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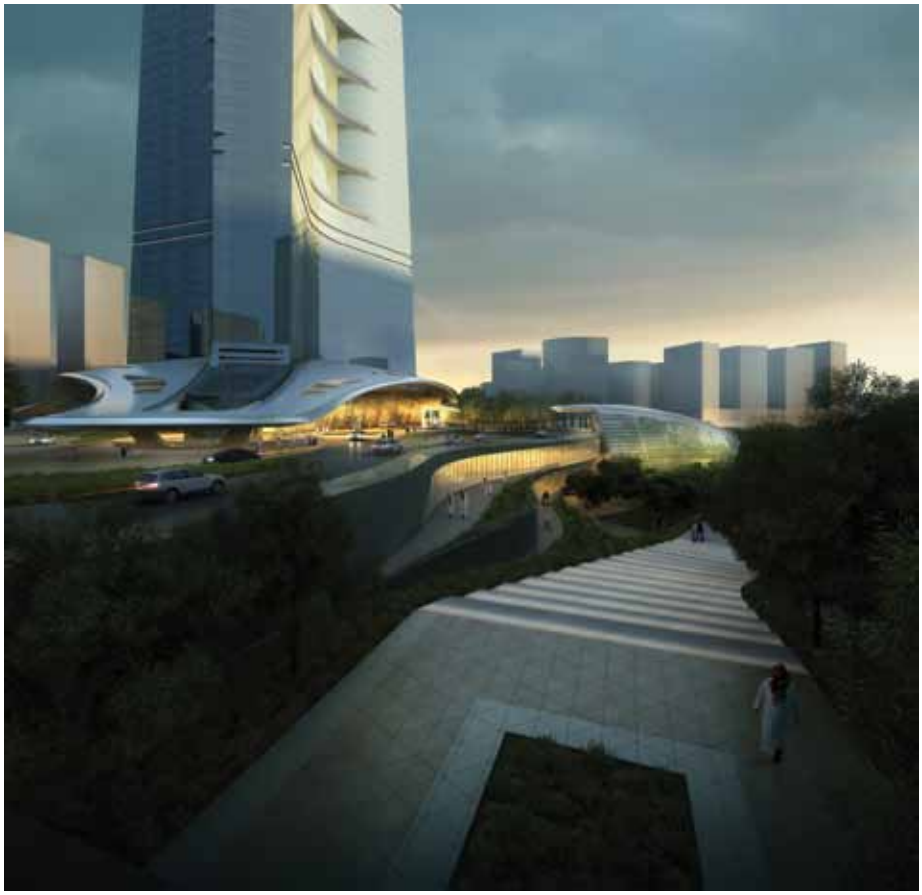
Elevator Designs for the Kingdom Tower

James Fortune, Partner, *Fortune Shepler Saling Inc. Elevator Consulting*

When it is completed in 2018, the mixed-use Kingdom Tower will become the new World's Tallest Tower. It will contain multiple, stacked mixed-use population zones, including subterranean parking, building entry/amenity/ retail floors, office zone floors, hotel levels, serviced apartment floors, residential zones 1-6, and two roof-top Observatory/Sky Terrace Levels, served by double deck elevators. Each of these zones will be served by their own sets of local and express high speed sky lobby shuttle lifts. The project will be equipped with 36 gearless and 22 machine-room-less (MRL) elevators and eight escalators serving the estimated 4,000-5,250 tenants/occupants. The elevator groups will be provided with the most advanced, all-digital destination dispatching, motor, and motion controls. Lift safety designs will include lifeboat evacuation capabilities, seismic and high wind designs, world class lift car ride qualities, and high car pressure (windage) mitigations.



Elevator Design Considerations

The new multi-use Kingdom Tower will contain the following key occupancies, in ascending order:

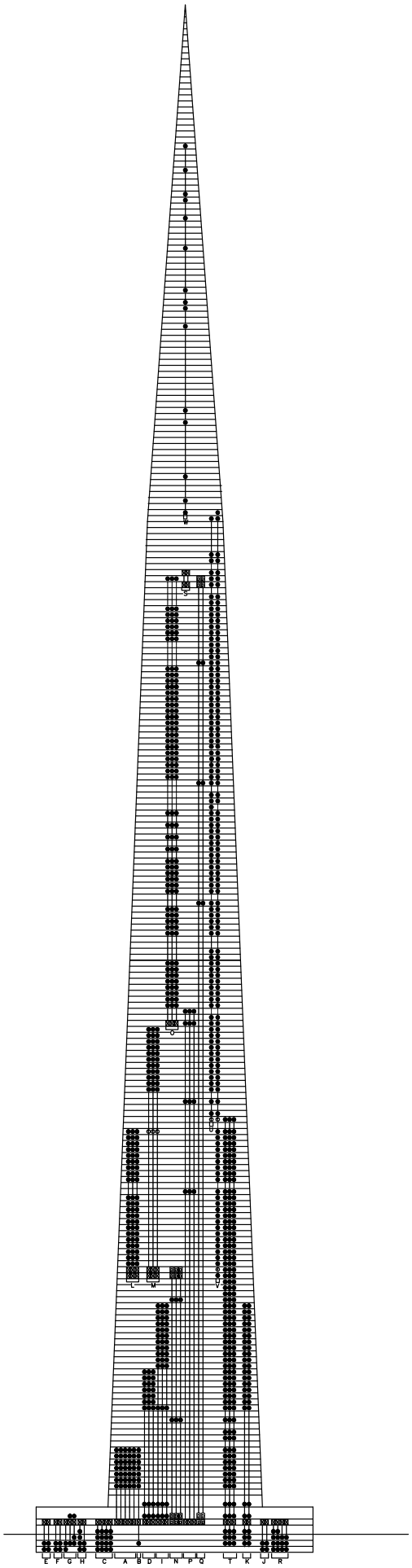
- Two levels of subterranean parking for about 2,205 automobiles that are to be served by dedicated office, hotel/ amenity/serviced apartment, and residential parking shuttle elevators
- Two levels of main floor entry points for the office, hotel, serviced apartment, residential, observatory, and hotel amenity (ballroom, meeting rooms, restaurants, etc.) floors. These levels are to be served by the various local and sky lobby shuttle elevators and escalators.
- A seven story office portion containing about 22,500m^2 of diversified tenancy types.
- A 200 room, luxury hotel located on seven levels.
- A 121 unit serviced apartment zone located above the hotel floors on 11 levels
- Six zones of dedicated residential units with about 439 units containing one, two, three, and four bedrooms, sub penthouse, penthouse and super penthouse (royal) suites.
- Building top observatory/restaurant viewing decks (the world's highest public viewing area at 630m).
- Communications/High Definition TV spire (service to top floor level 230 located at 922m)

Because of the extreme building heights and required elevator distances, the best way to provide elevator services to the various building segments is the use of dedicated, multi zone local and express elevators, plus sky lobby shuttles and inter zone upper transfer floors. We have also separated each type of traffic by zone and function, and provided multiple vertical transportation (VT) equipment cores, so that the various tenants, visitors, employees, and service requirements are separated from one another, while permitting their own private building entrance and exit points. The use of multiple sky lobby and transfer floors makes the building cores more efficient, as many of the local elevator cores can then be vertically stacked on top of one another.

The midpoint transfer floors are necessary for the dedicated fire/service/transformer/

Opposite: Rendering of the Kingdom Tower podium.
Source: Adrian Smith + Gordon Gill Architecture

Right: Kingdom Tower elevator stacking diagram.
Source: Fortune Shepler Saling Inc. Elevator Consulting



medical emergency elevators, because the present state-of-the-art maximum practical vertical height for high speed elevators – single deck or double deck and passenger or service elevators – is about 550-600m. (The highest present elevator rise is 504m in the Burj Khalifa Tower.)

The elevators have been designed to incorporate state-of-the-art, cutting edge technologies such as "Lifeboat" emergency evacuations, destination dispatching with integrated building security lobby turnstiles, and green LEED technologies. However, the present VT equipment designs utilize proven, present day elevator technologies that have previously been provided in some of the world's existing tallest towers, including Burj Khalifa, Taipei 101, Shanghai Tower, and the Ping An Insurance Tower. The Kingdom Tower VT Equipment Tendering Construction Documents were set up to encourage competitive bidding. At the end of the Lift Tendering Process, KONE Elevator Company was awarded the VT equipment contract and installation.

Office Portion

The seven story office floors are to be located on top of a four-level entry, retail, and hotel amenity complex. Based upon the projected 22,500m^2 GFA, that the total office population could be in the 1,900 person range. Based on these projections, a group of five single deck passenger elevators would be sufficient to meet the World Class "A" office building tenant vertical transport requirements.

The 21,725m^2 of net rentable area indicates that at least one dedicated service elevator should be provided for office tenants. The following service elevator selection design criteria standards apply:

Hotel Spaces

The 200-room luxury hotel is to be located above the office floors on levels 20-26. The hotel will be served by a three-car group of guest passenger elevators shuttling between the 1st level entry/reception floor, the 2nd hotel restaurants floor, the 4th level hotel spa, and guest room levels 20-26.

Service Apartment Spaces

The 121 serviced apartments will be located above the hotel and are to occupy tower levels 27-37. They are designed to be rented to short term expatriate workers, and will also serve as overfill hotel rooms during peak periods. The serviced apartments' three-passenger-elevator group will share the 1st and 2nd level entry/reception areas with the hotel guests, stop at the 20th floor hotel Executive Lounge, and then run express to the serviced apartments levels 27-37.

The hotel and serviced apartment floors are to be served by a combined group of two dedicated service elevators with stops at levels B2 & B1, B1M, 1 & 2, 4 (spa), 20 (Executive Lounge/Back-of-House and Marshalling Area), and guest room floors 21-37.

Residential Spaces

The remainder of the Kingdom Tower is to be devoted to six groups of residential units. The Group 1 residential portion is to contain 21 levels with 159 units, and will be served by three, top/up local passenger elevators operating between the 42nd sky lobby and apartment floors 44-55 and 58-66.

The Group 2 residential portion is to be provided with 61 units, located on levels 73-83 (11 floors), and is to be served by three, top/up local passenger elevators, operating from the 43rd floor sky lobby with a Group 2 to 1 transfer floor located at level 66.

The Group 1 and Group 2 residential local apartment zones are to be served by a three-car passenger, double deck sky lobby shuttle group, with express service between levels 1, 2, 42 (SL), and 43 (SL). By utilizing double deck sky lobby shuttles, the number of shuttles required are reduced, while providing segregated, exclusive entry/exit floors for the Group 1 and Group 2 apartment residents.

The Group 3, Group 4, Group 5, and Group 6 residential units are to be served by a combined three-car local passenger elevator zone. The Group 3 residential portion is to contain 40 apartment units located on levels 87-94. The Group 4 residential portion is to contain 58 apartments located on levels 99-103 and 106-120. The Group 5 residential portions will contain 90 units located on levels 125 - 143. And the Group 6 residential portions will have seven units located on levels 148 - 154.

The three elevator combined local lifts will be dispatched from the 84th floor sky lobby, with a load of 1,350kg at a speed of 7.0 M/S, and stops at levels 84 (SL), 87-94, 99-103, 106-120, 125-154 and restricted/special service to the observatory at level 158.

The three express shuttle lifts are to provide sky lobby service to the local Group 3-6 residents, with a load of 1,350kg at a speed of 9.0M/S, and stops at levels 1 (entry/exit) and 84 (SL).

Service/Firefighter/Medical Emergency/ Goods Lifts

In order to meet the International Building Code requirement, as seen in Table 1, to have at least one elevator serve every building level for firefighters and medical emergency service, the tower will be provided with three separate groups of single deck, dedicated service/firefighter/medical emergency high-speed elevators. Because of the extreme vertical distance, these firefighter/service elevators must be divided into a low rise group (three units), a high-rise group (one unit) and a super penthouse group (one double deck unit). When required, inter-Group 6 transfers would also be possible at levels 154 – 158 onto the top deck of lifts S3 and S2 and then transfers between elevators S3 and S2 (upper decks) at level 43, if OB1 and OB2 are out of service.

Number of Service Elevators	Net Rentable Area Increments (Sq. M.)
1 combination passenger/service	Less than 20,000
1	Greater than 20,000-25,000
1-2	Greater than 25,000-45,000
2	Greater than 45,000-55,000

Table 1: Service elevator selection design criteria standards. Source: Adrian Smith + Gordon Gill Architecture

Opposite: Observatory rendering.
Source: Adrian Smith + Gordon Gill Architecture

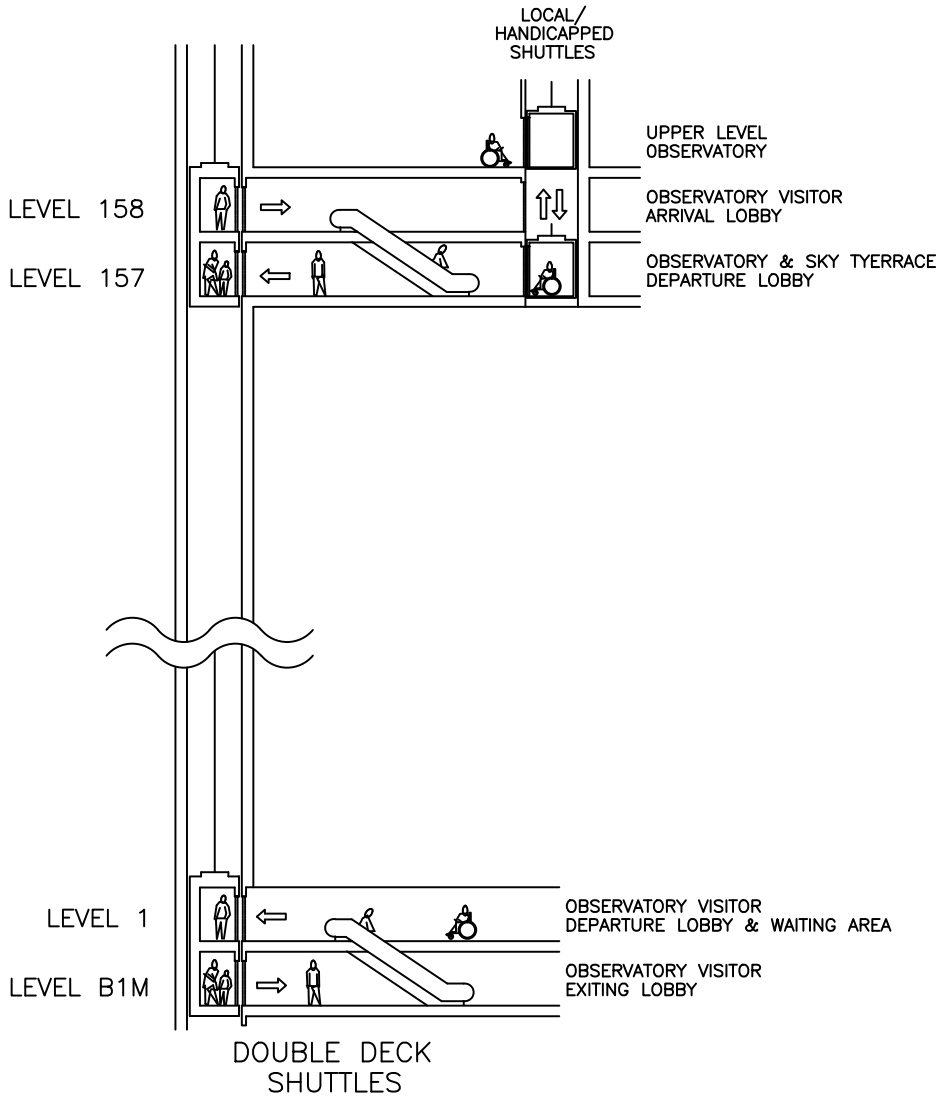
Bottom: Kingdom Tower double deck observation loading scheme. Source: Fortune Shepler Saling Inc. Elevator Consulting

"Because of the extreme building heights and required elevator distances, the best way to provide elevator services to the various building segments is the use of dedicated, multi zone local and express elevators, plus sky lobby shuttles and inter zone upper transfer floors."

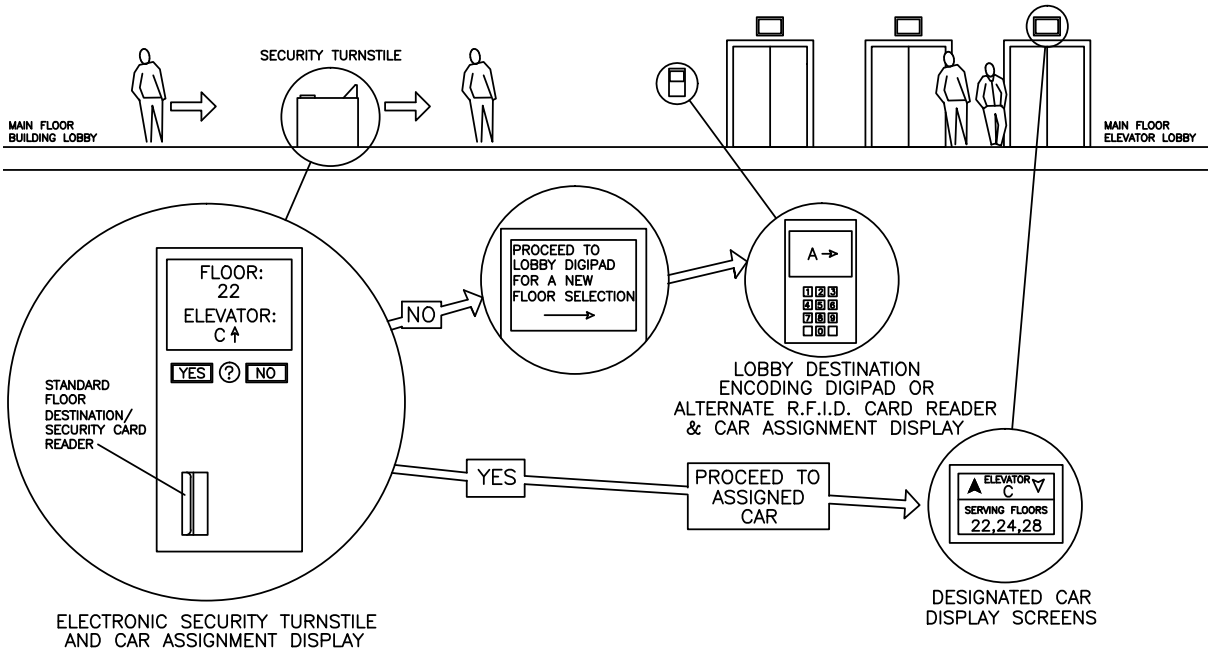
These elevators will normally be utilized for residential service functions to Groups 1 - 6, such as maids and cleaning crew movements, tenant deliveries, move-ins/outs, tenant unit fit outs/improvements, and transporting repair/support personnel. These cars will also be available for safe lift (transformer core) replacements, the observation/Sky Terrace 157th level and the 159th upper observatory floor replenishments, firefighter/evacuation service, any required hotel (food, service/maids) residential service deliveries, and employee shift change transfers between the B2 loading dock and the upper floor marshalling areas.

Observatory Portion

The world's tallest observatory/Sky Terrace floor is to be located at level 157 (630m), and the upper observatory level 159 (638m). These floors are to be served by two express, double deck, high speed shuttle elevators. Because of the extreme loads (1,600kg at 10.0M/S) and long journeys, the elevators are to be equipped with special KONE "UltraRope" carbon-fiber synthetic hoist ropes. Large observatory visitor queuing areas are to be located away from the



KINGDOM TOWER
OB1 & OB2 DOUBLE DECK LOADING / UNLOADING SCHEME



Top: Call destination dispatch encoding operation with security interface. Source: Fortune Shepler Saling Inc. Elevator Consulting

Opposite Top: Up peak call destination dispatch encoding operation. Source: Fortune Shepler Saling Inc. Elevator Consulting

Opposite Bottom: Future Call Destination Dispatch Encoding Operation. Source: Fortune Shepler Saling Inc. Elevator Consulting

main tower building entry floors at level 1 for loading the arriving visitors on the top deck of the elevator, while simultaneously unloading of the departing passengers occurs at level B1 from the bottom deck.

It is envisioned that the OB1 and OB2 decks will load and unload simultaneously. Local transfers between Observatory Levels 157 and 159 will be available for handicapped persons by using two 1,350kg /1.75M/S local passenger lifts.

Subterranean Parking Service

The office tenants, hotel guests, serviced apartment guests, and residential tenants are to be provided with separate sets of parking shuttle passenger elevators and ballroom escalators.

Destination Elevator Dispatching and Integrated Building Security

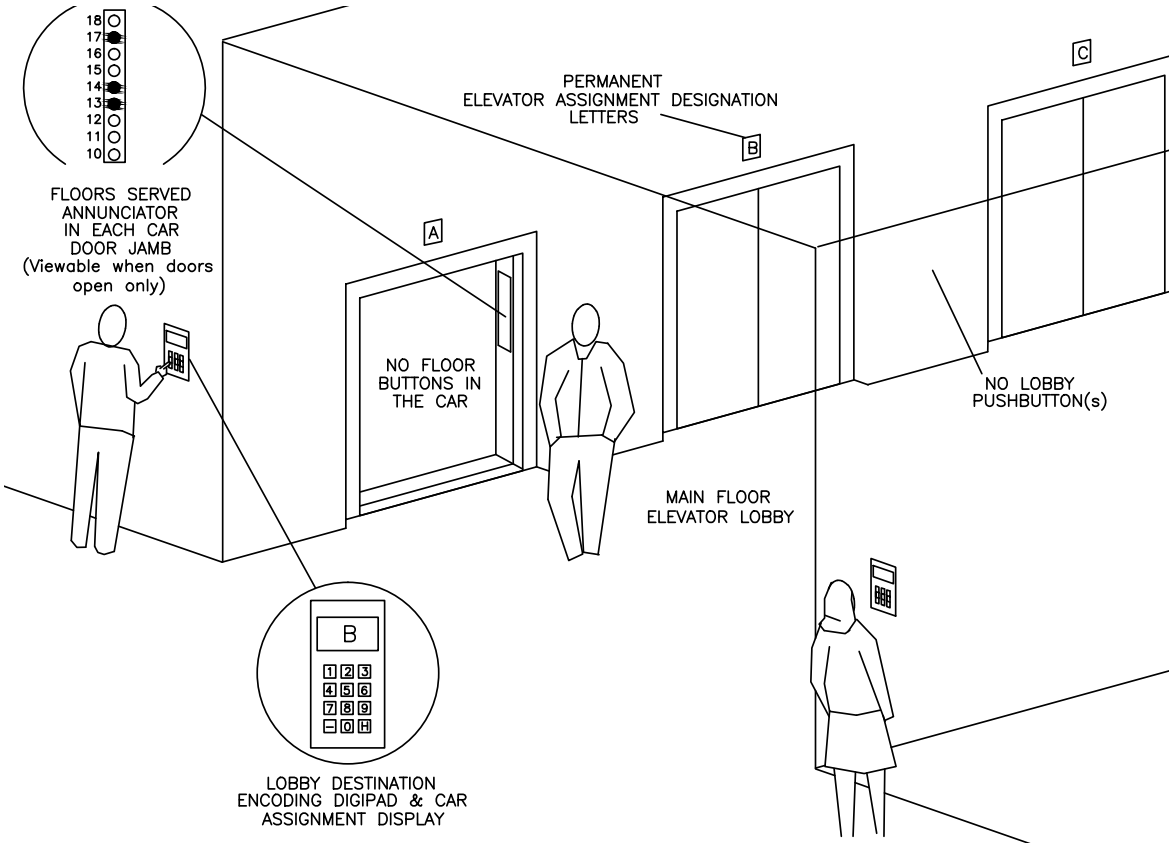
The latest elevator designs for mega high-rise towers are also integrating the office building entry floor lobby security turnstiles with the elevator destination dispatching strategies so that building tenant and guest security cards can access both systems simultaneously. It is possible to devise a similar system for the residential zone tenants – particularly the Group 6 VIPs – to provide them with hierarchical modes of selective dispatching, if so desired.

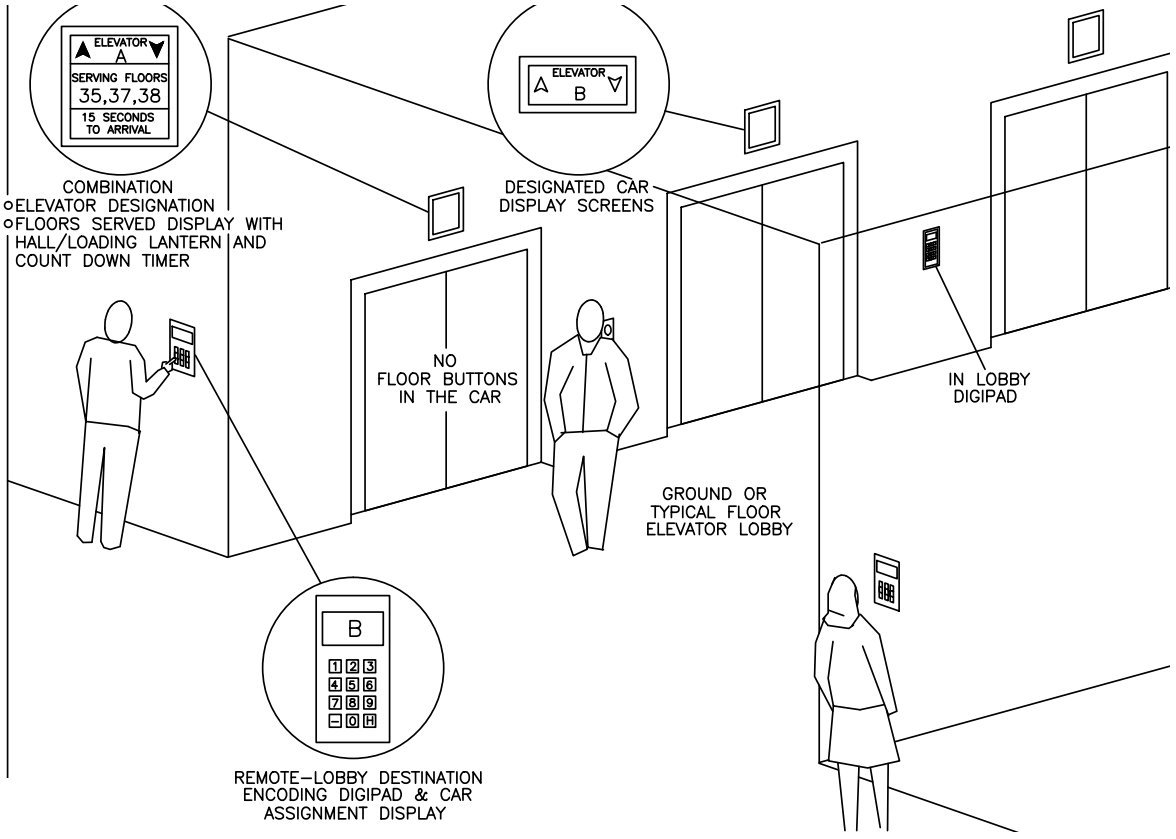
Emergency Tower Evacuations Via Elevators

Many modern high-rise towers are presently being designed with "Lifeboat" Phase 3 Firefighter Elevator Evacuation capabilities on selected group lifts. The maximum time to completely evacuate a building's tenants and visitors via the emergency exit stairs and elevators has not been set by any building codes. However, an appropriate model has generally been established at 1/2 to 2/3rds of the building fire rating (2.0 hours multiplied by 50% = 60 minutes; 2.0 hours multiplied by 66% = 80 minutes), or less than the time it took for One World Trade Center to collapse after the September 11, 2001 airplane impact (102 minutes). (Reportedly Two World Trade Center only lasted 56 minutes before it collapsed.) A time of 60 minutes or less has been selected for ideal evacuation utilizing the Kingdom Tower Lifeboat Lifts.

Building Area of Refuge (AOR) floors, as required in the Middle East, are generally located roughly every 15-20 floors on vertical centers, and placed so that building tenants can use the emergency stairs to access these "holding" floors. It is assumed that evacuating tenants can walk up about five to 15 floors and down about 15 to 20 floors to reach a nearby refuge floor. It is also becoming standard practice to have the building emergency evacuations stairs recycle at each refuge floor in order to permit walking tenants to rest at the refuge floors before re-entering the exit stairs to continue their trip.

Some of the psychological and physiological assumptions used for the Kingdom Tower Lifeboat Evacuation study – and that would likely prevail during an actual building emergency – are listed below.


18
17
16
15
14
13
12
11
10
FLOORS SERVED
ANNUNCIATOR
IN EACH CAR
DOOR JAMB
(Viewable when doors
open only)
PERMANENT
ELEVATOR ASSIGNMENT DESIGNATION
LETTERS
A
B
C
NO FLOOR
BUTTONS IN
THE CAR
NO LOBBY
PUSHBUTTON(s)
MAIN FLOOR
ELEVATOR LOBBY
B
1 2 3
4 5 6
7 8 9
– 0 H
LOBBY DESTINATION
ENCODING DIGIPAD & CAR
ASSIGNMENT DISPLAY


ELEVATOR
A
SERVING FLOORS
35,37,38
15 SECONDS
TO ARRIVAL
COMBINATION
ELEVATOR DESIGNATION
FLOORS SERVED DISPLAY WITH
HALL/LOADING LANTERN AND
COUNT DOWN TIMER
ELEVATOR
A B
DESIGNATED CAR
DISPLAY SCREENS
NO
FLOOR BUTTONS
IN THE CAR
IN LOBBY
DIGIPAD
GROUND OR
TYPICAL FLOOR
ELEVATOR LOBBY
B
1 2 3
4 5 6
7 8 9
– 0 H
REMOTE–LOBBY DESTINATION
ENCODING DIGIPAD & CAR
ASSIGNMENT DISPLAY

Bottom: Kingdom Tower rendering.
Source: Jeddah Economic Company

- It is extremely difficult if not impossible, to completely evacuate any 150 – 200 story building via the exit stairs during the allotted time.
- There would typically be a number of elderly, infirm, and handicapped persons, (an estimated 1-2% of the population), particularly those located in the residential zones, who would not be inclined or agile enough to use the exit stairs to walk down 100 – 150 floors.
- Most present building codes have been designed to address building fire emergencies and evacuations only via the exit stairs, or to direct tenants to a refuge area where they are then ordered to wait for further instructions.
- After the events of September 11, building tenants will likely not be content to wait in the affected building or accumulate on refuge floors and wait for further instructions. Instead they would welcome the opportunity to be safely and quickly evacuated from the refuge floors via the Lifeboat Elevators.
- Selected elevators should be designed and equipped with special Lifeboat Operations so they can be utilized in the building evacuations, probably with on board human monitors or firefighters running the designated lifts on attendant service and manually controlling the car door opening and closing operations. Other hall monitors would likely be stationed at each upper refuge floor in assigned muster stations in order to assist with crowd control and tenant

Duty	Levels Served	Net Rentable Area (Sq. M.)	Floor Loading (Sq. M./ Person)	Projected Zone Population (Persons)	Individual Car Load (Persons) (+/-)	Round Trip Time (Seconds)	Number of Elevators	5-Minute Evacuation Peak Elevatoring		Time to Empty the Zone (Minutes)	Meets the FCL Design Criteria?
								Average Interval (Seconds)	Group Handling Capacity (Persons/ Percentage)		
Residential Group 6 & Residential Group 7, Combined – ES1-ES3											
1350 KG @ 3.5 MPS	144 & 124	–	–	108 x 100% = 108	16.0	110.0	2	55.0	87/80.8%	6.2	Yes
							3	36.7	131/121.2%	4.1	Yes
Residential Groups 7 & 6, Executive Shuttles Group 5 and Observatory – OB1 & OB2											
1350 KG/1350 KG / 1800 KG* @ 10 MPS	124 & 1	–	–	771 x 100% = 771	22*	186.8	1	186.8	35/4.6%	110.1	No
							2	93.4	71/9.2%	54.3	Yes
Residential Groups 2, 3 and 4 Combined – R4-R6											
1600 KG @ 9 MPS	85 & 1	–	–	757 x 78% = 594	19	153.3	2	76.6	74/12.5%	40.1	Yes
							3	51.1	112/18.8%	26.5	Yes
Residential Group 1 & Serviced Apartment Tenants Combined – RS1-3											
1600 KG/1600 KG* @ 6 MPS	38 & 1	–	–	735 x 50% = 368	19	123	2	61.5	93/25.2%	19.7	Yes
							3	41	139/37.8%	13.2	Yes
Hotel Guests – HS1 & HS2											
2000 KG @ 5 MPS	18 & 1	–	–	318 X 25% = 80	23	128.9	1	128.9	54/66.9%	7.4	No
							2	64.5	107/133.8%	3.7	Close

Table 2: Kingdom Tower Elevator Emergency Evacuation Traffic Analysis. Source: Fortune Shepler Saling Inc. Elevator Consulting

* Typically used for sky lobby shuttles

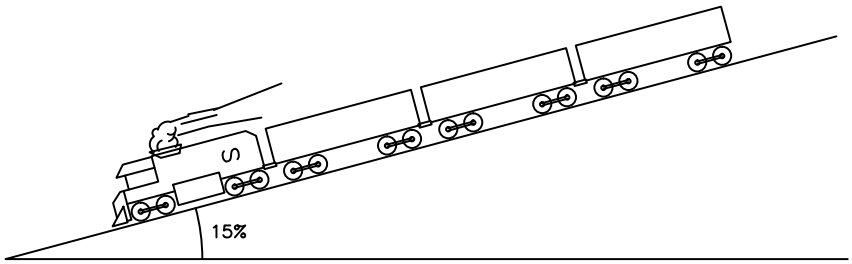
"In order to meet the International Building Code requirement to have at least one elevator serve every building level for firefighters and medical emergency service, the tower will be provided with three separate groups of single deck, dedicated service/ firefighter/medical emergency high-speed elevators."

queuing to expedite an orderly evacuation process.

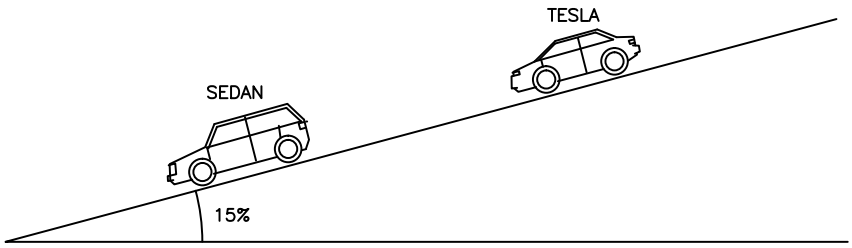
- The higher a tenant/guest/visitor is located in the tower during an emergency event, the less likely they are to utilize the exit stairs and the more likely to walk to a refuge floor, where they would no doubt welcome quick Elevator Lifeboat Evacuation operations.

What follows are the typical operations that have been specified in order for the designated special evacuation Lifeboat lifts to be operable:

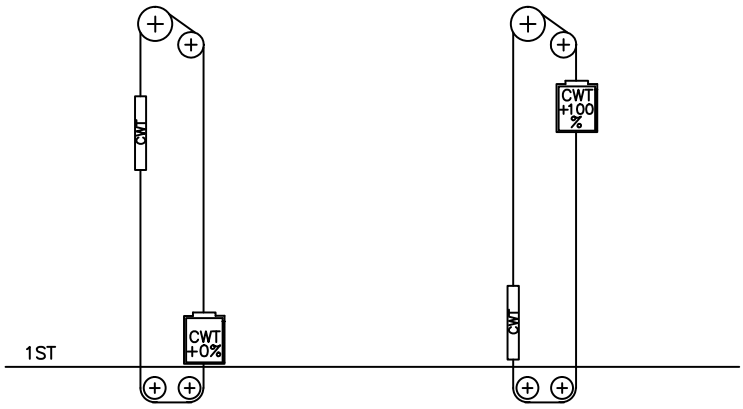
- Before double deck or triple deck elevators are to be used for Firefighters' Phase 2 Service or Lifeboat Phase 3 Evacuations, the lower deck(s) must be cleared and shut out of service. After "clearing," only the upper decks can be used for Phase 2 Firefighters' Service or Phase 3 Lifeboat Evacuation, as only one set of cab doors can be visually observed and controlled from the upper car by the single on board lift emergency attendant. It would be possible to utilize all decks for Lifeboat evacuations only if they were all equipped with attendant operations and inter-cab communications.
- All special lifts to be used for evacuations are to be equipped to operate continuously on the building emergency generator on standby power, in case normal power is lost.
- All special evacuation lifts are to be equipped with Phase 3 Operations, attendant service, and pre-assigned hoistway clearing operations (not required for fire induced evacuations), utilizing car-top CCTV cameras and lights and test runs before Lifeboat Operations begin.
- All special operation evacuation elevators are to be equipped with on board paging, firefighters' sound-powdered phone jacks, an intercom system, attendant operations (constant pressure door close and hall call bypass buttons), and refuge floor special arrival/loading lanterns and crowd detectors. The elevator



A DIESEL / ELECTRIC FREIGHT TRAIN GOING DOWN HILL IS REGENERATING ELECTRICAL POWER (CONVERTED TO HEAT) AND PROVIDING DYNAMIC BRAKING (HOLDS THE TRAIN BACK)



AN ELECTRIC OR HYBRID AUTOMOBILE GOING DOWN HILL IS REGENERATING POWER (RECHARGING THE ON BOARD BATTERIES) AND PROVIDING DYNAMIC BRAKING (HOLDS THE CAR BACK)



ELECTRIC ELEVATORS TRAVELING "EMPTY" IN THE UP DIRECTION OR "FULL" IN THE DOWN DIRECTION ARE REGENERATING ELECTRICAL POWER (FEEDBACK INTO THE BUILDING GRID) AND PROVIDING DYNAMIC BRAKING (HOLDS THE ELEVATOR BACK)

platforms must also be designed for ASME.A17.1 Elevator Code – 125% of the nominal car loads (capacity rating) – so the lifts cannot easily be overloaded and "stuck" (until someone gets off) by onrushing, panicked passengers. These proposed Kingdom Tower Lifeboat systems and emergency elevator evacuation operations closely parallel those specified by FS2 and installed by Otis Elevator Company on the selected Burj Khalifa Lifeboat Elevators.

Lifeboat capabilities and special operations have been added to the Kingdom Tower sky lobby shuttle elevators, the two observatory shuttle elevators, and main service elevators. Calculations show that by using these selected lifts in the Lifeboat evacuation mode, the various zone building populations can be completely emptied within four to 54 minutes.

Elevator Hoistway Venting and Stack Effect Mitigations

Since the adoption of the first elevator design codes, there have been provisions to provide the top of high-rise elevator shafts with hoistway venting directly to the outside air. The vents consist of about 3 square feet (0.3 square meters) of open area, with the intended purpose of venting hot smoke and gasses that may accumulate at the top of the elevator hoistway during a building or pit fire and to prevent a flashover "ball fire" from reigniting after the main building fire is extinguished.

With the development of modern elevators – equipped with car and counterweight roller guide shoes running on milled steel rails – the older greased and oiled solid guide shoes, sometimes running on wooden rails, were no longer used. The application of roller guides and steel rails dramatically reduced the accumulation of combustible materials in the elevator pits, which then eliminated the frequency of pit and hoistway fires, and therefore the need for hoistway vents.

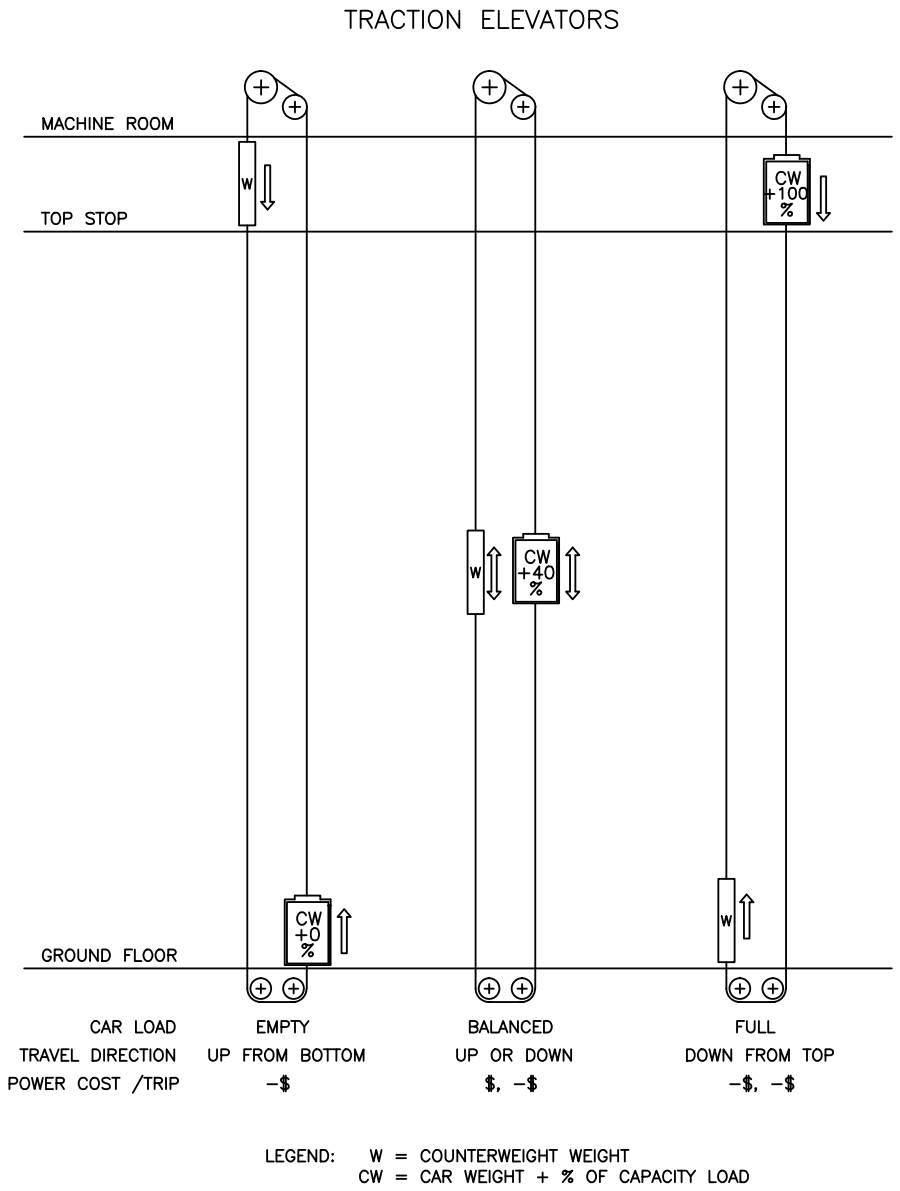
As tall building designs continued to evolve, the fully sealed and air-conditioned building became commonplace. The hoistway venting requirements did not change except when energy costs increased, necessitating the addition of motorized or spring-operated shutters added to the vents in order to minimize the loss of normal building heating and air conditioning.

Building "stack effect" normally occurs in high-rise buildings located in northern climates when the cold outside air entering the building at the ground floor(s) flows into the elevator shafts and escapes through the upper levels (often through the hoistway smoke vents) to outside air.

Some building codes permit the deletion of the hoistway smoke vents if the hoistways are fully sprinklered (usually not permitted in buildings provided with overnight sleeping quarters). Even though the Kingdom Tower is located in a desert climate, with summer temperatures approaching 120° F, it was estimated that due to the extreme building height, the outside temperature at the building top could be 15° F less than at the bottom. If the elevator hoistways were to be equipped with normal smoke vents, it was feared that a reverse stack effect could occur with anticipated outside building temperature variations, causing the building cooling to flow out of the building. Therefore, it was decided to not use any hoistway venting but instead provide each elevator hoistway

Opposite: Examples of electrical regeneration and dynamic braking. Source: Fortune Shepler Saling Inc. Elevator Consulting

Right: Elevator electrical regeneration and dynamic braking. Source: Fortune Shepler Saling Inc. Elevator Consulting



top with a building fire sprinkler head that is responsive to heat and smoke. The elevator machine rooms have similar sprinklers and are also to be equipped with shunt trip devices that prevent the sprinklers from being energized until electrical power is removed from the Lift hoist machines.

Elevator Designs Sustainability Features

Sustainable elevator designs require that the Kingdom Tower Lifts be provided with selected World Class "A" performance and group design criteria. These provisions may require slightly higher capital costs but often times result in reduced equipment, operational, and maintenance costs. Green elevators are designed to efficiently transport building tenants and visitors to and from their destinations within an optimal time. The proper lift design selections often result in increased tenant productivity, as reflected in reduced waiting times, faster call response, quicker floor-to-floor performance times, and hoist equipment dynamic braking, while using less energy to transport the passenger loads.

The following sustainable features were included in the elevator equipment designs and bid specifications:

All of the Tower's 58 elevators are to be equipped with the latest, high-tech, selected group demand destination dispatching, digital motor and motion controls, and World Class "A" floor-to-floor performances. The technology includes:

- Elevator Group destination dispatching – Passengers going to the same or contiguous floors are assigned to the same elevator and the elevators only "move" in response to registered hall and/or car call demands or assignments.
- Reduced average group waiting times and quicker times to destinations.
- All elevator hoist machines are to be equipped with permanent magnet, synchronous motors (PMSM) and ACV3F power conversion units and technologies.
- All lifts are to have regenerative operations and dynamic braking, i.e., they pump electrical power back into the building electric grid and hold the elevators back when running in an "overhauling" mode.
- Observatory passenger shuttles elevators OB1 & OB2 will have double deck duties of 1,600kg/1,600kg with speeds at 10.0 M/S, and are equipped with the most advanced "UltraRope" carbon-fiber hoist ropes (which reduce the required hoist motor sizes and electrical power demands).
- All elevator capacities and contract speeds were selected to provide World Class "A" designs and utilize various combinations of single deck and double deck lifts for local and sky lobby shuttles to serve the various life zones, stops, tenancy types, and building core designs.