then be incorporated correctly into traffic flow models:

- height of the building and its individual storeys
- distribution of the population throughout the building
- main entrance level(s) (points of entry and exit)
- distribution of population over elevator groups (if the same destination can be reached using more than one group)
- stair usage

This allows the building's anticipated traffic flow to be established and a corresponding elevator configuration to be specified. Initially, an estimate of the elevator group requirements is made on the basis of past experience. This estimate should take the following into consideration:

Primary Considerations:

- number of elevators per group
- nominal elevator load capacity (based on car floor area)
- realistic car occupancy
- nominal elevator speed

Secondary Considerations:

- elevator acceleration
- door times (opening and closing, door type, dimensions, et cetera)
- entry and exit times (dependent on type of user, free passageway and car occupancy)

SPECIFICATIONS FOR ADEQUATE TRAFFIC FLOW MANAGEMENT

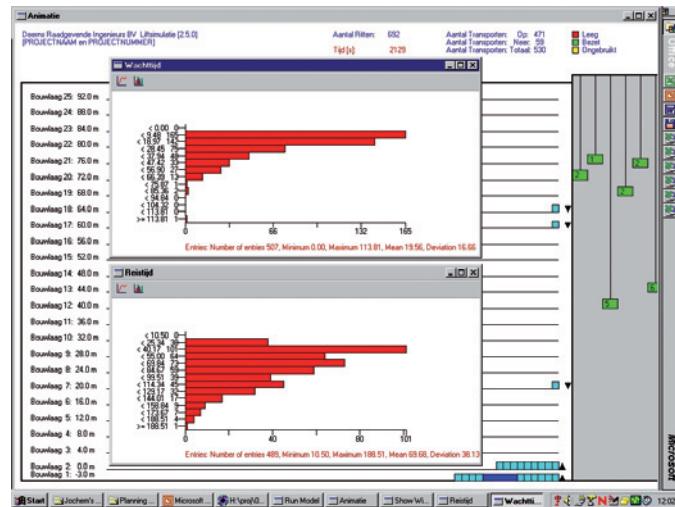
The following issues should be taken into consideration in order to determine whether adequate traffic flow management exists in high-rise buildings:

- Primary Considerations: Peak demand capacity must be sufficient, i.e. the elevator configuration should provide sufficient transportation capacity to deal with the demand.
- Secondary Considerations: Waiting times should remain acceptable even in peak periods (not only on main levels, but throughout the building)
- Tertiary Considerations: Elevator speeds must be high enough to reach the destination within an acceptable time (specifically on direct journeys without stops)
- Supplementary Considerations:
 - Robustness (failure): In the event of elevator malfunction and/or maintenance, or use of an elevator for goods or moving home/office, the remaining transportation capacity should remain sufficient to deal with continued demand.
 - Robustness (deviations from norm): If transportation capacity is rated to saturation tolerance thresholds, then any deviations or incorrect estimates concerning traffic flow can lead to greatly increased waiting times and even capacity shortages.
 - Durability (design): Elevator configurations should be designed to deal with any future traffic flow changes that might reasonably be anticipated. If calculations show low occupancy and low peak demand, then the number of elevators can be reduced, but this may result in the building being unsuitable for rental to future tenants with a different profile (i.e. higher occupancy, e.g. a call centre with high peak demands at fixed times). This entails that a certain degree of over-capacity should be incorporated into the design.
 - Requirements, or necessity, to include separate goods elevators and/or fire fighting elevators in towers, and consideration as to whether these may be integrated into passenger elevator group(s).

The considerations listed above can – within reason – be subjected to considerable influence. A common mistake is often made when confronted with unfavourable outcomes, i.e. traffic flow/elevator capacity mismatches. Instead of adjusting the basic elevator concept, the basic assumptions, which cannot be influenced, are tweaked to force a match, e.g. entry and exit times, car occupancy, stair usage, etc. Sometimes, even population, occupancy and peak demand figures are retroactively adjusted down to force a match with the elevator system design's maximum attainable capacity (both financial and spatial). This is in fundamental denial of original basic principles whereby reality is adjusted to match the design. A more correct and realistic approach to this conundrum is to adjust the building's properties – height, occupancy per storey, reduced number of main stops, separate car park elevators, escalators, restaurant location, etc. – or to adjust the elevator system's primary parameters – number of elevators, load capacity, nominal speed, et cetera.

Acceptable Performance

The ultimate assessment criterion for acceptable traffic flow management always remains the waiting time and/or the destination time. There are no hard and fast standards for acceptable waiting times, only experiential data. Guidelines for acceptable waiting and destination times should be determined on a project-by-project basis taking into account the building's



Elevator simulation example.

function, its ambitions and the available budget. Table 2 offers an illustration of various experiential data concerning waiting times for various building functions and ambitions.

Function	Excellent	Good	Moderate
Office Space	≤ 25 sec	≤ 30 sec	≤ 35 sec
Hotel	≤ 20 sec	≤ 25 sec	≤ 30 sec
Residential	≤ 35 sec	≤ 40 sec	≤ 45 sec
Healthcare	≤ 30 sec	≤ 40 sec	≤ 50 sec

Table 2: An indication of acceptable waiting times for various building functions.

An indication of nominal travel times (travel height / nominal speed) acceptable for an office block is somewhere between 25 and 30 seconds, and for housing, between 30 and 40 seconds. The nominal travel time can be viewed as a near constant value that should be used to determine the nominal elevator speed.

CALCULATION VERSUS SIMULATION

Whereas round-trip time calculations suffice for simple low to medium-rise office buildings, simulations are an absolute requirement for high-rise traffic flow analysis.

Traditional **round-trip calculations** examine the theoretical total cycle time for a single elevator during up-peak demand. Estimates are made using statistical probabilities as to how many stops are made on the ascent and descent for a complete round trip, where the elevator is assumed to have a full passenger load at the main entrance level. By evaluating the sum of time lost for each individual component of the cycle (ascent, descent, exiting, entering, acceleration, deceleration), a total round-trip time (RTT) can be calculated. The theoretical round-trip time can be defined as the time elapsed between two successive arrivals of the **same** elevator at the main entrance level. By dividing the RTT by the number of elevators in a group, the interval (INT) can be derived and is defined as the time elapsed between two successive arrivals of **any** elevator at the main entrance level. The INT is generally used as a measure of an elevator group's performance. In general, this should be less than 30 seconds.

Through dividing the realistic elevator car occupancy at departure from the main entrance level by the interval time, an indication of the elevator group's transportation capacity can be calculated.

Although the round-trip time provides an accurate estimate for



elevator groups in many instances, this approach may only be applied under the following conditions:

- An RTT calculation can only be used for simple **up-peak** demand. It cannot therefore be applied to residential tower blocks (**morning down-peak** demand), hotels (**morning bi-directional** peak demand) and office blocks at lunch times (**bi directional** peak demand).
- An RTT calculation can only be used where there is one main entrance level, which excludes buildings with a subterranean car park, with a restaurant on a level other than the main entrance level, or with other main interchange levels.
- An RTT calculation can only be used where there is no disruptive inter-floor traffic flow during the determining up-peak demand.
- An RTT calculation can only be used where all elevators in a group are identical.

An additional problem is that the ultimate RTT analysis criterion, the interval, is often an unreliable indicator for the actual waiting time. This is certainly the case when transportation capacity is inadequate; intervals can remain acceptable whereas waiting times increase drastically. Additionally, the use of the interval as an elevator group performance indicator is fundamentally flawed for elevator groups with destination control (see inset). Where destination control has been implemented, passengers sometimes have to wait for elevators travelling to other destination zones to pass, before their designated elevator arrives. By definition, this invalidates the already dubious relationship between interval and waiting time for destination control entirely.

The abovementioned limitations – plus the fact that high-rise and stacked construction is becoming ever more popular – means that elevator planning is increasingly performed by means of simulation. Traffic flows, the building and elevator groups are modelled within one integrated simulation environment. Each

Residential towers Hong Kong

traffic flow or storey is simulated by a random generator that inputs a realistic and reliable flow to the virtual elevator system. However complex or non-compliant the individual flows may be (inter-floor traffic flows, bi-directional traffic patterns, simultaneous goods flows, et cetera), they can all be modelled for any given elevator system. The virtual elevator system deals with the input requests as if it were a real system, and waiting times and destination times are recorded. Results are stored in a database, which can be queried to draw conclusions about average and maximum passenger waiting and destination times during peak demand. Results for various traffic flow management scenarios for multiple elevator configurations can then be evaluated and compared to one another. By applying an iterative process, elevator configurations can be fine-tuned to arrive at the optimal solution for any given building. Using elevator simulations, it becomes evident that the interval is no longer the key performance indicator, but that waiting and destination times are now the determining factors.

In short, elevator planning in high-rise buildings is an iterative and time-intensive process. It is crucial that the main features of the elevator core configuration be set in stone as early as possible in the design process. A thorough understanding of elevator technology, control systems and simulation methods are essential for estimating the required elevator configuration capacity for high-rise buildings. It is only possible to derive a balanced and reliable analysis of a building's transportation requirements with a good intuitive estimate of the usage and the peaks in demand for the building's envisaged functionality, and the relative effects of the various parameters used in the simulation method (sensitivity analysis). Correct assessment of the effect of human behaviour as well as user experience, access systems and access control also play an important role in this whole process.

CHALLENGES INHERENT IN DESIGNING HIGHRISE ELEVATOR SYSTEMS

The differences between capacity studies for low-rise and high-rise construction are immense, in terms of both the depth of analysis and the effort required. These differences can be attributed to the following four points, in addition to the various analysis methods mentioned above (see "Calculation versus Simulation"):

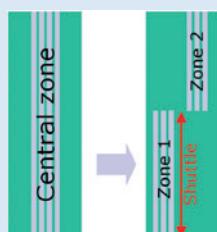
- **A wider variety of elevator configurations is possible for high-rise construction than low-rise**

A central elevator group is generally adequate for low-rise and medium-rise buildings up to 70 m (230 ft) tall. There is, however, a whole host of options available for managing access within high-rise buildings depending on their height. The essence lies in the benefits that can be gained by splitting a building into elevator system zones, e.g. a two-zone layout (low-rise/high-rise) or three-zone layout (low-rise/medium-rise/high-rise). In buildings taller than about 200 m (650 ft), serious consideration is given to a physical segregation of elevator systems into multiple stacked towers. Lower tower zones are served by elevators from the main entrance level and upper zones are accessed by elevators boarded at sky lobbies (transfer levels) reached by shuttle elevators. Passengers then have to transfer to local elevators at these sky lobbies. The higher the tower, the more elevator system segments are incorporated (see Taipei 101 inset). If one of these options is chosen, then fine-tuning is needed to determine the correct positioning of the transfer levels, and the elevator loads and speeds required. (see Specific Highrise Challenges inset for further details)

SPECIFIC HIGHRISE CHALLENGES

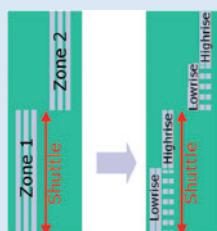
Optimising traffic performance in high-rise:

Traffic handling is more efficient when the number of destinations per elevator is reduced. This minimizes the number of stops, the travelling distance and thus the time required for the (empty) return ride. There are 3 basic methods for reducing the number of destinations:



Method 1:

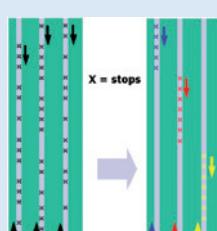
High-rise buildings (>150-200 m high) are split up in separate stacked towers (zones) to minimize continuous shafts over the tower's total height. To reach the skylobby of the higher zone(s) shuttle elevators are required.



Method 2:

Elevators in local tower zones are split up in groups, serving local low-rise and high-rise floors. Low-rise and high-rise elevators in the same zone serve the same home floor (ground floor or skylobby). For methods 1 and 2, part of the optimization lies in finding the optimal skylobby level and the optimal separation level between low-rise and high-rise groups, to minimize the total number of shafts.

This is an iterative process.



Method 3:

Destination control reduces the number of destinations per car and thus the number of stops per cycle. This decreases the average travel height and the cycle time. When elevators are equipped with destination control, this can even reduce the number of elevators per group.

The real challenge lies in stacking uniform cores from different zones on top of each other by integrating elevator pits and machine rooms in technical layers. This results in consistent core lay-outs over the height, which is

advantageous for the construction and minimizes suboptimal office space (pantries et cetera) in redundant core areas.

Additional optimizing possibilities are using double deck elevators and TWIN elevators. These can further increase the traffic capacity per shaft, usually resulting in less shafts.



- Minor considerations can suddenly become far more influential – striking the balance

The individual effects of each traffic flow parameter on transportation capacity are many times greater for high-rise construction than for low-rise. Marginal differences when fine-tuning parameters such as peak demand, population, door times, entry and exit times, et cetera can all influence traffic flow management to a high degree. The balance between demand and handling is so sensitive that even the slightest deviation can result in the need to change the entire elevator system concept. Traffic flow management is nowhere near as complex for low-rise construction as it is for high-rise.

- Tight margins – right the first time!

Designs for high-rise construction projects have to be right the first time. There are never, or hardly ever, opportunities to make subsequent changes. Retroactive changes to the basic assumptions are near impossible without the design having to be recalculated. The available design margins often have to be made known in the preliminary design phase, if high-rise construction plans are to become viable. This often conflicts with the flexibility required in subsequent phases. The freedom to make programmed or architectural changes are minimal. If changes are made nonetheless, then the elevator design and/or concept must be amended quickly.

- Various control systems available

A simple hall call collecting elevator control system is adequate for most low-rise buildings, but destination control should be considered for high-rise buildings (see inset). The quality and artificial intelligence level of the group control system is then of critical importance, whereas these have far less influence in low-rise buildings. Traffic flow pattern recognition, adaptation of traffic flow management in response to these patterns and self-learning play an important role in the selection of a suitable control system. The Twin Lift concept (see inset) is also a consideration worth taking into account.

TECHNOLOGY AND COMFORT

High-Speed Elevator Technology

Although there are no major differences with regard to suspension and guidance systems between high-rise and low-rise elevator systems, there are other aspects to be considered that complicate matters, such as system technology and passenger comfort levels. Control system artificial intelligence levels, safety requirements, load-bearing component ratings and subsequent pricing increase almost exponentially in proportion to the height of the building. The same applies to cable weight and energy consumption.

High-speed elevators in high-rise buildings pose a serious challenge with respect to the reciprocating air displacement in elevator shafts. Air resistance results in not only higher energy consumption levels, but the air being displaced past the car also generates whining and whistling noises inside the car. To prevent this, cars in high-rise buildings have to have aerodynamically designed exteriors resembling a drop-like shape with spoilers to channel air past the elevator. To prevent hammering sounds caused by the passage of the elevator past the landing doors, shafts have to be fully cladded between levels to create an even, flush surface. Cars also need to be soundproofed to reduce noise emission levels within the car. Noise transmission through car ventilation systems also needs to be minimized.

An additional problem associated with high-speed elevators is the plunger effect caused by the car's movement inside the shaft. In high-rise buildings, it is essential that displaced air can

be interchanged between elevator shafts. A preferred option is to suspend all elevators in one open shaft; however, this reduces the structural load-bearing capacity of the elevator core. The entire shaft then has to be fitted out to the same system integrity, fire resistance and high-pressure ventilation levels for all elevators. In practice, shaft partitioning walls are often perforated, or interconnecting openings (bypasses) are incorporated at the top (headroom) and base (pit) of adjacent shafts to allow the interchange of displaced air columns.

A robust car guidance system with meticulously aligned tracks are essential for reducing vibrations to an acceptable comfort level. Tracks must be rated for heavy-duty usage, guidance surfaces and welds have to be totally flush, and mounting points have to be positioned to within microns, as every irregularity in the guidance system causes an unpleasant and uncomfortable transverse vibration within the car at high speeds. High-quality roller guidance systems are also required. To complicate matters still further, the elevator guidance system must be able to withstand the effects of the building settling and the response of the building's structure to thermal and climatic changes.

The pressure difference between the base and the top of a building's elevator shaft also plays an important role in elevator design. To prevent the shaft acting like a chimney, and air causing a whistling noise when passing door seals, elevator shaft doors have to be made airtight, e.g. by implementing interlocking labyrinth seals. At main entrance levels, direct passage to the outside air should be eliminated by incorporating

double airlocks, et cetera. Elevator machine rooms should also be made as airtight as possible, and despite the use of mechanical ventilation, no vents should open directly to the outside air.

Ride Comfort

Elevator comfort is principally determined by interior noise levels and transverse car vibration. Cars should be designed to suppress interior noise levels to less than 48–52 dB(A) for superior ride comfort, as for low-speed elevators. Noise levels above 60 dB(A) are generally acknowledged to be inadequate. In contrast to low-rise buildings, high-rise buildings require additional measures to reduce noise levels (see "High-Speed Elevator Technology").

Transverse car vibration also needs to be minimized to ensure acceptable comfort levels. This imposes high demands on suspension, track and roller guidance systems. At high speeds greater than 3.0 m/s (10 ft/sec), additional technological and alignment measures are vital to ensuring acceptable comfort levels, in contrast to low-speed systems less than 2.5 m/s (8 ft/sec), where little if any attention needs to be paid to such matters.

To achieve improved comfort levels in high-speed elevator systems, additional requirements are also imposed on axial acceleration/deceleration (for smooth pick-up and braking) and axial jerk (acceleration/deceleration build-up).

Pressurization and depressurization of the elevator car should

Conventional versus Destination Control

Conventional elevator controls allow users to indicate their chosen direction of travel by means of up and down buttons. Cars are typically filled in the same order that user requests are received. The control system gathers all requests for each travel direction, but does not know in advance which destinations will be selected by users once inside the car. Chances are high that there will be a large number of destinations entered for each round trip, as well as a high probability that several elevators will simultaneously serve the same range of destinations.

Destination control eliminates this problem because final destinations are already selected by users when calling the elevator. This allows the control system to cluster destinations for each car using dynamic zoning, thus significantly reducing the travel time and the number of stops. Moreover, not every elevator has to travel all the way to the top of the building on each round trip. When calling an elevator, passengers are notified as to which elevator will be transporting them. Destination control is optimized on the basis of destination time (waiting time + travel time) and not on waiting time. The total passenger destination time is reduced although the waiting time often increases with respect to that for conventional control systems.

Destination control is ideal for situations in:

- high-rise buildings where large dynamic zones can be defined
- large elevator groups where multiple dynamic zones can be defined
- buildings with high peak demand
- buildings with marginal disruptive between-floor traffic flows
- buildings with a fixed population that will become familiar with such systems

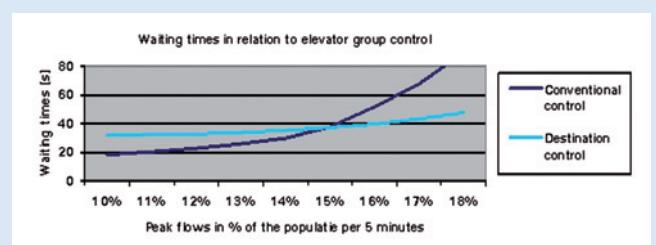
Advantages of destination control include the following:

- passengers make fewer stops en route and arrive at their destinations very quickly

- car occupancy is lower and therefore more comfortable for passengers
- capacity is sufficient even during peak demand (14–18% of the population per five minutes). Destination control can be used as a capacity booster where additional capacity is achieved using existing elevator systems
- in some cases, destination control saves the need for an additional elevator and elevator shaft
- given that passengers are assigned to an elevator, they can stand at the correct location in the lobby allowing more flexibility in the layout of the elevator core
- a reduced number of stops means that an increase in the elevator speed has an even greater effect on dealing with traffic flows

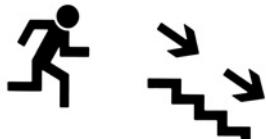
Disadvantages of destination control include the following:

- waiting times are generally longer than for conventional control, even when traffic flows are low (see graph)
- elevator users have to accept that sometimes, several elevators will come and go before their assigned elevator arrives
- each user has to enter their destination, even for groups
- misuse and accidental usage (ghost passengers and missing passengers) are seriously detrimental to traffic flow handling capacity
- not yet viable for public buildings, as the general public is still insufficiently familiar with such systems



also be minimized. At descent speeds above 8–10 m/s (26–33 ft/sec), car pressurization can be painful to passengers' ears. The absolute pressurization from start to end and the period over which the pressurization persists both play a role. At extremely high speeds, such as the Taipei 101 elevators that travel at 17 m/s (56 ft/sec), elevator cars have to be fitted with fully pressurized cabins similar to aircraft specifications. Although depressurization on ascent is generally experienced as being less painful than pressurization on descent, this should also be regulated as far as possible.

A final consideration relating to journey comfort involves car occupancy. This is not an issue specific to high-rise elevator systems, but – according to European rule of thumb – should be limited to a maximum of 70% of the theoretical load limit (based on an average weight of 75 kg (165 lb) per person).



Elevator Evacuation

Everyone has always been taught not to use elevators in the event of a fire or other emergency. In ultra-high-rise buildings taller than 300 m (980 ft), full evacuation using the stairwells is however a utopian dream. To evacuate an entire tower measuring 400 m (1,310 ft) would take one to three hours.

For this reason, two trends have become increasingly evident in recent years, predominantly in Asia and Australia – evacuation by zone and evacuation by elevators. Evacuation by zone involves a phased evacuation whereby only the zone affected by the emergency is evacuated, not the entire building. Each zone has a designated evacuation level to which people can escape by stair until the danger has passed. These evacuation levels can maintain systems integrity for up to one hour and allow escape flows to switch escape stairwells. The Taipei 101 has an evacuation zone at the base of every eight-storey segment.

The second trend, evacuation by elevator, no longer reserves the use of elevators for fire fighters and emergency personnel; certain (or all) elevators are specifically designated for evacuation purposes. It is implicitly understood that such elevators are subject to a host of additional safety requirements covering systems integrity, fire resistance, control and monitoring. To handle transportation under panic conditions, it must be possible for elevators in emergency mode to operate according to a different set of overload controls, door closing characteristics and load-non-stop conditions. It remains to be seen whether it is feasible and/or sensible to increase descent speeds and acceleration rates in such situations. In conclusion, it must also be possible – using sophisticated building management communication systems – to alter evacuation procedures on a real-time basis, depending on the type and location of the emergency, such that options for alternative evacuation routes are made available (zoned, complete, bottom-up or top-down). Checks would then be required to verify whether exiting at main levels is a safe, viable option, or whether an alternative escape route is required (consistent with the European NEN-EN 81-73). Shafts should also be pressurised to remain smoke-free. It is vital that this air is channelled from safe zones, i.e. guaranteed smoke-free. Future options might include dynamic ventilation systems that automatically search for areas from which safe, smoke-free air can be channelled.

A lot of research is currently being conducted into the possibilities for and hazards associated with evacuation by elevators. Even in the Netherlands, elevator evacuation is back on the agenda since the publication of the SBR's practical guidelines, Brandveiligheid in hoge gebouwen [Fire Safety in High-rise Buildings]. This topic will be receiving a lot of attention under the auspices of the National High-rise Covenant currently being drafted in collaboration with NEN.

Twin Lifts

The ThyssenKrupp Twin Lift concept has been available for the past few years and involves the operation of two separate elevator cars within one shaft. The elevators use the same tracks and elevator shaft access points, but have separate cars, drives, suspension and control systems. Triple-layer mechanical and electronic safety systems ensure that the two cars remain out of each other's way. The upper car generally serves destinations in the top half of the building and the lower car the bottom half – with destination control. The lower car can only let on passengers at the main entrance level once the upper car has departed, and is required to wait below the main entrance level whenever the upper car needs to return to that level.

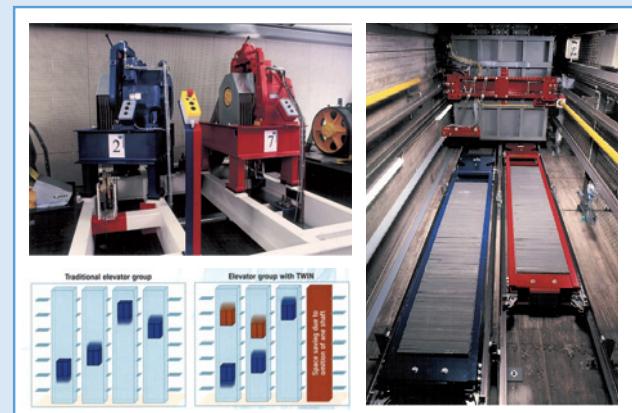
Depending on traffic flows, the twin lift concept provides an additional capacity of approximately 30–40% per elevator shaft. This means that for larger elevator groups fewer shafts are required.

Twin lifts are ideal for situations in:

- high-rise buildings with high peak demand
- buildings with large elevator groups
- buildings with a lot of between-floor traffic flows

Twin lifts can only be implemented under the following conditions:

- destination control is in use to dynamically keep cars out of each other's zones
- at least one conventional elevator must be included in the elevator group for transportation from the lowest to the highest stop. This must also be designated as the fire fighting elevator.
- a holding pit of at least 8–10 m (26–33 ft) deep must be available in which the lower car can wait until the upper car has departed, before it can let on passengers at the main entrance level. This could be a car park or basement level, or the main boarding level could alternatively be moved to the 2nd or 3rd floor, accessible by escalator.





'Strijkijzer' The Hague (132 m)



Shuttle elevator Atomium Brussels

CONCLUSION

High-rise elevator systems demand meticulous and impartial capacity analysis and detailed simulation. Not only should the building, its population and peak demands be correctly modelled, but elevator configuration and physical and/or dynamic zoning should also be determined. The correct choice of group control system plays a vital role, as does the correct choice of group sizing, elevator capacity and nominal speed. Given that the elevator core forms the building's load-bearing structure and such factors are determined early in the design process, the right choices have to be made first time round. There are few if any opportunities to correct mistakes later. This demands logistical and elevator planning insight, extensive expertise and experience, and the application of correct safety margins. Using simulations, safeguards must be in place to ensure that invalid adjustments are not made to parameters when specifying traffic flows.

A variety of additional technical measures is required to ensure safety and comfort within the car at high speeds. Extremely high demands are placed on the suspension, track and guidance systems, and transmission and control systems must also be heavy-duty, reliable and accurate. The group control system's quality and artificial intelligence levels ultimately determine transportation efficiency. These issues cause high-rise elevator system costs to increase proportionally by more than the square of the building's height. Even though Dutch high-rise buildings may not even be considered high-rise from a global perspective, high-rise elevator system logistics and technology should not be underestimated. These issues require serious attention for continued development of high-rise buildings in the Netherlands given that increasingly taller buildings are being constructed and evacuation by elevators is becoming inevitable.



Author: Jochem Wit Msc.

Jochem Wit (1971) graduated from the Technical University (TU) in Delft in 1995 with a degree in Mechanical Engineering, specializing in Transportation Technology and Logistics.

After graduation, he went to work at Deerns Consulting Engineers BV where he is team leader of the Transportation & Logistics expertise group, a department specializing in elevators, escalators, moving walkways (travelators), façade maintenance systems, baggage handling systems, pneumatic dispatch systems, passenger boarding bridges et cetera.

Wit also heads up complex projects in the field of new transportation system construction and renovation for the non/residential, healthcare and aviation sectors. He specializes in performing capacity planning studies to determine optimum elevator system configurations for buildings and specifically, traffic flow studies for high-rise buildings and hospitals.

Wit is also a member of the Technical Workgroup for the National High-rise Covenant and chairs the Transportation System sub-workgroup. The National High-rise Covenant being drafted in collaboration with NEN aims to arrive at sector-specific agreements (so-called NTAs [Dutch Technical Agreements]) relevant to high-rise construction projects in the Netherlands.

Several Deerns High-Rise Projects

Our complete high-rise project portfolio is available on request.

New Orleans & Havana, Rotterdam



Height: 154.7 m (508 ft)
Function: residential, medical centre, office space, museum and cinema
Floor Space: approx. 210,000 m² (2,260,420 sq ft) GFA
Customer: Vesteda/TRS Ontwikkelingsgroep
Architect: Cruz y Ortiz (Spain), Alvaro Siza (Portugal)
Status: under development (2009)
Deerns: concept and preliminary design

Prinsenhof Tower E, The Hague



Height: 109 m (358 ft) including antenna 128m (420 ft)
Function: office space
Floor Space: approx. 32,700 m² (351,980 sq ft) GFA
Customer: BPF Bouwinvest
Architect: Kraaijvanger Urbis (R. Ligvoet)
Status: completed in 2004
Deerns: complete design

Ministries of Internal Affairs and Justice, The Hague



Height: 146.5 m (481 ft) (x 2)
Function: office space
Floor Space: 105,000 m² (1,130,210 sq ft) GFA
Customer: Riksgebouwendienst
Architect: Kollhoff (Germany)
Status: under construction (2011)
Deerns: complete design

Mahler4, Amsterdam



Height: 98 m (322 ft)
Function: office space
Floor Space: approx. 32,600 m² (350,900 sq ft) GFA
Customer: G&S Vastgoed
Architect: Toyo Ito (Japan)
Status: completed in 2004
Deerns: complete design

Height: 96 m (315 ft)
Function: office space
Floor Space: approx. 29,200 m² (314,310 sq ft) GFA
Customer: Mahler4 Consortium
Architect: Rafael Viñoly (Italy)
Status: completed in 2004
Deerns: master plan and preliminary design

Millennium Tower, Rotterdam



Height: 132 m (433 ft) including antenna 149 m (489 ft)
Function: hotel and office space
Floor Space: approx. 39,000 m² (419,790 sq ft) GFA
Customer: Kintel Rotterdam BV
Architect: Webb Zerafa Menkès Housden (Canada)
Status: completed in 2000
Deerns: schedule of requirements and design supervision

Height: 88 m (289 ft)
Function: residential
Floor Space: approx. 31,700 m² (341,215 sq ft) GFA
Customer: Mahler4 Consortium
Architect: de Architecten Cie.
Status: under construction (2007)
Deerns: master plan and preliminary design

Woontoren Strijkijzer, The Hague



Height: 132 m (433 ft)
Function: residential
Floor Space: approx. 30,000 m² (322,920 sq ft) GFA
Customer: Vestia/Ceres Projects
Architect: Architectenassociatie (P. Bontenbal)
Status: completed in 2007
Deerns: complete design

Erasmus MC Faculty Tower, Rotterdam



Height: 112 m (367 ft)
Function: university
Floor Space: approx. 65,000 m² (699,650 sq ft)
Customer: Erasmus MC
Architect: A. Hagoort & G. Martens
Status: completed in 1968, renovated 2006–2008
Deerns: renovation of various laboratories, logistics study and elevator renovation

Willemsswerf, Rotterdam



Height: 88 m (289 ft)
Function: office space
Floor Space: approx. 35,000 m² (376,740 sq ft) GFA
Customer: Koninklijke Nedlloyd Group
Architect: W. Quist
Status: completed in 1988
Deerns: complete design

Deerns consulting engineers
P.O. Box 1211
2280 CE Rijswijk (The Hague)
T +31 (0)70 395 74 00
F +31 (0)70 319 10 71
E contact@deerns.nl

www.deerns.com

Other offices in:

The Netherlands Amsterdam, Eindhoven, Groningen,
Maastricht, Nijmegen
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