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Carbon-Fiber Hoisting Technology

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The ability to build ever higher has always pushed available technologies to their limits, including elevator technology. Traditional elevators utilizing steel ropes are limited by how high they can travel, often requiring transfer floors for passengers to get to the top of high-rise buildings. Global population growth and increasing urbanization have meant solutions need to be found to build further upwards rather than increase urban sprawl. The development of carbon-fiber rope has doubled the potential height of future buildings, and this can be seen to good effect in the Kingdom Tower development in Jeddah. The superlight technology is also ideal for modernization projects, where it can reduce energy consumption and maintenance costs. Innovations like this are just one step towards a more sustainable – and more vertical – urban future.

Supertall and megatall buildings, previously looked upon as primarily prestige projects, have an ever-increasing relevance in a rapidly urbanizing world. As populations grow, more people increasingly live in cities – one estimation predicts that by 2050 there will be a global population of nine billion, 70% of which will live in an urban environment. To avoid the many issues associated with increasing urban sprawl, solutions need to be found to overcome the limitations of building upwards.

The Limitations of Steel – Keeping Buildings Down To Earth

One major restriction when building upwards has been the technological constraints of elevators. The conventional hoist elevators that have traditionally transported people to the top of the world's tallest buildings have had a practical travel limit of about 500 meters due to the weight of the steel ropes. Taller buildings mean longer and therefore heavier ropes: in a 500 meter elevator shaft, up to three quarters of the energy needed to move the elevator is just used transporting the ropes themselves. Increasing the shaft height beyond 500 meters begins to exponentially increase the number of ropes and the weight taken on each rope, causing reduced rope lifetime. At extreme ranges, the physical limit of rope strength is reached.

This limitation places a restriction on just how high buildings can be without requiring an unfeasible number of elevator transfer floors, or sky lobbies. In the past, with building heights relatively low and dispatching systems not yet having the benefit of microprocessors, the most effective way to manage high-rise people flow was to define elevator groups to serve all floors in specific areas of the building. As microprocessor control became available and building heights increased, the concept of zoning for elevator groups came into being. This allowed individual elevator groups to serve the lower part of the building, and other groups to serve the higher portions of the building. This is a very effective way of decreasing both waiting and travel time, and taking advantage of the increased speed available in elevators through advances in machinery and control systems.

As building heights increased further than a single shaft could serve, sky lobbies and transfer floors became more prevalent, adding time and complexity to traveling from the bottom floor to the top floors. Modern high-rise buildings are commonly structured with elevator groups serving all floors from ground to sky lobby, and shuttle elevators taking direct trips to the sky lobby for those traveling to destinations above it. Additional elevator groups then serve those floors, from the sky lobby upwards. To get to the top of a mile-high building using traditional steel ropes could mean as many as ten sky lobbies. This is prime building space that can't otherwise be used, not to mention being impractical, time-consuming, and frustrating for passengers.

As buildings get higher they are also more prone to swaying in high winds and storms, and this building motion is transferred to the elevator ropes. With traditional steel ropes the motion is amplified when the natural frequencies of the building and the elevator ropes are the same. This phenomena often requires elevator speed reductions, and in the worst case, complete elevator shutdown. Steel rope maintenance and replacement is also expensive, time consuming, and complicated. Steel ropes tend to stretch during the elevator's operational lifetime, meaning they require periodic adjustment, with full replacement necessary on average every seven years. Furthermore, the lifespan decreases as travel height increases. These time-consuming and costly processes cause huge disruption as elevators are taken out of service, impacting people flow throughout the building and, in the case of specialty elevators, reducing revenue from entertainment sectors.

Energy consumption also increases as weight increases, meaning higher costs and greater environmental impact. The moving parts of a single high-rise elevator with conventional steel ropes carrying 24 passengers can weigh up to 27,000 kg. This single elevator can consume up to 130,000 kWh of energy a year. Reducing the energy consumption by reducing weight has a direct impact on the bottom-line operating costs of the building.

People Flow Intelligence – The Smarter Way To Help People Flow

A building of Kingdom Tower's size can be looked upon as a form of vertical city, populated by thousands of people, each using an elevator on average six times a day. Intelligent state-of-the-art solutions are needed to keep these people moving smoothly, especially in times of peak traffic flow.

Kingdom Tower is equipped with suitably advanced technology: the latest people flow intelligence solutions. For some elevator banks, the traditional elevator buttons are gone, instead replaced with a destination control system, making upward travel

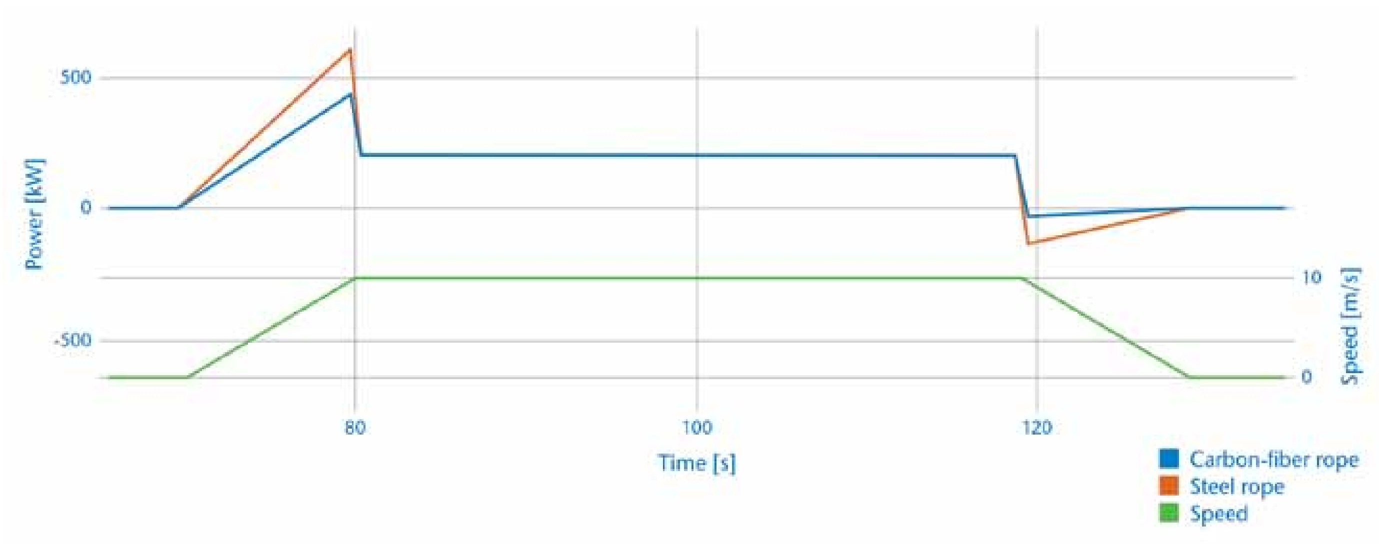
Right: Kone UltraRope. Source: KONE

smoother and less time consuming. Keypads in each elevator lobby allow passengers to enter their destination floor, meaning elevator use can be organized more efficiently. People travelling to the same floor can be grouped together into one elevator – shortening wait times, making the journey quicker with fewer stops, increasing handling capacity and available car space, and getting everyone to their desired destination much more energy-efficiently.

Information screens will deliver relevant information and entertainment, improving guidance and showing the next elevator stop, as well as having the potential to deliver news, weather, advertising, or building announcements. The screens can be centrally updated and controlled, making them an ideal way to direct people flow and keep building users informed.

A remote monitoring system will allow all the elevators and escalators to be monitored from one single location. The system provides an accurate real-time view of equipment status, demand, traffic performance, and availability using traffic displays and reports, helping to ensure elevators and escalators deliver the best possible performance at all times. Traffic history can be played back for security, event history, and legal purposes, with any deviation from normal operation logged instantly with an audible and visible alert to ensure quick attention. Any problems can therefore be reacted to faster, maintaining the best possible service in the building. The system also provides intelligent

Bottom: Peak power demand comparison between steel and carbon-fiber ropes in a high-rise elevator.
Source: KONE



access control, allowing users to be given personalized access to individual elevators, floors, or elevator groups, or changing access based on time or day.

Record-Breaking Elevators – and a Revolutionary Development

Like other megatall buildings, Kingdom Tower offers the challenge of how to organize elevators to provide smooth, safe people flow throughout the building. Individual groups of elevators are used to move people from various parking and pre-event locations to the building's main entrance floor. Depending on their desired destination, people move from these locations to individual elevator banks serving the office, hotel, or serviced-apartment portions of the building. This segmentation of elevator banks according to destination allows for efficient elevator usage, as well as segment specific dispatching and user-input methods. For example, the serviced apartments with longer-term tenants take advantage of destination control systems that may not be the best solution for hotel use.

A further challenge in such megatall structures is how to quickly and safely evacuate the building in case of emergency. Emergency evacuation strategy is a key component of all building design, but due to the height and number of people in future high-rise buildings, traditional strategies such as relying on staircases are no longer enough. Megatall buildings are now often equipped with occupant evacuation elevators, which are specific elevators that are programmed to move people from specified refuge floors to the building exits in a fast and safe manner. These elevators are controlled from a centralized location to ensure that the journey is safe throughout the evacuation process. This centralized control also allows coordination between first responders and building management, ensuring that emergency responders can focus clearly on the situation at hand and carry out the evacuation in an efficient manner.

Kingdom Tower is equipped with record-breaking elevator equipment, including the world's highest and fastest double-deck elevators, reaching speeds of more than 10 meters a second to travel up to the highest livable floor in the world very quickly. Because of their high-speeds, these elevators have been designed to take aerodynamic considerations into account. When an elevator car travels up or down inside the shaft, it causes turbulence in the surrounding air. This turbulence, particularly vortexes in the air current and drag, needs to be minimized in order to reduce the amount of energy consumed by the elevator. Minimizing turbulence also helps to reduce noise and vibrations in the elevator car. To counteract turbulence, air deflectors are fixed to the top and bottom of the car. When the elevator is traveling the deflectors reduce the air turbulence in both the car's leading and trailing edges, thus reducing the amount of energy required to move the car and improving the passenger experience inside the car.

In addition to these units, the building houses five additional double-deck units used for passenger, fire, service, and evacuation. Other highlights are an additional 50 machine room and machine room-less units, some reaching a speed of 9 m/s. There is a service elevator in the spire of the building, allowing for continual maintenance and management of the equipment, and the provision of mechanical services for the building. Eight escalators

“For some elevator banks, the traditional elevator buttons are gone, instead replaced with a destination control system, making upward travel smoother and less time consuming. Keypads in each elevator lobby allow passengers to enter their destination floor, meaning elevator use can be organized more efficiently. People travelling to the same floor can be grouped together into one elevator – shortening wait times and making the journey quicker with fewer stops.“

Steel Rope vs. Carbon-Fiber Rope			
	Traditional High-Strength Steel Ropes	**Carbon-Fiber Rope**	**Units**
Total Rope Weight	20,365	2,946	kg
Total Suspended Mass on Machine	46,340	29,320	kg
Nom Line Current	340	326	A
FL Peak Accel.	1,102	804	A
Main Fuse Size	3 x 500	3 x 400	A
Annual Energy Consumption	258,540	217,060	kWh
Travel Height: 634 meters, speed 10 m/s, capacity: 2 x 1,600 kg double deck			

Table 1: A comparison of steel rope and carbon-fiber rope. Source: KONE

serve various locations in the building, maximizing people flow to all segments in a smooth and coordinated manner.

A specific people flow challenge in Kingdom Tower is the observation deck elevators. To combat the challenge of moving massive amounts of people constantly from the entrance to the observation deck, the building’s record-breaking double-deck elevators travel an unprecedented height of 634 meters. These elevators are hoisted using UltraRope, a revolutionary new carbon-fiber elevator rope technology. The use of carbon-fiber rope on these elevators allows visitors to travel from the building’s entrance to the world’s highest observation deck in a single elevator ride. This development means better building security, faster cycle time of visitors, and a smoother journey for passengers.

Taking Megatalls to New Heights – Carbon-Fiber Ultrarope

UltraRope redefines what is possible in megatall buildings, allowing travel heights of up to one kilometer – twice the height possible with conventional hoisting technologies. This reduces the need for transfer floors, making it possible to build ever higher and opening up a world of possibilities in high-rise building design. The carbon-fiber rope has been designed to have a greater tensile strength than steel ropes, while only weighing one seventh as much. At its core are four tubes of carbon-fiber with a unique clear epoxy coating. This coating increases friction and reduces slippage, meaning no lubrication is required to maintain the ropes, enabling further reductions in environmental impact.

To get an elevator to Kingdom Tower’s observation deck using traditional technology would require a mind-boggling 21,000 kg of steel rope. A single elevator using carbon-fiber rope only requires about 3,100 kg of rope for the same distance. These weight savings equal a huge reduction in energy consumption: as much as 21%, as seen in Table 1. With an elevator travel height of 500 meters, carbon-fiber rope cuts the elevator’s total moving mass by 60% and reduces energy consumption by 15%. When travel heights increase, even greater reductions are possible: at 800 meters, carbon-fiber rope offers a 90% moving mass reduction and a 45% decrease in energy consumption.

Due to the reduction in moving mass, the peak current requirements during acceleration and deceleration are greatly reduced. This means a reduction in the main power supply needed to be dedicated to the elevator units – in a typical high-rise elevator, carbon-fiber ropes reduce the peak power and peak current demand from the mains by approximately 30%. In addition, there is a huge reduction in the size of the copper power wires required to feed the elevator drives. In ultra high-rises, this reduction in wire size results in large savings for the power infrastructure of the building.

Carbon-fiber rope reduces the full-load peak power demand. Shown in blue is the peak power demand of a steel rope high-rise elevator with a 3,100 kg load, travelling 490 meters at 10 meters a second. Replacing the steel rope with carbon-fiber rope reduces the peak power demand from 620 kW to 450 kW; the acceleration current drops by the same ratio.

An additional benefit of the reduction in moving mass allowed by carbon-fiber rope is on the building structure itself. The impact loads on the building structures are lower,

and the structural requirements of the machine room slab are greatly reduced. This results in savings and efficiency beyond just the elevator system.

Because carbon-fiber rope is very strong and highly resistant to wear and abrasion, it has an exceptionally long lifetime – at least twice that of conventional steel rope – with an expected average lifetime of 15 years. Maintenance costs and downtime are also significantly reduced, with no rope stretch due to carbon-fiber's solid structure and tensile strength, and fewer requirements for rope maintenance such as lubrication. Rope replacement is much less frequent due to the extended lifetime, and much faster to complete due to the reduced weight of carbon-fiber ropes compared to steel ropes. Elevator downtime due to sensitivity to building sway is almost eliminated as carbon-fiber ropes resonate at a completely different natural frequency to steel ropes. The natural frequency of carbon-fiber rope is higher than that of traditional building materials such as steel or concrete, which reduces the overlapping natural frequencies between the building and the elevator system. For any high-rise building, but particularly supertall and megatall buildings, this brings significant advantages in terms of being able to offer enhanced elevator service during windy and stormy conditions.

With the advances in carbon-fiber rope and other technological developments now allowing for much higher single shafts, sky lobbies are no longer a requirement, as buildings can be zoned for low-, medium-, and high-rise direct from the ground floors. This reduces the total number of elevators required, decreases the complexity of travel from point to point in the building, and increases the security of the building as the entry point to the elevator banks is controlled in one spot. The ability to zone in this way allows for more architectural freedom in the design of the building, transforming sky lobbies from a requirement into an architectural choice for megatall buildings.

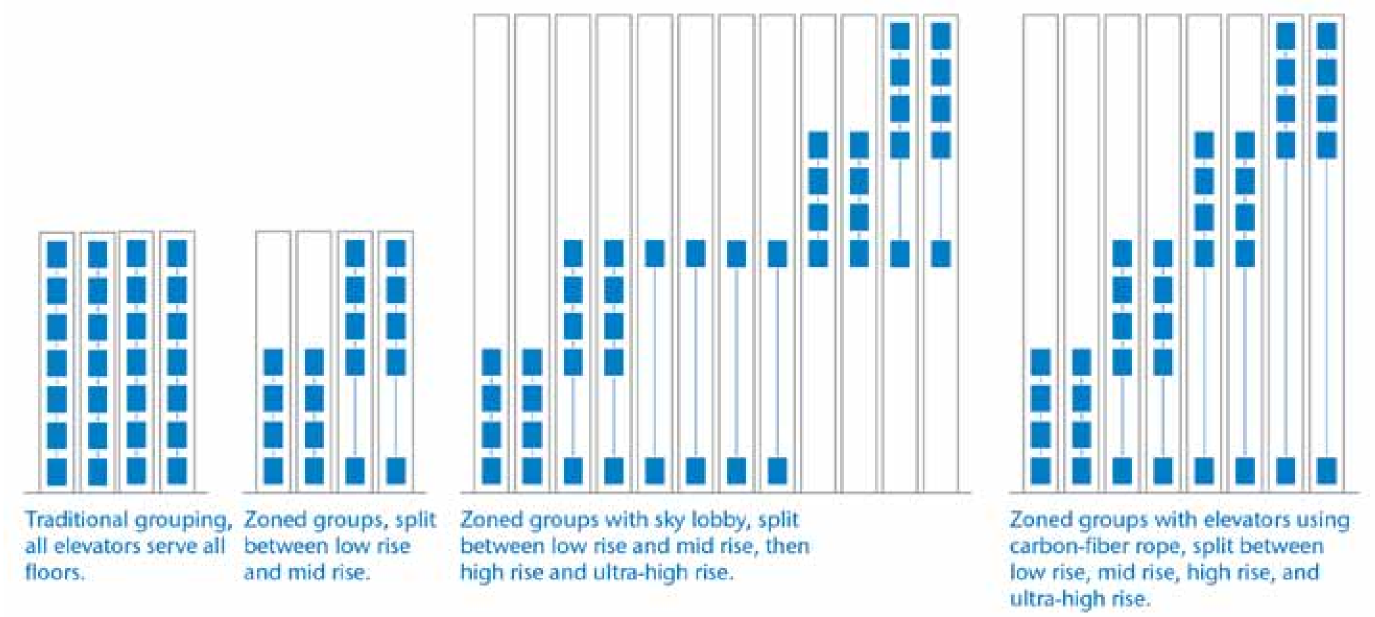
The benefits of carbon-fiber rope extend to passenger ride comfort, too: thanks to its light weight, an elevator hoisted with carbon-fiber ropes is quieter than one pulled by steel ropes, and provides a smoother ride due to the reduction in vibrations from building sway, making for a more pleasant journey. Carbon-fiber UltraRope has been thoroughly tested, including its tensile strength, bending lifetime, material aging, and its resistance to extreme temperatures and humidity. It does not rust, stretch, or wear, and can be monitored using a real-time rope condition monitoring system. This all adds up to unprecedented eco-efficiency, durability, reliability, and reduction in downtime for future high-rise elevator travel, promising a future where megatall buildings are thinner, taller, and more energy efficient.

Groundbreaking Benefits – Not Just For New Buildings

Carbon-fiber rope is also the perfect solution for modernization projects. The first global installation of the solution was in September 2013 at Marina Bay Sands, a luxury-integrated resort in Singapore. The move from steel ropes to carbon-fiber led to a reduction in nearly 2,700 kg of moving mass, and even bigger energy savings than first predicted: nearly 13% when compared to similar elevators using steel rope in the same tower. Due to this highly successful modernization and observable benefits, discussions are now being held to retrofit all the hotel passenger

Opposite: A close-up of carbon-fiber and steel ropes seen together. Source: KONE

Bottom: Examples of possible elevator grouping in high-rise buildings. Source: KONE



elevators with carbon-fiber rope, with expected similar energy savings on each unit.

There are currently approximately 3,000 buildings around the world that could benefit from having carbon-fiber ropes installed in modernization projects. Due to the robust design of the carbon-fiber UltraRope and its associated components, modernization from steel to carbon-fiber is efficient, fast, and in most cases requires no modification to any existing building structures. The benefits of reduced moving masses translate directly to the bottom line of building operations after modernization is completed. The lighter weight of carbon-fiber ropes allows the modernization to be carried out faster and more easily than completing the rope change on a traditional steel rope elevator. These advantages in time, energy, and future maintenance add real value to existing buildings.

Building A Future in the Sky – The Impact of New High-Rise Technologies

At least twenty buildings more than 500 meters high are currently being planned around the world, and this number is only expected to grow as rapidly increasing urbanization leads to more people living in cities. More than half of the world's population already live in urban areas, and the UN estimates that 200,000 people will move to or be born into an urbanized environment every day. To accommodate these numbers, the equivalent of a new city of more than one million people needs to be built every week.

As ground space is limited, we need to build upwards rather than outwards to find a sustainable urban solution – the possibilities of vertical urbanism could be the key to having space for everyone who wants or needs to live in these megacities of the future. Nearly 70% of people living in cities around the world see tall buildings as an essential part of the modern cityscape, with 63% believing that building upwards is a sustainable way to develop urban areas.

Future urban design is often more about what you don't see than what you do, with hidden technology like carbon-fiber hoisting rope leading to huge leaps in what's possible, while improving sustainability and finding answers to an increasing number of essential environmental considerations.

Carbon-fiber rope and similar advances in building technology are making the future urban density needed to support our growing population possible. The first mile-high building envisioned by Frank Lloyd-Wright over half a century ago cannot be far off.