Elevator traffic analysis and elevator configuration options: Best practices for high-rise buildings

Hans Sacherer
Head of High Rise Sales and Consulting, Europe Africa
thyssenkrupp Elevator

Scope overview

This white paper[1] describes best practices in the design of elevator configurations for high-rise buildings. In an effort to support architects, owners and investors, it addresses the following questions:

(1) what elevator traffic analysis (ETA) is and how it informs an iterative design process;
(2) which qualities to look for in an elevator consultant;
(3) why to involve the elevator consultant very early in the design process;
(4) why it helps to work with a provider who offers a wide range of elevator types for more options when designing the building core;
(5) why the quality of ETA input data matters;
(6) which ETA input parameters can lead to good results "on paper", but poor performance in the completed building.

[1] In order to provide the most objective information for the market, this white paper refrains from the use of product names, promotion and sales arguments.

Elevator Traffic Analysis: what it is and how it influences design

The Elevator Traffic Analysis (ETA) predicts the future performance of a given elevator layout. The analysis should be carried out via simulation for tall buildings. Provided with good input, ETA simulation offers specific data points on how well the future system will function, such as the average passenger waiting time for an elevator or five minute handling capacity[2].

[2] According to ISO 8100-32, a round trip time calculation is also possible, but this is not adequate for the complexities of passenger traffic in tall buildings.

After simulation, the elevator layout can be adapted or improved depending on the results. At this point, it is possible to choose among different elevator layout options that can provide different benefits to the future owners and users in the building. One of the most important benefits is to find the layout(s) that offer the opportunity to reduce the number of shafts to a minimum, and thereby free up more rentable space within the building.

The ETA is part of an iterative design process. If used by an experienced elevator consultant, the ETA is a tool that makes it possible to further refine each iteration of an elevator layout for the most optimal result. It also creates the opportunity to develop and compare different layout options to best meet the needs of a particular project in terms of the number of shafts, budget, passenger comfort, energy savings and system efficiency.

There are, however, certain factors that can reduce the accuracy and reliability of an ETA, limiting the ultimate value provided by the analysis. This normally comes as a result of unrealistic assumptions made during the simulation phase. The results of such an ETA simulation will not be comparable to the results of other elevator companies provided during the tendering phase, i.e. the results might look better or worse than the other companies' results due to improper inputs (more information under "Common ETA input & design errors that falsely provide good output figures").

Timing: When to involve an experienced elevator consultant

In order to determine the most beneficial elevator configuration and test it via ETA, it is important to involve an experienced elevator consultant from the earliest stages in the structural design of tall buildings.

Architects need to know the exact number of elevator shafts required as well as their planned arrangement in terms of number of elevators, number of elevator lobbies/sky-lobbies and the arrangement of the lobbies. A sound traffic analysis aids in the development of multiple viable solutions for a building's elevator core. Every solution has its advantages and disadvantages. Making the right choice at the very beginning of a project saves a lot of money and prevents costly surprises at a later stage.

The following figure outlines the process of finding elevator configurations.

Figure 1: Elevator layout design process according to ISO 8100-32:2020

1. Collect building data
2. Choose traffic analysis method (for tall buildings = simulation)
3. Select performance goals (based on industry standards[3] and client needs)
4. Provide elevator configuration (i.e. initial layout)
5. Determine performance via simulation tool
6. Performance goals met?
   a. Yes: Create more elevator configurations to provide additional options
   b. No: Modify configuration before creating further options
7. Present results in a report

[3] Generally accepted performance standards for the elevator industry have been defined in CIBSE GUIDE and ISO 8100-32.

If an elevator consultant is not contacted until after the elevator core layout is finalized, it will be too late to reap the attractive benefit of reducing shafts, i.e. ensuring more rentable space. At that point, there only remain some lesser benefits of reducing the number of required elevators, such as re-purposing unnecessary shafts in a passenger elevator lobby for use as service or firefighter elevators, or using the space for pipework, HVAC and electrical systems.

High costs will be incurred in the future if it is decided to change the elevator configuration in a later stage of a building's structural design. In most cases, and for structural reasons, architects start high-rise designs with the building core which houses the elevators. If the core is changed too late, the architect will have to revise the entire structure of the building and the load-bearing walls of the core. By starting early with the configuration of elevators, the elevator consultants will have the time to provide advice on any standards or best practices that need to be upheld, and they will have enough time to create new opportunities by suggesting different layout options.

Ample experience is required to carry out sound traffic analyses for tall buildings which take account of all known aspects. There is no shortage of elevator consultants in the world. However, it is highly recommended to work with elevator consultants who have already provided consulting for high-rise projects. They must have proven experience using simulation tools for the traffic analysis, and their experience enables them to provide several reasonable scenarios, as they will not assume that only one solution fits all. Most of all, consultants must be able to show that their recommendations are not just theoretically sound, but that their original traffic performance simulations will fall in line with the actual performance of the elevator system.

Optimal results depend on the range of elevator types available

For nearly any type of technical challenge, better results can be achieved when you have more resources. Standard elevator solutions may often be the best choice, but it is important to have the option of seeing what state-of-the-art elevator solutions can offer. Although some of the latest elevator designs do require a higher initial investment, they often provide an immediate Return on Investment as a result of reduced construction costs when they facilitate a decrease in the number of elevator shafts, which also provides for additional Return on Investment within two to five years as a result of increased rentable space. Other goals – such as ensuring the highest possible traffic flow efficiency or attaining green building certifications – also require an intelligent mix of state-of-the-art elevator solutions. With respect to the COVID-19 pandemic, lift capacity, social distancing, air conditioning and other factors will also need to be considered if the COVID-19 pandemic becomes prolonged.

The combination of different elevator types ensures the ability to reach the highest level of efficiency, as well as the ability to ensure the greatest range of layout options without sacrificing a high level of comfort for the end users. The optimal solution often results from the combination of the best suited elevator types and the ability of the supplier to innovate and to solve the requirements and challenges of the architects, the investor and the builder.

Taller buildings pose a particular challenge in terms of practicability, because the higher floors can become much less attractive if there is not a quick connection to the street level. An elevator mix that delivers an optimal level of comfort and convenience is often the only way to keep the upper floors of a tall building attractive in a competitive real estate market.

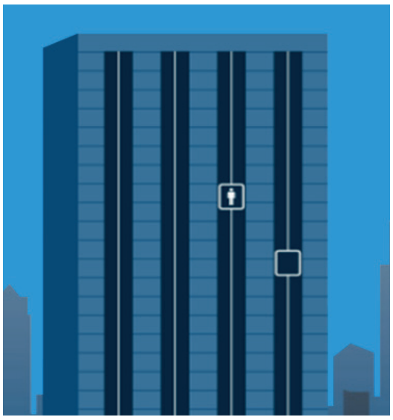
Figure 2: Overview of elevator types:

Single-deck elevators

Standard: Best value for low-rise buildings or for short distances in high-rise, or when an investor is not so interested in gaining more rentable space.

High-speed: Whether single-deck or not, most elevators will be high-speed for high-rise buildings.

Service/firefighter elevators: Heavy-duty elevators required in all tall buildings.

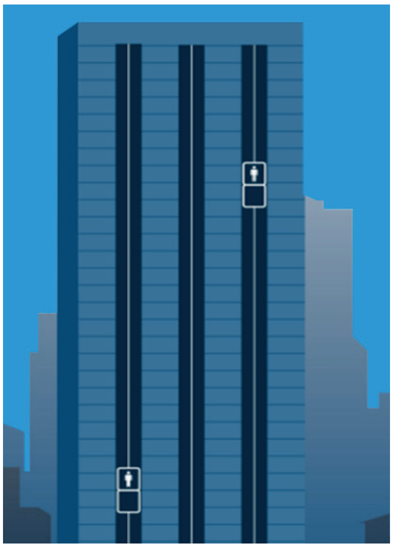


Double-deck elevators

Two cabins stacked on top of one another. The most efficient use is that of a high-capacity shuttle to sky lobbies.

They require two-floor entrance lobbies and for each landing floor to be the same height. They become disadvantageous if used as distributors (see “Common ETA input errors” below), and they are particularly disadvantageous for single-tenant buildings with high inter-floor traffic.

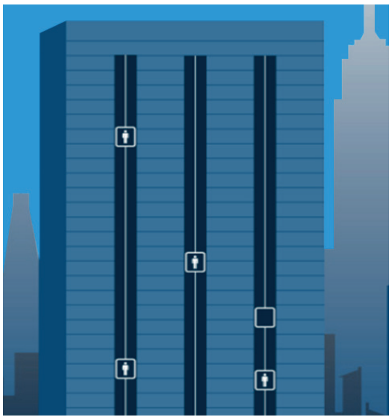
To overcome the necessity of all landing floors requiring the same height, adjustable double-deck elevators have been introduced. However, these are only adjustable to a limited extent, and are still not completely flexible.



Twin elevators

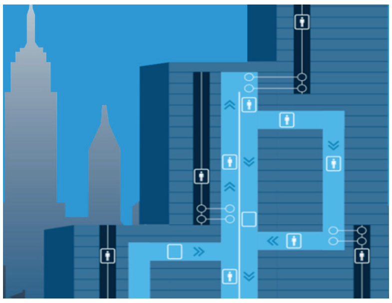
Two flexible, intelligently controlled elevator cabins that operate independently within one shaft, using the same landing doors and guide rails. This system enables a greater reduction in the number of shafts required. They are the most efficient inter-floor distributors for tall buildings and ensure a natural and comfortable flow of passengers.

Twin elevators perform best if they also have two main entrance floors. However, the distance between landing floors can differ.



Multi elevators

Multiple elevators that operate in a loop. Each car has a linear drive and horizontal travel is possible. High passenger throughput is possible when implemented as a "metro-style" circle line with fixed stops. Technically, no travel height restrictions.



Combination of elevator types

In practice, the most efficient solution for high-rise buildings comes from relying on a mix of different elevator types in combination with an intelligent destination dispatch system[4].

For most high-rise buildings under 250 meters, a mix of high-speed single-deck and twin elevators will provide a more efficient solution and allow for fewer shafts than if only single-deck or twin elevators were used (i.e. all elevators of one type).

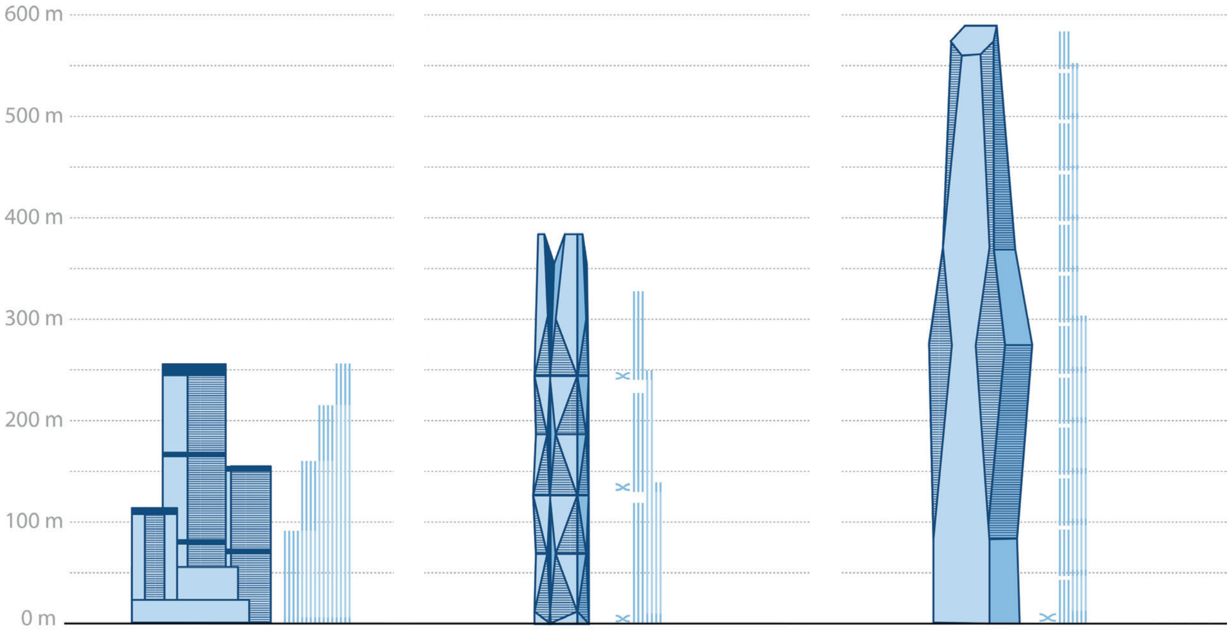
For taller buildings (over 250 meters), such as super- and mega-tall buildings, it's also the combination of solutions that creates the greatest traffic flow efficiency. By using high-speed single-deck elevators and twin elevators as inter-floor distributors in combination with double-deck elevators as high-capacity "shuttlebuses" to lobbies in the upper floors, elevator cores can be reduced in size by approximately 30-50%.

The latest elevator solution on the market, the "multi" elevator, can provide a similar or even greater reduction in core size, with the added benefit of much higher passenger throughput. Multi elevators feature an almost unlimited number of cabins operating in a loop, similar to a paternoster or a high-rise metro system. At the ground floor lobby, the elevator doors would open every 15-30 seconds and take passengers to fixed stopping points (i.e. every 10-20 floors) where they could get out and take a single-deck or twin elevator to their final destination. Since each car uses an individual linear propulsion system rather than cables, the building sway, which limits the usage of normal elevator systems, is not an issue for multi elevators, and there is no limit to how high a cabin can travel (maximum height with cable-stayed elevators: approx. 600m).

[4] Destination dispatch systems are not the subject of this white paper. The paper assumes, however, that all high-rise solutions will rely on a modern control algorithm to achieve maximum efficiency.

Figure 3: Sample elevator combinations in relation to core size

Standard high-rise elevators only, arranged in traditional elevator groups.	The combination of different elevator types to reap all the possible benefits: Double-deck elevators as shuttles, stacked twin and high-rise single-deck elevators for the local elevator groups	No restriction in height: Combination of multi, double deck, twin and high-speed standard elevators



Quality of results depends on quality of input

Of course, building owners expect the actual performance of their elevator solutions to live up to the predictions made by the ETA simulation. However, this is not always the case. In order to ensure that the ETA simulation provides realistic data that truly reflects the future performance of elevator systems, it is important to work with trustworthy elevator consultants with ample experience in high-rise projects.

Elevator consultants should be familiar not only with the minimum performance standards of the elevator industry[5]. Tenant satisfaction requires the elevator system to meet or exceed these standards in terms of average waiting times, number of stops before reaching destination, etc. Most tenants will also expect modern user interfaces, smart building innovations and access control interfaces.

[5] For more information on these performance standards, see CIBSE GUIDE-D 2015 or ISO 8100-32.

ETA simulation software is a powerful tool, but its accuracy depends on the quality of the input. It must take all aspects into account and rely on data that reflects actual user behavior. The following section explains specific data points that are frequently incorrect when entered by an inexperienced or unprofessional elevator consultant.

Common ETA input & design errors that falsely provide good output figures

Sometimes a given elevator solution might look quite good on paper (ETA simulation results), but then underperform when the completed building is occupied. This inevitably leads to dissatisfaction among tenants and users. Such a situation is often the result of using unrealistic input data in the context of the ETA simulation. The simulation program has no technical limits to ensure more realistic results. Therefore, the input should reflect the technical reality of the elevators, special site and access conditions and passenger flow especially during peak times, along with factors such as human behavior and the need to ensure passenger comfort.

The following data points should always be subject to extra scrutiny.

Common ETA input errors:

- **Door opening/closing time:** In some cases, elevator door opening/closing times are set too short in the simulation program, and therefore do not reflect the technical reality of the elevators or typical human behavior. This makes the elevator seem more efficient.

- **Elevator passenger capacity:** If the simulation program assumes, for example in office buildings, up to a 100% car load factor and an 85% average car load, the results will not reflect reality. In general, people do not like to enter a crowded elevator. In reality, an elevator will only ever reach a maximum 85% car load factor, and that will only happen in rare cases.

- **Jerk level:** Although it would improve time-to-destination, excessive jerk would result in passenger discomfort. As a rule of thumb, some passengers feel sick if this figure exceeds 1.6 m/s^3, so it is better to use a maximum of 1.2 m/s^3 in simulations.

- **Acceleration:** To ensure passenger comfort, acceleration and deceleration should not exceed 1.2 m/s^2. It is better to use a maximum of 1m/s^2 in simulations.

- **Top speed:** High-speed elevators are essential to high-rise buildings, but they should arrive at their top speed gradually (see acceleration) and, in general, they should not exceed 12-15m/s when moving up or 10m/s when moving down, as faster speeds could cause sickness.

- **Absenteeism:** Assuming an excessively high rate of absenteeism in office buildings or an overly optimistic use of the stairs by tenants will improperly decrease waiting times on paper. Absenteeism should generally be no higher than 15%, but the specific figure depends on the country and the type of tenants or purpose of the building.

- **Double-decker as distributor:** On paper, double-decker elevators used for inter-floor traffic can achieve similar results to twin elevators (with 2 flexible and independent cabs). The usage of double-decker elevators as distributors, however, relies on the acceptance of some disadvantages (i.e. passenger discomfort due to phantom stops[6] and very poor energy efficiency[7]) and potentially relies on false assumptions. In the simulation program, it is possible to set the percentage of passengers travelling up verses down along with inter-floor traffic. Double-deckers implemented as distributors will appear extremely efficient on paper if one assumes that all passengers want to travel in the same direction at certain times (e.g. 100% up peak mode), but this is not a realistic assumption.

Planning for change and extraordinary situations (e.g. COVID-19 pandemic)

Apart from following widely accepted standards and specific project goals, it is increasingly important for elevator consultants to take consideration of the changing nature of high-rise buildings which are increasingly multi-use in nature. Multi-use buildings, for example, may contain hotel, residential, retail and office spaces in one structure. Furthermore, they may offer co-working areas or special-purpose levels (like restaurants and skygardens, etc.) instead of traditional office levels.

Elevator systems should plan for flexibility, such as when the population per floor changes, the function per floor changes or even when the purpose of a building is completely converted from residential to office space.

Furthermore, when the world is faced with the challenges of a global pandemic such as COVID-19, it is also important for elevator consultants to plan for situations that call for a very small number of passengers per trip, so that building owners have the ability to easily comply with social distancing regulations. Here, too, experience and flexibility, along with creativity and innovation, are just as important as access to flexible elevator systems.

[6] “Phantom stops” are experienced by passengers in double decker elevators when used as distributors. If passengers need to get out of one cabin, passengers in the other cabin will be confused and potentially nervous when they experience a stop where the doors do not open.

[7] By definition, double-decker elevators always move both cars simultaneously and thus the system is heavier. Their only energy efficient application is as “shuttles” for large numbers of passengers, particularly during peak traffic times. These heavy elevators will result in high energy consumption if used for inter-floor travel by small numbers of people during off-peak hours.

Conclusion

The Elevator Traffic Analysis is the foundation of sound elevator configurations. It simulates the anticipated reality in the building in terms of people flow and the performance level of the elevators. The better the assumptions, the better the service level in the finished building. The traffic analysis cannot prevent planning errors, however, if the underlying assumptions are completely wrong or unrealistic. It is therefore highly recommended to work with elevator consultants who are very experienced in high-rise projects and who follow widely accepted standards[8] for their planning assumptions, while also planning for change and extraordinary situations, such as a pandemic.

[8] For more information on these performance standards, see CIBSE GUIDE-D 2015 or ISO 8100-32.

A sound traffic analysis carried out by experts will lead to highly efficient elevator shaft layouts and thus to more rentable space and better Return on Investment for the building owner. The right choice of elevator technology also reduces the number of empty trips (and phantom stops), while decreasing energy consumption and ensuring higher traffic performance and greater comfort for the tenants.

Annotated list for further reading:

- Cheeseright, Robin. (2020). Vertical Transportation: A Primer. Council on Tall Buildings and Urban Habitat.
  This comprehensive overview of vertical transportation written specifically for architects, owners and developers provides an in-depth introduction to the topic in order to help them better understand the broad topic of vertical transportation.

- GVD/15 CIBSE GUIDE D: Transportation Systems in Buildings 2015.
  A standard reference work for professionals in the field of vertical transportation. Primarily used as a resource for those working within the industry, it also provides valuable insight for owners, developers and architects.

- ISO 8100-32 “Lifts for the transportation of persons and goods – Part 32: Planning and selection of passenger lifts to be installed in office, hotel and residential buildings”.
  Formerly ISO 4190-6:1984, this updated standard outlines norms for various parameters used in elevator traffic simulations. Elevator traffic analyses should adhere to these generally accepted standards.

- Ridder, Michael. (2019) “Remove the Rope, Remove the Limitations”. Elevator World Europe, January-February 2019 (pp. 98-102).
  An article explaining the potential of multi elevators, particularly for tall buildings.

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