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Mitsubishi Elevator Equipment in Shanghai Tower

上海中心大厦中的三菱电梯设备

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Abstract

Shanghai Tower has a height of more than 600 meters above the ground and consists of five zones of skirt building zone, office zone, hotel zone, boutique office zone and observation zone. The concept of transportation is to, utilizing the shuttle elevators, access to main lobby of each zone firstly, then changing to and utilizing the satellite elevators in each zone for access to each floor. A total of 106 units of elevators will be installed in Shanghai Tower, which include three world's records; 1) The fastest single-deck elevators at 18 meters per second, 2) The fastest double-deck elevators at 10 meters per second, and 3) The elevators with the longest travel of 579.78 meters. Furthermore, adopting the latest technology, these elevators secure safety, reliability and a comfortable ride. They also contribute to energy savings of the building.

Keywords: The world's fastest elevators, The world's longest travel elevator, Drive & control system, Safety, Comfortable ride, Energy saving

摘要

高度在600米以上的上海中心，由裙楼、写字楼、宾馆、高档写字楼及观光5大区域构成。共计安装了106台电梯，包括18m/s的世界最快单轿厢电梯、10m/s的世界最快双轿厢电梯和579.78米世界最大提升高度的电梯。此外，最新技术的应用使得这些电梯实现了安全、可靠、舒适及节能。

关键词：世界最快的电梯，世界最快的双轿厢电梯，世界最大提升高度电梯，驱动控制系统，安全，乘坐舒适，节能

Elevator Layout for Efficient Vertical Transport

In a high-rise building, a well-designed elevator layout will make a remarkable difference in vertical transport. A total of 106 units of elevators will be installed in Shanghai Tower, which are arranged in such a way as to facilitate vertical movements of large numbers of people and goods in the high-rise.

Office Zone (From 8th to 81st Floor)

For efficient vertical transport, the office zone will be laterally divided into five sections. The two bottom floors in each section, excluding the lowest section, are sky lobbies. Each section is further subdivided into two, for higher and lower floors.

Between the ground level and the sky lobbies, a group of four double-deck elevators per section will shuttle a large number of passengers at a high speed of 5 to 10 meters per second. Within the section, a group of three (four in the lowest section) cars with a middle speed of 2.5 meters per second and a group of four (six in the lowest section) cars with a high speed of 3.5 meters per second will be installed as satellite elevators for the lower and higher floors, respectively.

For smooth transfers from double-deck shuttles to satellite elevators, two sky lobbies

垂直交通的有效布置

在高层建筑中，电梯的最佳布置会对垂直交通产生很大影响。上海中心的106台电梯的布局就是按着在高层建筑中有助于大量人流及货物垂直运送的这种理念进行的。

写字楼区（第8层到第81层）

为了提高垂直运送效率，写字楼区被纵向分成五个部分。除最低部分以外，每部分的最下两层作为大堂。每部分又被进一步分成高区和低区。

在地上一层和各部分大堂之间，由一组四台穿梭双轿厢电梯，以5m/s～10m/s速度输送大量人员。每部分内，又分别由一组三台（最低部分为四台）和四台（最低部分为六台），以2.5m/s和3.5m/s速度服务于低区和高区。

为了使得双轿厢的乘客能够顺利转乘到各部分内电梯，两层大堂根据目的层不同被区分开。上层大堂用于高区，下层大堂用于低区。例如，想去高层的乘客，乘双轿厢的上层轿厢，到达每部分的上层大堂。

酒店区（第84层到第110层）

一组四台超高速双层电梯将有效地运送从1层到宾馆的乘客。下层轿厢的乘客将以10m/s速度从1层被运送到101层宾馆大堂。宾馆内，安装有一组四台、4m/s速度的电梯，另外，还有两台无机房观光梯服务于从101层的宾馆大厅到102～104层的

will be segregated by destination. The upper sky lobby will be used by high-speed satellite elevators for higher floors, and the lower sky lobby by middle-speed units for lower floors. Passengers, for instance, traveling to higher floors in a section will board the upper decks to arrive at the upper sky lobby.

Hotel Zone (From 84th to 110th Floor)

A group of four super-high-speed double-deck elevators will efficiently transport passengers between the ground and the hotel. Passengers in the lower decks will be shuttled between the 1st floor and the hotel lobby on the 101st floor at a super-high-speed of 10 meters per second. Within the hotel, a group of four satellite elevators will transport passengers at a speed of 4 meters per second, and two observation elevators without machine rooms will serve the 101st floor hotel lobby, 102nd to 104th floors hotel restaurants and 105th floor hotel conference center.

Boutique Office Zone (From 111th to 115th Floor)

While the lower decks of the double-deck elevators will shuttle between the 1st floor and the hotel lobby on the 101st floor, the upper decks will shuttle between the 2nd floor and the 102nd floor where passengers can transfer to/from satellite elevators for boutique office zone. A couple of satellite elevators with a speed of 4 meters per second will serve not only the 102nd and boutique office floors, but also floors with public facilities: the 103rd to 105th floors with hotel restaurants and conference center and 120th floor with a sky restaurant.

Observation deck and sky restaurant zone (From 118th to 120th floor)

A group of three world's fastest elevators can take passengers straight up from the 2nd basement floor to the observation decks on the 118th and 119th floors at a speed of 18 meters per second. To access the express elevators, passengers can take a machine-room-less elevator or escalator from the 1st floor to the 2nd basement floor. Beyond the observation deck, passengers can use three machine-room-less elevators to the sky restaurant on the 120th floor.

Skirt building (From 2nd basement to 5th floor)

Thirteen passenger elevators and 10 service elevators will connect facilities in the skirt building such as public space, retail areas, event center, conference center, and parking. This skirt building will be connected to a subway station on the 2nd basement floor.

Service elevators in main building

In addition to passenger elevators, 12 high-speed service elevators will be installed in the main building. Among them, two are designated for VIP operation as well as fire emergency operation and can serve every floor between the 3rd basement and 121st floor. Two other service elevators, with large capacities of 3500 kg, will be splitting the travel distance at the 50th floor where passengers transfer from one to the other. Within office, hotel and boutique office zones, two to three service elevators will operate. Furthermore, a group of three service elevators will provide express service at a high speed of 8 meters per second, especially for the convenience of maintenance, between the ground level and floors where mechanical, electrical, and plumbing (MEP) rooms are located directly under the sky lobbies.

Three world's records

The elevators in Shanghai Tower will have three world records as of the completion of the building's construction.

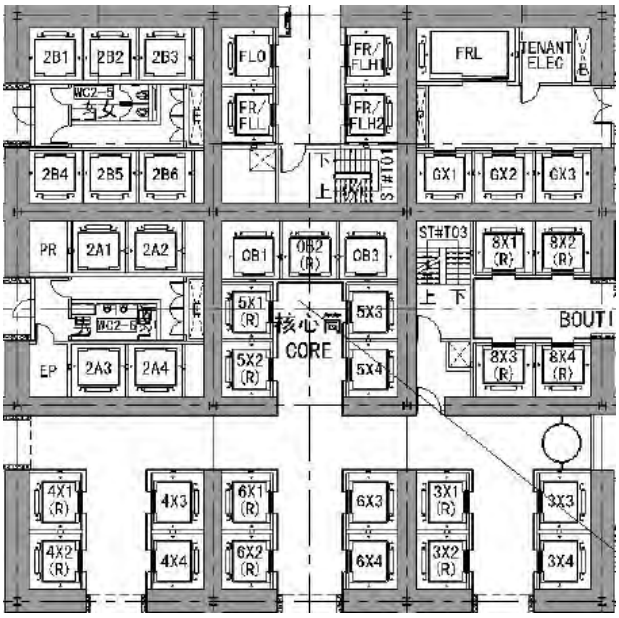

Figure 1. Elevator Core Layout at the First floor (Source: Building Design Drawing)
图1. 一楼电梯核心筒布局（出自：建筑设计图纸）

餐厅及105层的会议厅。

高档写字楼区（第111层到第115层）

双轿厢的下层将在1层和101层的宾馆大堂之间运行，双轿厢的上层将在2层和102层之间运行。乘客可以在102层进行换乘。两台4m/s的电梯不仅服务于102层和高级写字楼层，而且也服务于103层到105层的餐厅层和会议中心以及120层的观光餐厅。

观光层和观光餐厅区（118层到120层）

一组三台世界最快的电梯将以18m/s的速度，把乘客从地下2层送达到118层和119层的观光层，乘客可以利用从1层到地下2层的无机房电梯或自动扶梯到达地下2层。到达观光层后，乘客可以乘3台无机房去120层的观光餐厅。

裙楼（地下2层到5层）

13台客梯和10台服务梯将服务于裙楼的公共场所、租赁区、活动中心、停车场等公共设施。裙楼将与地下2层的地铁连接。

主楼的服务梯

除客梯以外，主楼中还装有12台高速服务梯。这中间有两台作为消防及VIP电梯服务于从地下3层到121层的每一层，另外两台大载重3500kg的电梯将在50层处分成两段进行换乘。在写字楼、宾馆、高级写字楼区内，有2到3台服务梯运行。另外，一组3台8m/s的高速服务梯将提供更快需求，特别是对于在1层和观光层下面的机械、电器、管道等设备层之间的维修。

三个世界记录

伴随着上海中心完成，上海中心安装的电梯将产生3个记录。

Elevators 电梯	Capacity 载重量	Speed 速度	Traveling distance 提升高度
World's fastest elevators 世界最快电梯	1600 kg	18 meters per second	565.4 meters
World's fastest double-deck elevators 世界最快双轿厢电梯	1600 kg/1600 kg	10 meters per second	470.0 meters
World's longest traveling distance 世界最大提升高度电梯	1350 kg	8 meters per second	579.78 meters

Table 1. Specifications of three world's top elevators.
表1. 具有三个世界记录电梯的规格

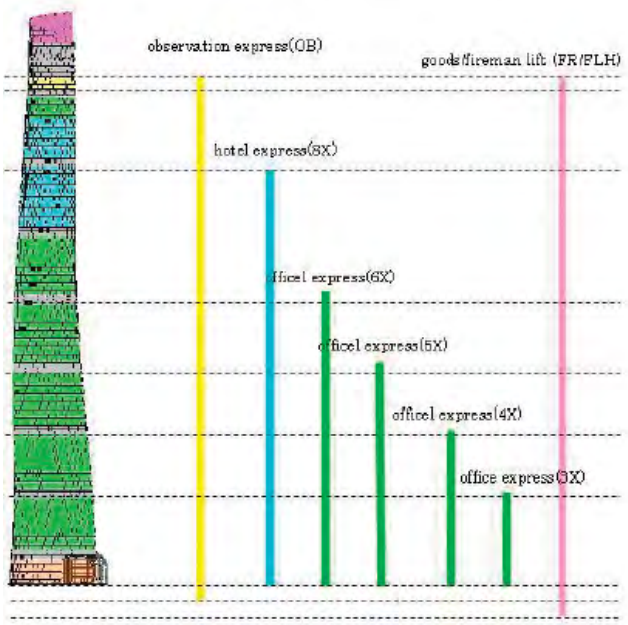

Figure 2. Main Elevator Map (Source: Mitsubishi Electric)
图2. 主电梯示意图（出自：Mitsubishi Electric）

The world's fastest elevators – 18 meters per second
A group of three shuttle elevators, surpassing the current world record of 16.8 meters per second held by elevators in Taipei 101, can ascend 565 meters in approximately 55 seconds at 18 meters per second. The descending speed will be kept at 10 meters per second or less to mitigate ear discomfort, which tends to be more noticeable during descent than during ascent.

The world's fastest double-deck elevators – 10 meters per second
A group of four double-deck shuttle elevators will travel at the world's fastest speed of its kind, 10 meters per second, from the 1st and 2nd floors to the 101st and 102nd floors.

The world's longest travel – 579.78 meters
Two elevators designated for VIP operation and fire emergency operation will have the world's longest traveling distance of 579.78 meters, serving every floor between the 3rd basement floor and the 121st floor.

To realize elevators with super high speeds and long traveling distances, Mitsubishi Electric developed various new technologies as follows to secure safe and comfortable rides and to save energy and space.

Technical Characteristics of Elevators

Highly-efficient drive and control systems
All 106 elevator units, including the world's fastest elevators (18 meters per second) and machine-room-less low-speed elevators, will be equipped with traction machines with permanent magnet motors.

Major advantages of traction machines with permanent magnet motors

- Reduced vibration: Torque ripple during elevator operation (including acceleration and deceleration) is only a few %.
- Reduced noise: Noise during traction machine operation is approximately 10 dB(A) less than that of induction motors.
- Energy-savings: The energy efficiency is approximately 5% better than that of induction motors.

Figure 3. PM Traction Machine (Source: Mitsubishi Electric)
图3. PM 牵引机 （出自：Mitsubishi Electric）

世界最快电梯 – 每秒18米
一组3台穿梭电梯将超过现在台北101大楼的16.8m/s的世界纪录，以18米每秒的速度在约55秒中上升565米。为了减轻人耳不适，由于下降区间比上升区间更加明显，所以下降时，保持在10m/s或低于10m/s。

世界最快双轿厢电梯 – 每秒10米
一组4台双轿厢穿梭电梯，以其10m/s的全球最快速度，运行于从1层和2层到101层和102层之间。

世界最大提升高度 – 579.78米
两台消防兼VIP电梯将具有世界最大提升高度579.78米，服务于3层到121层之间的每一层。

为了实现超高速、大提升高度电梯的设计，三菱电机开发了很多下面提到的最新技术来保证安全、乘坐舒适以及节能和节省空间。

Figure 4. Doubling Safety Gear (Source: Mitsubishi Electric)
图4. 双倍安全传动装置 （出自：Mitsubishi Electric）

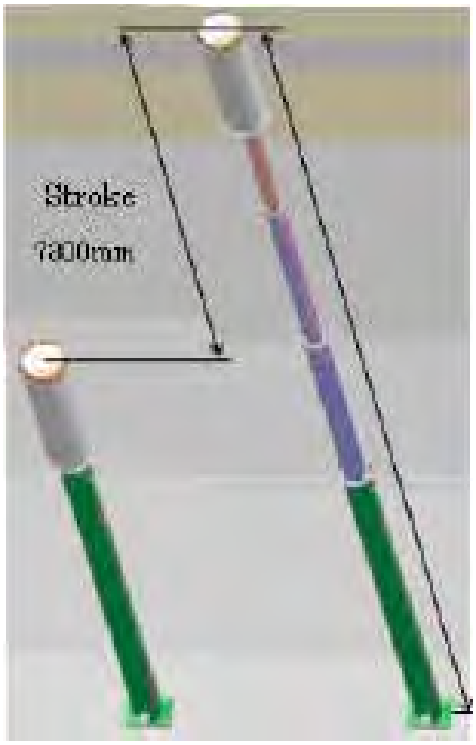

Figure 5. Multi-plunger Buffer (Source: Mitsubishi Electric)
图5. 多柱塞缓冲器 （出自：Mitsubishi Electric）

In the course of development of the world's fastest elevators, Mitsubishi Electric has successfully minimized equipment size, despite the large capacity, by adopting double three-phase winding and by a parallel drive system with two control panels. For steady braking of super-high-speed elevators with large loads, double hydraulic disc-brakes with clamps have been adopted.

Safety and Reliability

High-strength hoisting rope: Mitsubishi Electric developed a high-strength hoisting rope that can withstand its own weight in an extremely long shaft. Compared to conventional ropes, it has higher intensity per weight with an ensured safety factor. Furthermore, effective cross-sectional area was expanded by increasing wire density, which ultimately reduced rope stretch approximately 25% and stabilizes ingmotion .

Lightweight traveling cable: For long and heavy hanging parts of cables in the tall shaft, the intensity of the cables was enhanced by increasing the steel core diameter. On the other hand, to reduce its weight, a lightweight casing is employed. Also, a highly-efficient power transmission system was developed to reduce the weight of power lines.

Fine ceramics safety gear: The high resistance to abrasion and thermal shock of fine ceramics ensures reliable braking performance of brake shoes at high temperatures caused by friction. By adoption of double safety gears, the total load could be significantly increased.

Multi-plunger buffer: The higher the elevator speed, the longer the buffer stroke and thereby the deeper the pit required. This is to comply with regulations stipulating that the average deceleration must be kept to 1G or less when a buffer is struck at the maximum speed. However, total height can be shorter by approximately 30% with a three-plunger buffer than with a single-plunger buffer.

Emergency operation against strong wind: High winds against high-rise buildings can cause sympathetic vibration, which can sway the upper floors. If elevator ropes resonate with the building

Figure 6. Actie Roller Guide (Source: Mitsubishi Electric)
图6. 活性辊引导 （出自：Mitsubishi Electric）

电梯的技术特性

高效的驱动和控制系统

所有106台电梯，包括世界最快电梯(18 m/s)以及无机房低速电梯都使用永磁电机的曳引机。

永磁电机曳引机的主要优点：

- 减振：电梯运行（包括加速和减速）时的转矩脉动仅是百分之几。
- 降噪：曳引机运行中的噪音约为10 dB(A)，小于感应电机。
- 节能：能效约比感应电机好5%。

在开发世界最快电梯的过程中，尽管是大载重量电梯，通过采用双三相绕组以及两个控制柜的并联驱动，三菱电机成功地缩小了设备尺寸。为了获得大载重量超高速电梯的平稳制动，采取了具有夹块的双液压碟式制动。

安全和可靠性

高强度曳引钢丝绳：三菱电机开发了在超大提升高度时，也能承受自身重量的高强度曳引钢丝绳。与传统钢丝绳相比，具有较高的重量比强度，安全系数大，另外，通过增加钢丝绳的密度，有效地增加了截面积，进而减小了钢丝绳伸长约25%，增强了钢丝绳的稳定性。

轻型随行电缆：对于井道内悬挂的既长又重的电缆，通过增加钢芯直径来加大电缆的强度。另一方面，通过采用重量较轻的外皮材料，减轻了电缆的重量。再者，通过开发高效的动力传输系统，也减少了动力线的重量。

优质陶瓷安全钳：优质陶瓷具有高度耐磨损及耐热冲击性，能够保证在由摩擦产生的高温下，安全钳闸瓦完成可靠的制动动作。通过采用双安全钳，总载荷能够明显增加。

多活塞缓冲器：电梯速度越高，需要的缓冲器行程就越大，进而导致地坑深度越大。这是由于需要满足当缓冲器被以最大速度撞击时，它的平均减速度必须等于或小于1G的法规要求。因此，比起单活塞缓冲器来说，三个活塞缓冲器可以使地坑深度缩小近30%。

抗强风紧急运行：强风可以摇晃顶层导致高层建筑的共振。如果电梯钢丝绳随建筑物的运动而产生共振的话，它们将会和井道内其他设备缠绕。当钢丝绳摆动幅度过大时，电梯将停靠在最近楼层，疏散乘客。

乘坐舒适性

movement, they may be caught in other equipment in the shaft. If the ropes are expected to swing widely, the elevators go to the nearest floor to evacuate passengers before going to 'stand-by'.

Comfortable Ride

Vibration reduction. Two major causes of car vibration are warped rails and windload while the cars are running. As cars run faster, the magnitude and frequency of the vibration increases. There are no quick-fixes, such as the addition of vibration insulators. Diverse approaches were required to curb vibration materially through adoption of high-precision rails, pneumatic-resistant car design and a proactive vibration control system.

- High-precision rail: Straight rails manufactured with high precision will minimize excitation forces during car operation.
- Active Roller Guide: When vibration of a car or car frame is detected, the roller guides supporting the car act to cancel this vibration. The device ensures a more comfortable ride than conventional roller guides.

Noise reduction. Noise prevention is a difficult challenge in designing high-speed elevators, as the volume of noise in a cabin increases as the elevator runs faster. There are two main approaches: One is to reduce the source, pneumatic noise itself, through streamlining the airflow around the car; The other is to enhance acoustic isolation of the car by blocking airborne sound.

- Streamlined fairings: Mitsubishi Electric has designed the optimum streamline for fairings according to the results of simulation and wind-tunnel tests and will cover roller guides since noise is notable around them, especially concerning high-speed elevators.
- Soundproofing car structure: Through a series of tests and thorough study, a car structure with the optimum degree of sound absorption was developed. Since noise in cabins can be significantly reduced by minimizing door draft, the structure employed a mechanism that blocks door draft almost completely during car operation.
- Atmospheric pressure control in cabin: Ear discomfort occurs by changes in air pressure in cabins due to elevation difference. To examine ear discomfort in relation to atmospheric pressure, tests were performed in a compression chamber with various pressure patterns. These led to a control system that can keep atmospheric pressure in cabins optimum for ear comfort.

Energy savings

The following technologies helped acquire a Leadership in Energy and Environmental Design (LEED) certificate.

Traction machines with permanent magnet motors. All 106 elevators are equipped with traction machines with permanent magnet motors. Unlike conventional traction machines with induction motors, they do not require an excitation current and thereby excel at controlling performance and energy savings.

Power regeneration function. The power regeneration function will be provided for all elevators with a speed of 2.5 meters per second or higher. The traction machine with this function works as a power generator (regenerative operation) when the motor rotates towards the heavier side of the car or the counterweight which is designed to be balanced with the car at a half-capacity load. The regenerated power is fed into the building's electrical grid along with general power supply to be used by other elevators, lighting and other electrical equipment.

Figure 7. Elevator Car with Streamlined fairings (Source: Mitsubishi Electric)
图7. 流线型整流罩轿厢 （出自：Mitsubishi Electric）

减振. 轿厢运行时，导致轿厢振动的两个主要原因是弯曲的导轨及风载。电梯速度快，振动的幅度和频率就增加。通过采取振动隔离等措施，不能有效解决。因此，需要不同的想法——采用高精度导轨、防风阻轿厢设计、抑制振动控制系统来从本质上解决振动的问题。

- 高精度导轨：高精度笔直导轨使得轿厢运行时产生的细小外力控制到最小。
- 主动滚轮导靴：当检测到轿厢或轿架的振动时，滚动导靴将随轿厢动作进行补偿而达到抵消这个振动。这套装置比传统的滚动导靴达到更加良好的乘坐舒适感。

降噪. 电梯运行越快，轿厢内的噪音就越大。防噪音是设计高速电梯时面临的巨大挑战。主要有两个解决办法：一是通过轿厢四周的整流结构来减小声源，即气动噪音；另一个是通过阻隔空气声音来增强轿厢内的隔音。

- 整流罩：三菱电机根据模拟及风洞试验的结果，设计了最有效的流线型整流罩。并且也罩住滚轮导靴，因为导靴附近的噪音很明显，尤其是对于高速电梯。
- 隔音轿厢结构：经过研究和大量试验，开发了最佳吸音轿厢结构。通过轿门气流的最小化，在电梯运行过程中，几乎完全阻隔轿门处的气流，使得轿厢内噪音明显减小。
- 轿厢内气压控制：由于高度差，轿厢内气压的变化导致人耳不适。为了检验人耳不适感和气压的关系，在压力室中，通过各种压力形式进行试验，找到了通过控制系统保持使得人耳舒适的最佳轿厢内气压。

节能

下面的技术为取得能源环境设计认证（LEED）做出了贡献。

永磁电机曳引机. 所有106台电梯都装有永磁电机曳引机。不像

Energy-Saving Operation – Allocation Control (ESO-W). All passenger elevators under group control are equipped with this effective feature for energy saving operation. When a passenger presses a hall button, this system estimates power consumption to serve the call based on position and load of all elevators in the same group and selects the car that best balances operational efficiency and energy consumption. Priority is given to operational efficiency during peak hours and energy efficiency during non-peak hours.

Conclusion

Efficiently arranged, all 106 elevators, including the world's fastest speeds or longest travel, will demonstrate easy and convenient vertical transport in such a tall building where dynamic traffic is expected. Traffic control, however, was not the only primary challenge in the Shanghai Tower project. Safety and comfort will not be compromised. The enhanced technologies that ensure safe and comfortable rides were adopted to assure the best performance, even under difficult conditions such as super-high speed and a long traveling distance.

Note: The information above is as of completion of building construction.

传统的感应电机曳引机，它们不需要励磁电流，因此，控制优良且节能。

发电功能. 速度在等于和大于2.5m/s的电梯，都有发电功能。当电机向轿厢或对重较重的一侧旋转时，对重是按轿厢额定载荷一半设定的，发出的电将向大楼电网回馈，以供其它电梯、照明及其他电气设备使用。

节能运行 – 分配控制 (ESO-W). 所有群控客梯都配有这个节能运行功能。但乘客按下厅门召唤按钮时，本系统将对呼叫位置及群组中电梯的载荷进行评估，选择能够达到效率最大化及节能的电梯进行服务。在高峰时，系统优先考虑效率。在闲暇时，系统优先考虑节能。

结论

包括世界最快和提升高度最大电梯在内的所有106台电梯的有效布置，将易于证明，是像上海中心这样高建筑的动态交通所期待的。交通控制不仅仅是上海中心的主要挑战，安全和乘坐舒适性也是不能忽视的。保证安全和乘坐舒适性的技术改进，实现了即使在困难像超高速、超大提升高度条件下的完美表现。

注释：上述内容是基于建筑完工时。