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Advances in Elevator Technology: Sustainable and Energy Implications

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Biography

Johannes de Jong joined KONE after receiving his master's degree in Engineering from the Polytechnical University of Delft in the Netherlands in 1977. He started in R&D as a designer, became a design team leader in 1978 and progressed to Project Manager in R&D in 1980. In 1986 he became the first Elevator System Manager in R&D and was nominated the Engineering Manager of the KONE High Rise Centre in 1988. In 1998 he joined the newly established Global KONE Major Project Organisation in his present function as Director – Products & Technology.

Due to his exceptionally wide technical expertise he functions as one of the senior vertical transportation advisors globally, and has received several awards and mentions for his work.
He is a member of the steering committee of the CTBUH and a member on several technical workgroups of the European Elevator Code committee preparing new revisions and interpretations on EN81-1.

Eleven years experience in R&D followed by 19 years of co-ordination with R&D, and holds over 500 different patents. He has also been involved in of many of the world's tallest buildings.

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Abstract

Elevator technology has seen dramatic changes the last couple of years. One of the most remarkable changes has been on the control algorithms side. The Introduction of the Intelligent Hall Call Destination Dispatching system has increased elevator efficiency tremendously, and has allowed a 20-25% reduction in the number of elevators required. Intelligent Hall Call Destination Dispatching has now also been introduced on Double Deck applications. A 52 storey office building, which earlier would have needed 24 single deck cars in 3 zones, can now be designed using only 2 zones with a total of only 13 Double Deck elevators, reducing the required core by no less than 11 hoistways.

Another remarkable change in elevator technology has been the application of Permanent Magnet Synchronous Motor technology. This technology with efficiencies up 96 % has allowed a dramatic drop in energy consumption of elevators. Where the elevators in a high-rise building could consume up to 8% of the total energy requirement 20 years ago, they nowadays only use about 2% of the total energy.

This paper will explain these technologies in a simplified way and how the above-mentioned benefits have been achieved.

Keywords: Hall Call Destination, Permanent Magnet, Energy Consumption, Core Reduction

Introduction

The modern elevator was born in the 1850's with the introduction of the safety gear. This invention made the use of the elevator safe, which on it's turn made the "high-rise" building possible. As elevator systems became more sophisticated they allowed ever-higher buildings. With an increase in height one will also see an increase in population, and an increase in the required number of elevators. There is practically nothing more damaging to Return on Investment than increased numbers of elevators, leaving less Net Usable Space to the owner. It was therefore important to find modern efficient methods to increase the transport capacity of the core.

Another problem modern society is facing today is the increased cost of energy increasing demands on buildings to be more energy conscience and less wasteful, more sustainable. Although energy consumption is only one aspect of sustainability, it is an important aspect also affecting both Image and Return on Investment.

Conventional ways to solve increased building height

As buildings get higher, more focus is needed on decreasing the number of elevators needed. Figure 1 describes how this is done as a function of the travel height. Zoning, splitting the building in stacked areas served from the entry lobby, is an efficient way to reduce the number of elevators required. As zoning reduces the number of stops an elevator makes on it's trip, it also reduces the time needed to return to the lobby. Elevators can make more trips and thus move more passengers. Zone lengths in offices are usually kept to around 10-20 floors, depending on the floor size, to keep waiting times short enough.

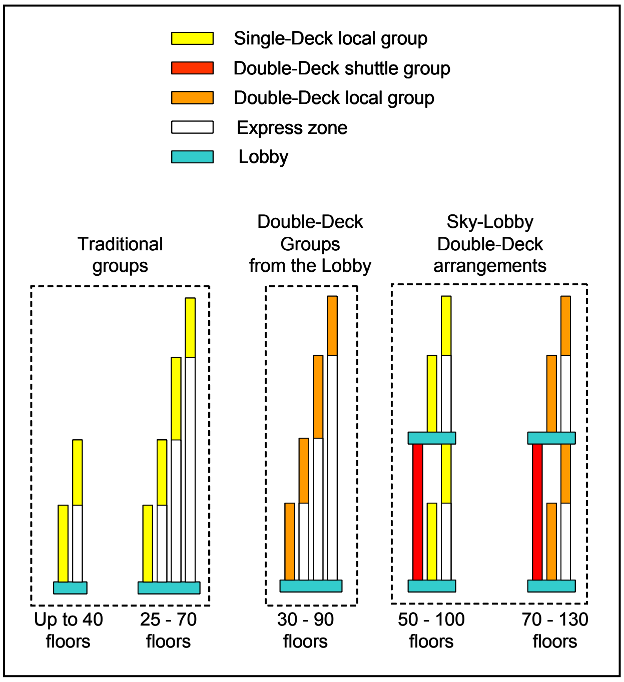

Figure 1. Zoning and stacking of high-rise buildings as a function of building height with conventional control (KONE Corporation).

As buildings get bigger more zones are needed and at about 3-4 zones buildings reached the next feasibility hurdle. Elevators simply start using too much space again, making buildings inefficient. This hurdle is reached in office buildings at heights of about 70 floors.

If the building needs to be higher, the next solution is again obvious; stack two cars on top of each other sharing the same hoistway. This system is known as the Double Deck elevator. The first Double Deck elevators were used in 1931 in the New York Subway Terminal Building. The double deck arrangement can cope with travels of up to 90 floors.

To go even higher two buildings now need to be stacked on top of each other. Shuttle elevators leaving from the entrance floor of the lower building now feed the lobby of the higher building, “the Sky-lobby”. To increase the flow of the shuttle elevators Double Deck shuttles are often used. To increase height even further local double deck groups can be used in conjunction with double deck shuttles. This arrangement is good up to travels of approximately 130 floors.

At present there are already plans for buildings exceeding these travels, but adding a third building on top of the second building is not an easy task. These buildings will now need shuttle elevators going 130 floors and some elevators going up nearly 200 floors. With these travels, building sway, suspension rope resonances and suspension rope weights, energy consumption per unit, become serious problems. The present rope elevator can go up to 200 floors, but rope weight increases rather exponential with height. When one sees rope weights of 50-70 tons to move just 21 passengers, one can hardly see the long-term financials and ecological values of these systems work. Before new revolutionary technology hits the market, elevator technology might be an obstacle for further increase of building heights.

Hall Call Destination Dispatching

Reducing stops, zoning and stacking of buildings, have been the basics behind efficiency of people flow in a building.

Hall Call Destination Dispatching is another way of reducing stops within a zone. With a Conventional Control system passengers enter their destination inside the car on the Car Operating Panel (COP). As passengers entering at the main lobby go to random floors, the result in a heavily loaded car is always a large number of floor buttons pushed (usually only slightly less than the number of passengers in the car), while the car always goes near the highest floor of the zone. This makes the time to drop of the passengers and to return to the lobby (the Round Trip Time RTT) very long.

If passengers going to the same floor could be gathered into the same car, the car could be filled with passengers going to just a small number of floors. The fewer stops will significantly reduce the RTT and cars will be available quicker for loading in the lobby. In other words, cars can make more trips, and thus move more passengers. In order to gather passengers with the same destination in the same car, the destination of the passenger must now be entered outside the elevator. The device on which the passenger enters the destination is called the Destination Operation Panel (DOP). The first systems were introduced already around 1964 in Australia, but were not very successful, as the relay systems used at those times could not handle this type of elevator dispatching efficiently.

With present day computer technology this is a much easier task. In 2001 KONE introduced the next generation of Hall Call Destination Dispatching systems using Genetic Algorithms to allocate the call to a car.

Gathering passengers with the same destination in the same car does not always provide the optimum solution.

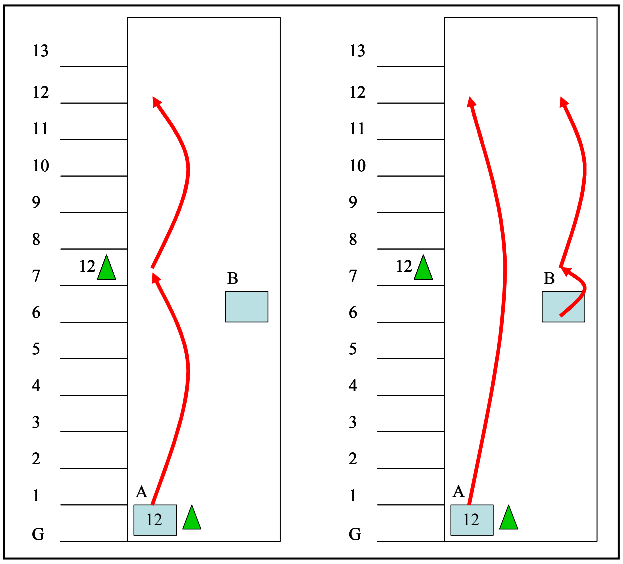

Figure 2. Example, gathering passengers with the same destination in the same car does not always the optimum solution (KONE Corporation).

Example (see figure 2): In conditions where traffic is not very heavy (outside peak periods), a person on the 7th floor wants to go to the 12th floor. Elevator A has just left the ground floor with another passenger assigned to the 12th floor. If passengers with the same destination are gathered in the same car, car A will now make a stop on the 7th floor to pick up the passenger. However on the 6th floor there is an idle car (B), as traffic is low. It would have been much quicker for both passengers if the idle elevator on the 6th floor had picked up the call on the 7th floor. Genetic Algorithms with Multi Target Optimization will optimize waiting times in low traffic conditions and would have assigned the idle elevator.

In medium traffic a combination of waiting time optimization and journey time optimization is used. In heavy traffic the system will shift completely to journey time optimization. This increases the journey speed and minimizes RTT.

When using journey time optimization the system also splits the zone it operates in into as many sub-zones as there are elevators. The length of the sub-zone will depend on the traffic intensity. When traffic is low sub-zones will be long and will substantially overlap each other. As traffic intensifies, sub-zones are shortened and the overlap is reduced. With more overlap there are more elevators available to the same floor and this reduces waiting time. With less overlap it becomes increasingly necessary to put passenger with the same destination in the same car, and this increases the capacity.

At optimum boosting where zones do not overlap anymore, zones have the minimum possible number of stops and provide the shortest possible RTT to the lobby. This system provides even more capacity than the previous generations of Hall Call Destination Dispatching systems.

As a result the Intelligent Hall Call Destination Dispatching system developed by KONE applying Genetic Algorithms with Multi Target Optimization, will provide the minimum possible waiting times and the maximum possible capacity (see figure 3).

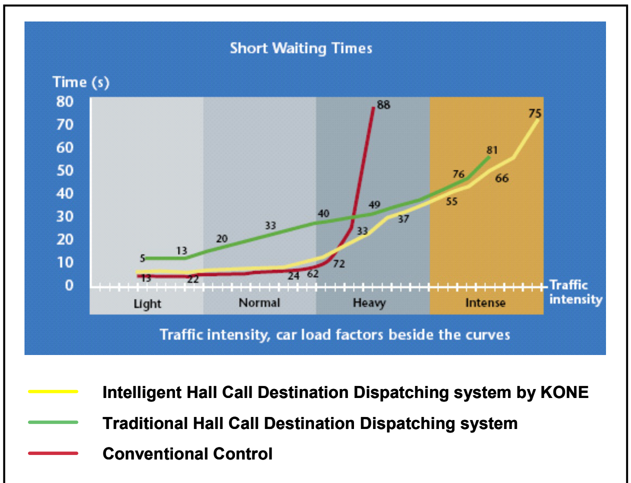

Figure 3. The Intelligent Hall Call Destination Dispatching system can provide the shortest waiting times and the maximum handling Capacity when needed (KONE Corporation).

The capacity of the Intelligent Hall Call Dispatching system is nearly as big as that of a conventional Double Deck system, which practically made the Double Deck system obsolete, due to the difference in investment costs. The exception is the Double Deck Shuttle. Shuttle situations cannot be boosted, as the number of stops cannot be reduced.

Introducing Intelligent Hall Call Dispatching systems on Double Deck arrangements provided similar capacity improvements to the Double Deck and revived these systems. The first such systems are now being installed by KONE in Projects such as the Broadgate Tower in London and Capital Plaza in Abu Dhabi.

The effect of Hall Call Destination Dispatching on the height of the building

With conventional control systems, the number of stops in a zone was usually kept to 10-20 floors in an office building. As the number of stops is reduced by the Hall Call Destination Dispatching system, and as the capacity is increased, the zone length can be longer than with conventional control systems. Zones using Hall Call Destination Dispatching can be increased up to about 1.4 times the length of zones using conventional control systems. This will allow the two-stacked office buildings arrangement to go up to about 170 floors, using Double Deck with Hall Call Destination Dispatching (also called Double Deck Destination or DDD) and Double Deck shuttles from Ground to the Sky-lobby. Figure 4 shows the building stacking diagrams with Hall Call Destination dispatching systems.

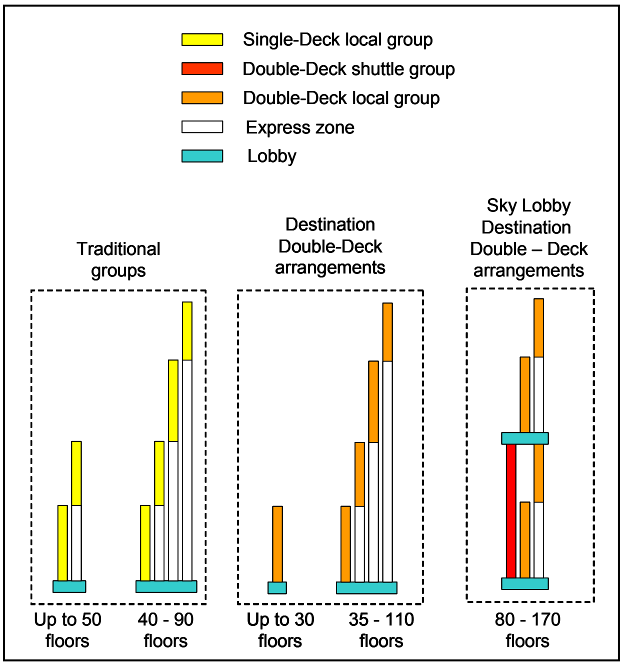

Figure 4. Building stacking diagrams with Hall Call Destination Dispatching systems (KONE Corporation).

This however still does not solve the problems mentioned earlier for the few full travel elevators, which now reach critical heights (fire operation use, service and goods).

Comparison between the different control systems

Let us assume an office building with a 4800 people and 52 floors above grade. With single deck elevators and conventional control the building would need 3 zones, each having an eight-car group, a total of 24 elevators.

With Hall Call Destination Dispatch Control this same building would need 3 zones, each having a six-car group, a total of 18 elevators. With Hall Call Destination Dispatch one can usually see a decrease of about 20 – 25% in the number of elevators compared to conventional elevators. This leads to a reduction in investment of about 20% compared to the arrangement using conventional control, while the increase in rental space (6 hoistways) also increases return on investment dramatically. The current rapid increased in demand for

Hall Call Destination Dispatch is easy to understand.

With Double Deck elevators using conventional control the building will now need 2 zones, each with eight elevators. In total one will need 16 double deck elevators. This is a reduction of about 33% compared to the original number of elevators used with the conventional single deck arrangement, but only 11% compared to the Single Deck system with Hall Call Destination Dispatch. Even if this arrangement frees up two more hoistways, the initial investment is clearly too high to make conventional double deck attractive, and it is therefore not strange that double deck more or less disappeared after the introduction of Hall Call Destination Dispatching systems.

With Double Deck using Intelligent Hall Call Destination Dispatching the building will still need two zones, however one zone will now need 7 elevators, while the other will need only 6, a total of only 13 double deck elevators.

This is a reduction of 45% compared to conventional single deck. The investment is about 10-30% higher than for conventional single deck, but the increase in rental area (about 11 hoistways) gives more than satisfactory return on investment. Compared to Single Deck with Hall Call Destination Dispatch, the investment is about 30-50% higher, but the savings of the extra 5 hoistways may make this arrangement attractive. Several projects, less than 60 stories, using DDD are being planned in London where rental rates are the highest in the world.

Energy consumption of elevators

DC motors were used in elevators in the early periods, as they were easy to control. Speed was a direct function of the Voltage, while Torque was a direct function of the Current. Wormgears were introduced to reduce the motor size while they provided smooth and rather noiseless transmission. A generator provided the early power to the elevator. This system is well known as the geared Ward Leonard Drive system.

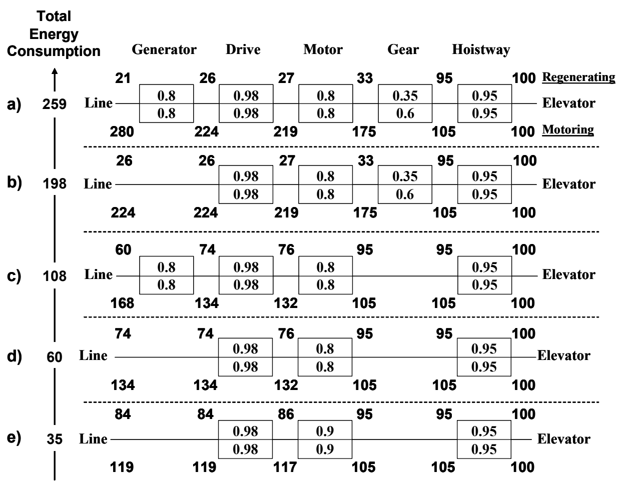

Figure 5. Comparison between the different drive systems on the market (KONE Corporation).

Figure 5 shows the energy train for the different Drive systems, and also provides an easy way to compare the different drive systems.

Figure 5 does not include the energy consumed by items such as lighting, fans, doors, brakes and energy used by the control systems.

When motoring more energy is needed when proceeding through the energy chain.

$$P_{next} = P_{previous} / \eta \qquad (1)$$

When a heavy car is returned to the ground floor the motor works as a generator and energy can be regenerated. KONE's Modulated Line Bridge (MLB) will return regenerated energy back to the line with very little distortion, and the returned energy is often cleaner than the energy coming from the line. Regeneration starts being attractive when the product of the rated load (in kg) and the speed (in m/s) exceeds values of 3500 kgm/s. When regenerating some energy is lost and less energy is returned when proceeding through the energy chain.

$$P_{next} = P_{previous} \cdot \eta \qquad (2)$$

Figure 5a is that of a geared Ward Leonard system. If the elevator itself needs a hundred energy units to move the load, the line will need to supply 280 energy units while motoring, while 21 energy units are returned when regenerating to the line, if regeneration is used. The total consumption is therefore 259 energy units (=280-21). When regenerated energy is destroyed in resistors, the drive efficiency is zero at regeneration, and the regenerated energy is zero.

Figure 5b shows the energy chain for modern geared applications. The total energy consumption for a similar size and speed unit will be 198 energy units (224 for motoring, minus 26 for regeneration) or 76 % of the energy consumption of a Ward Leonard system.

Figure 5c shows the energy consumption chain of a Ward Leonard gearless application, 108 energy units.

Figure 5d shows the energy chain for high speed asynchronous gearless and DC gearless. This figure is also valid for low speed Permanent Magnet Synchronous Motor elevators, as used in many of the Machine Room Less applications. Regeneration starts being very efficient and energy consumption is only 60 energy units.

Figure 5e shows the energy consumption chain for high-speed Permanent Magnet Synchronous Motor applications. Many of these machines already have Motor efficiencies clearly above 90%, saving even more than indicated here. These Ultimate Drive chains have energy consumption values of less than 35 energy units.

When considering energy consumption of elevators, the industry is now reaching a point where further reduction in energy consumption will require more focus on extremely efficient drives with low loss electrical components, even higher efficiency motors, and better aerodynamics of cars and more efficient roping systems.

The focus has now also shifted to the other energy used by the elevator, on items such as lighting, fans, doors, brakes and energy used by the elevator control systems. LED lighting and switching off lights in idle conditions are the latest attempts to decrease the elevator energy footprint to levels below the values found nowadays. Zero energy solutions or even energy producing solutions are already available, when elevators are combined with solar panels.

The energy consumed by an elevator is used to lift passengers to higher locations (potential energy). This is done at a certain speed (kinetic energy). With smarter control systems fewer elevators can be used. All our simulation studies however show that changes in the number of elevators do not dramatically change the hoisting energy consumed by elevators. The most important benefits in using less elevators is the reduced energy for the other elements such as lighting, fans, doors, brakes and energy used by the elevator control systems.

Simulations performed by Dr. Marja-Liisa Siikonen from KONE for the ABN-AMRO Tower in Sydney have shown that a Ward Leonard gearless system would consume no less than 8% of the total energy consumption of this office building.

With Asynchronous Gearless this value would reduce to approximately 4% of the total energy consumption.

With the KONE EcoDisc Permanent Magnet Synchronous Motor technology and modern energy saving features the elevator energy consumption is even less than 2 % of the total building energy consumption.

Similar tends can be found from the energy trains shown in figure 5.

Conclusion

Modern Control Algorithms such as Intelligent Hall Call Destination Dispatching systems have had a remarkable impact on the core size needed and have raised the possible building height for two stacked buildings to a height of no less than 170 floors.

If buildings need to go higher than this a third stacked building will be needed. Even though present elevator rope technology will allow travels up to 200 floors, these elevators can hardly be considered ecologically friendly anymore due to the exponentially increasing rope weight and consequently the increased energy needed to move all this mass (increased kinetic energy). Increased height will also require special attention to handle rope sway. It might therefore be wise to avoid full travel elevators until technology overcoming the above mentioned hurdles have been introduced.

Energy consumption needed to hoist passengers and loads has dramatically reduced over the past 20 years and with the introduction of Permanent Magnet Synchronous Motor technology we are very close to the "final optimum" solution. Minimizing energy consumption will get increasingly difficult as the elevator industry reaches efficiencies close to unity. The focus in energy reduction will now shift to reduced energy consumption of the other energy consuming elements, such as lighting, fans, doors, brakes and energy used by the elevator and group control systems.

Zero energy elevators or energy producing elevators are already possible if they are combined with energy capturing technologies such as solar panels.