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Design Challenges of the 3 Tallest Buildings in North/ East/ South China

华北/华东/华南区三大超高层建筑设计中的挑战

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Abstract

This paper describes the MEP and VTS design challenges of the tallest buildings in three major cities in China; namely, Beijing, Suzhou and Guangzhou. The 530m Guangzhou CTF (East Tower), is a mixed use building with office, luxury hotel, deluxe services apartments and commercial. The major VTS design challenge encountered was on changing the building form and shape. Further discussion on design difficulties for the current and upcoming ultra high-rise buildings in Beijing – the 528m CBD Z15 tower (Zhongguo Jun) and the 330m China World Tower. As well as design challenges for the coming two tallest buildings in Suzhou – the 598m (top landing) Suzhou Tower and the 450m Suzhou International Financial Square (IFS) will also be discussed.

Keywords: Mechanical Electrical & Plumbing (MEP), Vertical Transportation System (VTS), System Reliability, Energy Efficiency & Sustainability, Flexibility for Future Change, User-Friendliness

摘要

本文描述了中国三大城市 (北京、苏州和广州) 超高层建筑中机电及垂直运输系统设计的重大挑战。其中广州周大福中心 (东塔) 高530米，是一座集办公、奢华酒店、顶级服务式公寓和商业零售于一体的综合性建筑，主要的垂直运输系统设计挑战为楼宇核心筒形状的改变。本文还讨论了北京现有以及未来的最高建筑，包括528米高的CBD Z15塔 (中国尊大厦) 和330米高的中国国际贸易中心3A; 以及苏州未来的两座高楼，包括598米高 (上人高度) 的苏州塔楼和450米高的苏州国际金融广场 (IFS) 。

关键词: 机电系统，垂直运输系统，系统可靠性，能源效益和可持续发展，未来变化的灵活性，用户便利性

Mixed-Use Buildings in China

In an era when the population is increasing and availability of land is limited, developers and professionals are veered to design and build taller structures. Parsons Brinckerhoff serves as MEP & VTS design engineers and consultants for numerous ultra high-rise and mixed-use developments in China. Given the popularity of tall buildings, a survey has been performed on major cities in this country, yielding an unsurprising result of over 80 percent of them being mixed-use buildings (Vincent & Herbert, 2013). Indeed, a structure of a vertically stacked assortment of occupiable spaces such as offices, residences, services apartments, hotels, clubs, and observatory decks is attractive, but the trade-off lies in the challenges faced in the MEP & VTS design and operation. The MEP and VTS design challenges for tall buildings in the Northern, Southern, and Eastern China, specifically of the three first-tier cities, namely, Beijing, Guangzhou, and Suzhou are described in this present paper.

中国的综合体超高层建筑

随着人口的不断增长和可使用土地局限性的加剧，各个地产发展商和建筑界业内人士都逐渐转向设计及建造更高的建筑。柏诚已经在中国多幢超高层综合性发展项目中担任机电及垂直运输系统设计的工程师及顾问。超高层建筑目前在中国非常盛行。根据针对中国主要城市的调查显示 (Vincent & Herbert，2013) ，超过80%的超高层建筑都为综合性大楼。一幢包含办公、住宅、服务式公寓、酒店、会所，甚至观景台的综合性大楼确实很吸引人，但随之而来的挑战便是机电和垂直运输系统的设计和运营。本文重点介绍了华北、华南和华东三大城市——北京、广州和苏州——超高层建筑设计中的挑战及解决方案。

北京最高建筑群

柏诚是北京六幢现有或未建成的最高建筑的机电及垂直运输系统顾问，包括CBD Z15 (528米) 、CBD Z6 (405米) 、CWTC 3A (330米) 、CWTC 3B (310米) 、财富中心 (260米)

Tallest Buildings in Beijing

Parsons Brinckerhoff is the MEP and VTS design consultancy firm for six current and future ultra high-rise buildings in Beijing–CBD Z15 (528m), CBD Z6 (405m), CWTC 3A (330m), CWTC 3B (310m), Fortune Center (260m) and Park Hyatt/Yintai Center (250m) , as shown in Figure 1: Tallest Buildings in Beijing.

Beijing CBD Z15 will be the tallest building in Beijing by 2018 and at present, the CWTC 3A China World Tower is the tallest building in Beijing since 2008.

Beijing CBD Z15 (Zhongguo Jun)

Beijing CBD Z15 Tower's (Zhong Guo Jun) iconic silhouette is distinguished by a bottleneck at the middle of the tower to replicate an ancient Chinese wine vessel, "Jun" (Figure 2). This, however, complicates the fitting of the core with VTS and MEP plant rooms and causes difficulty in maintaining an effective usable floor efficiency of over 70 percent due to the inevitable smaller floor plate size in the middle.

Another VTS challenge that has been encountered in this project is the shifting of the building usage from offices/services apartments/hotels in the previous design to an all-office edifice in the current design. The difficulty arises from having to include more elevators and MEP risers for the offices while keeping the core area unchanged.

On the MEP side, the high Floor to Area Ratio of approximately 30 leads to a congested site area and lack of open space. The plan devised to mitigate this problem is to accommodate cooling towers on the mechanical floor with louvers for heat rejection. The arrangement of the cooling tower plant, the extent of louvers, the positioning of air discharges and make-up air intakes, and the means to minimize short-circuiting of discharge, intake air streams, etc., are all key design considerations in the planning and design of the cooling tower heat rejection system.

Nevertheless, there are also other systems and factors worth exploring. For example, a high capacity ice thermal storage plant will be installed at basement 7th floor of the development. Various modes of operation will be incorporated into the ice thermal storage to suit different operating and loading conditions. During the night time, the system will mainly operate in ice-charge mode in order to exploit the lower ambient air temperature and as a consequence, benefit from a cheaper electricity tariff, resulting in a cost effective and an efficient cooling system. In the day time, ice will be discharged to release cooling energy for air conditioning. This large capacity ice thermal storage enhances energy efficiency, cost effectiveness of the air conditioning system, improves system reliability, saves cooling plant capacity, and minimizes the risk of white plume being expelled from cooling towers during winter and/or off-peak seasons.

Environmental control and thermal comfort are key considerations in the HVAC (Heating, Ventilation, and Air-Conditioning) design. Offices will be provided with VAV systems where the air quality will be closely monitored and controlled, and thus, fresh air will vary according to the CO_2 level sensed. Good air filtering and air treatment will be integrated into the HVAC system to ensure good indoor air quality–specifically regarding the indoor air quality control to limit concentration of tiny particles in the air with diameter less than 2.5 micrometers (PM2.5)

Figure 1. The Tallest Buildings in Beijing (Source: Courtesy of KPF, SOM, Aedas & PB)
图1. 北京最高建筑群 (来源: KPF，SOM，Aedas和PB)

Figure 2. Beijing CBD Z15 Tower (528m) (Source: Courtesy of KPF)
图2. 北京中国尊大厦 (528米) (来源: KPF)

和银泰中心/柏悦酒店 (250米)，见图1: 北京最高建筑群。

北京CBD Z15于2018年建成后，将成为北京市最高建筑。目前北京的最高建筑为中国国际贸易中心3A期，自2008年起保持着该记录。

北京CBD Z15 (中国尊大厦)

北京CBD Z15塔 (中国尊大厦) 的建筑造型由底部至腰部逐渐缩小，同时至顶部又逐渐放大，形似中国古代礼器"尊"，因此取名"中国尊" (见图2) 。但此项设计加大了垂直运输系统和机电房与核心筒布置配合的设计挑战。中部狭窄造成楼层面积减小，为保持最大化的可使用楼层面积 (得房率不能小于70%)增加了不少难度。

垂直运输系统方面的另一个挑战是将原有的"办公室/服务式公寓/酒店"功能用途更改为现有的"全办公"设计。难度在于建筑需要更多的垂直电梯，且需要在保持核心筒尺寸不变的情况下增加电梯数量及机电的配套等。

机电设计方面，高达约30的容积率导致了非常紧张的室内空间和狭小的公共区域面积。为解决这一问题，设计计划在机电楼层安装冷却水塔供中央冷冻机组散热。冷却水塔机组设计主要考虑的因素包括机组布置、送排风布置、百叶设计及布置、避免排风及送风短路等。

除上述设计考虑外，其它系统和因素也值得进一步探究。例如，高效冰蓄冷设备将安装在建筑物的地下7层。冰蓄冷设备中将加入多种运营装置来适应不同的运营和冷冻负荷情况。晚间，系统将主要以制冰模式运行，此举可以利用夜晚电费谷段便宜电价而达到高成本效益和高能源效益。白天，冰会溶解以协助满足大楼的冷冻负荷要求。亦能帮助提升空调系统的可靠性，降低冷却塔容量，以及减少冬天或非高峰时段冷却塔释出白烟水雾。

In addition, system reliability, particularly the electricity supply, is one of the most important key issues since this office building is headquarters to many prestigious commercial organizations such as world financial institutions and banking facilities. In light of this, dual electrical plant rooms and dual risers will be provided to serve each office floor. These essential services will be further backed-up by emergency generators. Moreover, high quality tenancy provisions such as tenant chilled water supply, condenser water supply, and tenant special exhaust will be provided to meet tenants' demands. High system reliability together with an optimal vertical hydraulic zoning will also result from limiting the hydraulic pressure of water-side equipment, i.e., achieving pressure break through plate-type heat exchangers suitably located at high zone mechanical floor (Level 73), mid zone mechanical floor (Level 29) and low zone mechanical floor (basement 7th floor). The vertical distance between these Heat Exchangers will be controlled to around 200m so as to limit hydraulic pressure of the system to within 2.5MPa.

Last but not least, other energy-saving and green features such as variable pumping systems, free cooling, heat recovery, lighting control, fresh air control, intelligent building management, and energy management systems will be incorporated to provide an environmentally-friendly architecture design.

CWTC 3A China World Tower

Equally sophisticated, the 330m CWTC 3A China World Tower, the current tallest building in Beijing (Figure 3). This mixed-use building houses Grade A offices and the 5-Star plus Shangri-la Summit Hotel is the latest phase of the CWTC development. However, this multi-purpose building encompasses certain VTS and MEP design obstacles (Vincent, 2012).

For example, reduced shaft spaces compared to those of conventional elevator zoning arrangements suggested the adoption of a sky lobby transfer method for office and hotel areas. The office area has a sky lobby that serves as the interchange level between high speed shuttles and local zone elevators for passengers for the upper floors. There are also a group of elevator shafts stacked upon another. As for the hotel area, the hotel sky lobby is located at both the apex of the building and the lowest guestroom floor (Figure 4).

Since the travelling distance of the hotel shuttle exceeds 300m, a rated speed of 10m/s, is adopted to reduce the travelling time and satisfy the traffic demand. Streamlined fairings and double-wall constructions are provided to improve the elevator car construction for reducing car noise during the elevator operation of this super high speed elevator. Specially-designed guide rollers with large diameters and spring-loaded rollers are used to mitigate the lateral car vibration. Furthermore, elevator speed control to compensate for rope/cable swaying and specific parking strategies is provided to prevent the building sway from damaging the elevator equipment.

With the State-of-the-Art sustainable technology, the MEP design challenges encountered are the cold climate, system reliability and energy efficiency. Sustainable designs are categorized as passive and active. They are as follows.

Passive features include the following:

- low E-coated double insulated glass with low U-value and shading coefficient;

环境温度控制和热舒适度是暖通空调设计中的重点。办公室将安装VAV变风量系统，时刻监控室内空气质量，并根据二氧化碳水平调整新风空气量。暖通空调系统内将加入空气过滤及净化装置，并特别针对控制空气中的微粒浓度 (PM2.5)，以确保优质的室内空气质量。

此外，系统的可靠性 (尤其是电力供应) 是最为焦点的问题，因为众多顶级商业机构总部将进驻本建筑物，包括国际金融机构和银行组织等。每一楼层将提供双配电房和双配电干线，且备有紧急发电装置以提供额外保障。同时，高质量的租户要求，例如租户冷冻水供应、冷却水供应及租户特殊排风装置等，将按照租户要求予以提供。高系统可靠性及优化的水系统压力分区同样非常重要，其布置主要借助设于机电楼层的热交换器来实现压力减压及分区。热交换器主要放置在高区机电层 (73层)、中区 (29层) 及低区 (地库7层)，其垂直间隔均不超过200米，以便有效将系统压力控制在2.5MPa之内。

最后，其它节能及绿色设计，例如变频水泵系统、免费冷却供冷系统、热回收及再利用、节能灯具、新风空气量控制、智能楼宇管理和能源管理系统等，均会加入到整体设计中，实现建筑的节能环保。

Figure 3. CWTC 3A China World Tower (330m) (Source: PB)
图3. 中国国际贸易中心3A期 (330米) (来源: PB)

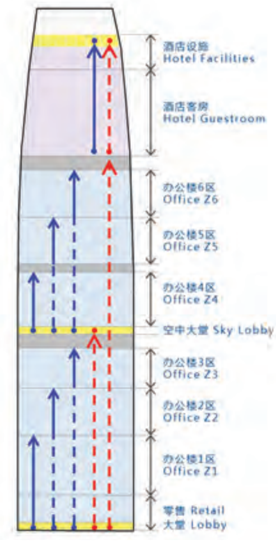

Figure 4. VTS Stacking of CWTC 3A (Source: PB)
图4. 中国国际贸易中心3A垂直运输系统示意图 (来源: PB)

- specially-designed external and vertical shading fins running along the tower to provide an architectural feature, and also enhance the overall energy efficiency performance of the building;
- strategic location and orientation of the mega tower and the large glass wall of retail block (facing South-25o-West). The benefit is by reducing solar heat gain in summer and enhancing solar heat gain effect in winter, therefore, reducing the demand on air conditioning to maintain the internal environment; and
- adaptation of a sky garden that not only provides a comfortable and green space for the occupants, but also serves as an insulator, minimizing thermal heat gain in summer and heat loss in winter.

Active features include the following:

- hybrid thermal energy center, which includes electric chillers, absorption chillers, and ice thermals storage system; making good use of waste heat from the nearby power plant and minimizing the peak demand power charges. Hence, this reduces the peak electrical demand consumption by over 40% and allow full utilization of the waste heat from the nearby power plant;
- automatic variable-flow chilled water circulation system;
- fan-powered variable air volume system for office floors is used for better indoor air quality and energy efficiency;
- water-side free cooling system incorporated as part of the thermal energy center. The use of cold environment can offset the internal building cooling load requirement;
- air-side free cooling system for the grand ballroom;
- - use of run around coil concept for heat recovery from exhaust air;
- use of energy efficient T5 light fittings with electronic ballast, LED directional and exit sign, and active harmonic filter in main distribution board; and
- inverter control using Variable Voltage Variable Frequency (VVVF) adopted for elevator and escalator motor to promote energy efficiency.

Overall, major MEP design challenges comprise of having to merge hotel and offices into what is currently the tallest edifice in an active earthquake region, and at the same time to maintain the building core to a minimum size yet fulfill the services requirements of the different users. Also, operating costs and energy consumption are very important design considerations of this project. Particular attention has been paid on "Stack Effect" in MEP Design (Donald, 2004) including 1) Divide vertical ventilation zone within 15-20 floor levels; 2) A near to neutral pressure regime has been implemented avoiding over pressurized the tower; 3) Special Design/Fabricated Lift Door with mechanism enhancing its operation under relatively large differential pressure; 4) Special attention to air tightness of floor or wall was implemented by proper sealing of gap or hole around MEP services. The design team devised passive and active sustainable design elements to minimize its environmental impact. An estimated annual operating cost savings exceed US$1 million, with a substantial reduction of greenhouse gases from the power plant.

中国国际贸易中心3A期 (CWTC 3A)

330米高的CWTC 3A是北京现有的最高建筑 (见图3) 。甲级办公室和五星级香格里拉大酒店是国贸中心开发的最新综合体项目。但这幢多功能大楼包含数个垂直运输系统和机电设计的难题 (Vincent，2012) 。

例如，相比于一般电梯井，此幢建筑内的电梯井较小，因此需要为办公和酒店区域设计空中大堂，以增加人流量转换面积。办公室区域的空中大堂是高速穿梭电梯和高层乘客本区电梯的换乘点，因此电梯井须要互相堆叠。酒店区域的空中大堂坐落于楼宇顶端和客房首层 (如图4所示) 。

酒店电梯运行距离超过300米，每秒运行10米的高速电梯可缩短运行时间，满足运行要求。流线型的整流罩和双层墙体设计可增强电梯轿厢的强度，并减少电梯高速运行时所产生的噪音。经过特别设计的大直径弹簧承载导轮可减轻垂直电梯运行时的震动。先进的电梯速度控制系统和停靠技术可减少缆索和轿厢的晃动，也可避免因电梯晃动而对设备产生损坏及破坏舒适性等。

可持续发展的机电设计所面临的挑战包括严寒天气、系统可靠性和能源效益。可持续发展设计又可分为被动式及主动式两类。

被动式设计包括:

- 低U值、低遮阳系数和低E涂层双重绝缘玻璃;
- 特别设计的外墙垂直遮阳板——用以增强楼宇的整体建筑效果及能源效益表现;
- 楼宇朝向和玻璃幕墙 (西南方位25度) ——夏天时可减少太阳热能摄取，冬天则可增加太阳热能摄取，降低暖通空调造价及运营成本;
- 空中花园——不仅为租户提供舒适、绿色的空间，更起到隔热作用，在夏天减少热量摄取，冬天减少热量流失。

主动式设计包括:

- 混合式能源中心——包括电冷冻机组、吸收式冷冻机组、冰蓄冷系统等，合理利用附近发电机组的废热，减少高峰时段的电力使用量，节电可达40%;
- 自动变流量冷冻水循环系统;
- 办公区域变风量系统——可优化室内空气质量，实现能源效益;
- 免费冷却水系统——融合至能源中心，可利用室外环境温度冷却楼体;
- 宴会厅空气免费冷却系统;
- 废热回收及再利用;
- 节能灯具——LED指示灯、出口指示牌上使用节能T5灯具及电子镇流器指示灯;
- 主配电屏使用有源滤波;
- 变压变频调速系统——控制电梯和扶梯，提高能源效益。

整体来说，主要的机电设计挑战在于同时将办公和酒店区域融合至现有的位于活跃地震带上的最高建筑内，同时将楼宇核心筒维持在最小规模，并满足不同租户的要求。运营成本和能源消耗是本工程的重点设计考虑。机电设计中, 烟囱效应的影响亦是设计考虑的重点之一 (Donald，2004) 。而在设计方面相关的应对措施包括: 1) 将竖向新风输配系统限制在15至20个楼层左右; 2) 建筑各空间内的空气压力尽可能与室外压力相平衡; 3) 采用加强型的电梯轿门闭门装置以配合其可以在较大压力差的情况下正常运行; 4) 对于机电管线穿越楼板和墙体时缝隙的封堵予以特别重视。

Tallest Building in Guangzhou

Guangzhou Chow Tai Fook Centre (Formerly Named East Tower)
Located in the Southern part of China, the 530m Guangzhou Chow Tai Fook Centre (GZCTF) or formerly named as East Tower is the highest ultra high-rise building in Guangzhou (Figure 5 GZCTF). This structure is more than a mere symbol of the fast-growing pace of Guangzhou, but it represents the most dramatic example of an integrated vertical city, fusing Grade A offices, luxury hotels, deluxe services apartments, restaurants, and retail spaces into one efficient tower; where people can live and work.

However, the challenge imposed on Parsons Brinckerhoff design team was to completely alter the building's core from a rectangular one into a stepped/trimmed one (Figure 6 Core Comparison for Original and Current Schemes) illustrates the physical difference between the 2 schemes for offices/services apartments/hotels. The high construction costs of the old GZCTF rectangular-cored scheme was less onerous of a challenge than those entailed by the current GZCTF stepped- or trimmed-cored scheme, including but not limited to the optimization of the floor plate size, maximizing of the usable floor efficiency and constructability, whilst reducing the core sizes from the MEP and VTS design perspective.

MEP and VTS designs features of the GZCTF are as follows:

- District chilled water was supplied to offices and podium areas since District Cooling System is available in the district the GZCTF is located in. A secondary central chiller plant is also designed in basement as back up facilities for office and podium retail floors. A remarkable achievement was the minimization of hydraulic pressure break with high energy efficiency and reliability by assigning a total of three separate chiller plants to the offices/podiums, services apartments, and hotels. The challenging part was to optimally locate the energy centers for an enhanced system reliability, energy efficiency, and coordination with architects and structural engineers. This is shown in Figure 7 (Location of Energy Centers).
- Variable Air Volume (VAV) system will be used for offices while Fan Coil Unit (FCU) system will be installed in services apartments and hotel. To enhance environmental quality, the design has been aimed to achieve the Green awards: LEED Gold for offices and hotels, and PRC Green Stars. One of the methods of attaining the aforementioned awards was to include relevant green engineering provisions such as VSD chillers, heat recovery chillers, VSD cooling towers and pumps, heat recovery wheels, CO2 fresh air control, water-saving valves, energy efficient lightings, air-conditioning condensate collection and reuse, waste water treatment and reuse, etc. (Herbert, 2013).
- The VTS design, on the other hand, is similar to that of the CWTC 3A tower and can be classified into four areas. The office area has an office sky lobby and is divided into four zones, which are all serviced by double-deck elevators. Zones 1 and 2 can be reached by direct elevators whereas zones 3 and 4 are serviced by shuttle elevators, making it necessary to transfer to the local elevators (at the sky lobby) for other floors. The designs for the services apartment area and hotel area are similar to zones 3 and 4 of the office area, except that all the elevators are of single-deck, which transfers are done at the services apartment sky lobby and hotel sky lobby, respectively.

Figure 5. Guangzhou Chow Tai Fook Centre (East Tower) (530m) (Source: Courtesy of KPF)
图5. 广州周大福中心 (东塔) (530米) (来源: KPF)

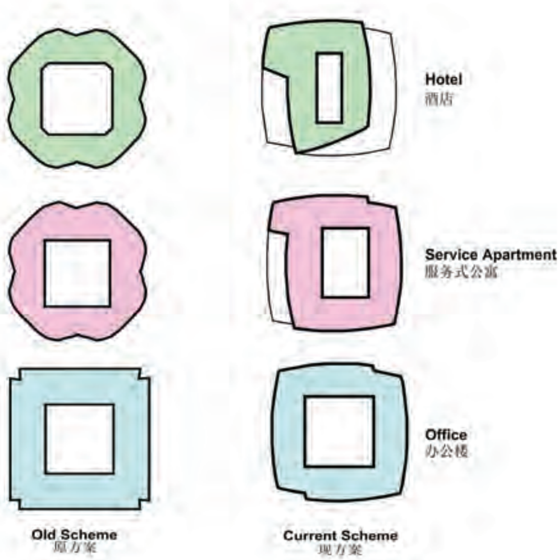

Figure 6. Guangzhou Chow Tai Fook Centre Core Comparison (Source: PB)
图6. 广州周大福中心核心筒设计比较 (来源: PB)

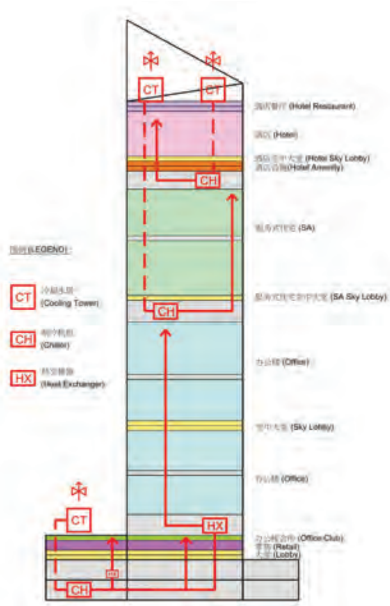

Figure 7. Guangzhou Chow Tai Fook Centre Energy Centre Location (Source: PB)
图7. 广州周大福中心能源中心布置图 (来源: PB)

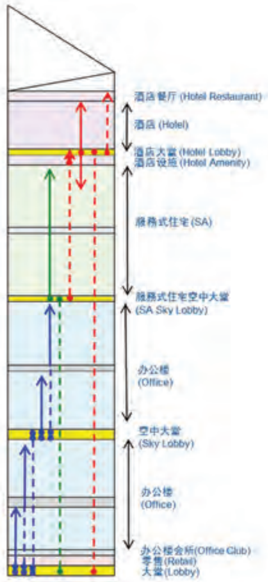

Figure 8. Guangzhou Chow Tai Fook Centre VTS Stacking (Source: PB)
图8. 广州周大福中心垂直运输系统示意图 (来源: PB)

- The hotel shuttle elevators that service the roof restaurant area allow transfers at the hotel sky lobby, such that the hotel guests can take the express elevators to reach the top restaurant floor. This scheme is illustrated in Figure 8 (VTS Stacking Diagram). Overall, the small core of the building will be an advantage as it permits higher usable floor efficiency and much less wind load impact on the structure, and therefore reduced capital cost in construction.

Tallest Buildings in Suzhou

Suzhou Tower

In the Eastern China, the future ultra high-rise building will be located at Suzhou. It will be about 600m (top landing) and it will be a mixed-use building. The building is currently in the design stage; due to privacy and confidentiality reason, information is limited for disclosure today.

Suzhou International Financial Square (IFS)

In retrospect Parsons Brinckerhoff has designed the MEP system and VTS for the second tallest building in Suzhou–the 450m Suzhou IFS in Figure 9. This combined office and luxury hotel structure located in Suzhou Industrial Park entailed various MEP and VTS design challenges in terms of the conversion of the residences of the building into offices without alterations to the core, the reduction of the core size, the core orientation and rotation, the maximization of the floor efficiency with the smallest core size possible, and the special requirements on shuttle elevators from the client.

With respect to the VTS, sky lobby transfer design approach is used for both office and hotel zone (See Figure 10 VTS Stacking of Suzhou IFS). For the office area, zones 1 to 4 are directly accessed from the lower-level elevator lobbies while zones 5 to 7 are accessed via the double-deck shuttle elevators with transfers to zones 5, 6, and 7 at the sky lobbies. For the hotel area, a sky lobby shuttle with top down local elevator system is implemented.

Regarding the MEP design, individual MEP systems are provided for each of the functional areas, i.e., offices and hotels, for the ease of future operations and management. Major MEP plants are located on

设计团队所提及的被动及主动式可持续发展设计最大程度地减少了楼宇对环境的影响。预计年度运营成本可节省超过100万美金，楼宇所产生的温室气体也会有所减少。

广州最高建筑群

广州周大福中心 (原名东塔)

位于华南地区、高530米的广州周大福中心 (原名东塔) 是广州最高的建筑 (如图5所示) 。该建筑不仅是广州迅猛发展的标志，更是集甲级办公楼、奢华酒店、顶尖服务式公寓、餐饮和商业零售于一体的综合性大楼，是办公和生活共享的绝佳地点。

柏诚设计团队面临的挑战是将建筑核心筒从长方形改为阶梯形 (如图6所示，原有和现在设计) ，两种设计对于办公/服务式公寓/酒店而言是完全不同的。原有的长方形设计模式为楼宇建造带来较高的施工成本，而现有的阶梯形设计则优化了楼层地板大小，最大程度地提升了楼层得房率和可实施性，并减少了机电和垂直运输系统设计的核心筒面积。

广州周大福中心机电系统和垂直运输系统设计特点:

- 因周大福中心所在位置可提供区域供冷系统，办公区域和地库裙楼均采用区域供冷冻水。二级中央冷冻站位于大楼地下室，为办公和地库裙楼区域提供后备冷冻系统。三个不同的能源中心分别为办公和裙楼区域、服务式公寓和酒店供冷，大大提升能源效益和系统可靠性，同时减低冷冻水系统的工作压力。挑战在于如何与建筑师和结构工程师配合，优化能源中心的位置，以此增强系统可靠性和能源效益 (如图7所示，能源中心位置) 。
- 变风量 (VAV) 系统将用于办公区域，风机盘管 (FCU) 系统则用于服务式公寓和酒店区域。为增强环境质量，设计旨在取得绿色奖项LEED金级认证和中国绿色星级认证，其中的一项方法是在设计中涵盖绿色工程设备，例如VSD冷冻机组、热回收冷冻机组、VSD冷却塔和水泵、热回收涡轮、二氧化碳及空气新风流量控制、节水阀、高能源效益灯具、空调冷凝水收集和再利用、废水处理和再利用等 (Herbert，2013) 。
- 垂直运输系统设计与CWTC 3A项目类似，可分为四个功能区域。办公区域设计有空中大堂，并划分为四个区域，全


Figure 9. Suzhou International Financial Square (450m) (Source: Courtesy of KPF)
图9. 苏州国际金融广场 (450米) (来源: KPF)

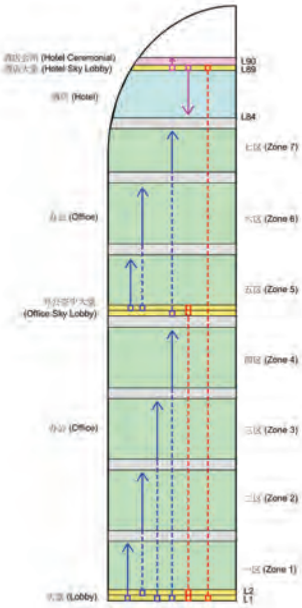

Figure 10. Suzhou International Financial Square VTS Stacking (Source: PB)
图10. 苏州国际金融广场垂直运输系统示意图 (来源: PB)

basement floors as well as mechanical floors above grade. The office area is served by a central water-cooled chiller plant at basement. Space heating system that utilizes the steam supplied from Suzhou Industrial Park is designed. Similarly, the hotel area has a separate water-cooled chiller plant and space heating is by means of the steam source from the aforementioned Park with back-up steam boilers.

All in all, the design challenges encountered in the MEP and VTS design of the Suzhou IFS are briefed as follows:

- Limited core area to accommodate different MEP system risers and equipment for various functional areas. Also, the core was trimmed at the top zone of the hotel due to the iconic shape of the building. Careful planning of the MEP vertical risers and VTS connections as to how they could be fitted inside the core with reduced sizes on the upper zones.
- There was continuing variation of floor numbers in each functional area during the entire design development phase, i.e., low-zone offices increased, mid-zone apartments increased, and high-zone hotels decreased. Each of these functional zones has its own MEP system with dedicated plant rooms and riser ducts. In achieving the target of higher floor efficiency, the core design constituted a great challenge for housing staircases, large amounts of elevator banks, and MEP risers for different functional zones. The attainment of maintainability, connectivity with mechanical floors, and minimum interference among systems, were possible due to the logical and strategic locations of the MEP risers and equipment within the tower core.
- The functional change from services apartments to offices at a later design stage of the project lead to the inclusion of more elevators and MEP risers for offices despite the limited core area. Double-deck office shuttle elevators were introduced to serve the upper office zones, so as to relax the core congestion, provide more room for additional MEP risers, as well as enhance the hotel shuttle elevators' performance by extending the elevator banks from 3 to 4 hotel shuttle elevators.

部由双轿厢电梯运行。区域1和2可直接乘坐直达电梯，区域3和4则须在空中大堂换乘短程本区电梯。服务式公寓和酒店区域设计与办公区域3和4的设计相似，但所有电梯为单轿厢运行，并可分别在服务式公寓和酒店空中大堂换乘本区电梯。

- 乘客可在酒店空中大堂换乘直达电梯，直接到达酒店顶层餐厅。此项设计如图8所示 (垂直运输系统示意图) 。总体来说，建筑核心筒面积的减少可提升楼层得房率，并降低风力对于建筑结构的影响，进一步减少建筑成本。

苏州最高建筑群

苏州塔楼

位于华东地区的超高层建筑当属未来建成后的某苏州塔楼，高约600米 (上人高度)，将成为一幢综合型发展超高层大楼。由于项目仍在设计阶段，因隐私和保密协议等原因，更多细节不便透露。

苏州国际金融广场 (IFS)

回顾过往，柏诚曾为苏州第二高楼——高450米的苏州国际金融广场 (IFS) ——进行机电和垂直运输系统设计 (如图9所示) 。此办公和酒店结合的建筑坐落于苏州工业园区，因不同的楼宇结构需要而产生机电和垂直运输系统设计难题。例如，在不改变建筑核心筒的前提下将住宅区域功能改为办公功能、建筑核心筒尺寸减小、核心筒导向和转换、在核心筒面积最少的条件下实现楼层效益得房率的最优化，以及客户对于电梯的特殊要求等。

在垂直运输系统方面，空中大堂转换设计应用于办公和酒店区域 (如图10所示) 。办公区域1至4区将可直接由首层电梯大堂进入，而办公区域5至7区将在空中大堂进行电梯转换。酒店空中大堂设在塔楼顶层，住客可换乘短程本区电梯往下到达各客房楼层。

在机电设计方面，办公区域和酒店区域将提供独立机电系统，便于日后运营和管理。主要机电房位于地下室和机电楼层，办公区域主要由位于地下室的中央冷冻机组提供空调冷冻需求，来自苏州工业园区的区域蒸汽作为采暖来源更增添设计亮点。类似的，酒店区域也由独立的冷冻机组供冷，并备有来自工业园区的蒸汽源和备用蒸汽锅炉作采暖及热源。

总体来说，苏州国际金融广场的机电和垂直运输系统设计的挑战如下:

- 有限的核心筒将容纳不同的机电系统立管和不同功能区域所需的设备。此外，由于塔楼顶端的独特设计缘故，酒店区域顶层的核心筒更为狭窄。如何将机电竖井和运输系统连接位合理地放置于顶层狭小的空间内，均须仔细规划。
- 各功能区域的楼层数量根据发展项目的设计进程不断发生变更，例如低层办公区域楼层增加，中层公寓区域楼层增加，高层酒店区域楼层减少等。每一功能区域都有独立的机电系统、机电房和立管结构。为保证高层区域的楼层效益和高得房率，如何将楼梯井、大量电梯组和不同功能区域的机电房/立管放置于核心筒内成为了核心筒设计的巨大挑战。在设计中须有技巧性地放置机电立管和其他设备，做到高维护性，并与机电楼层合理连接，以及让各系统间的干扰最小化等。
- 发展项目后期，服务式公寓区域转换为办公用途，这需要在有限的核心筒内放置更多的电梯和机电竖井。双轿厢穿梭电梯将应用于较高层的办公区域，以缓解核心筒面积不够的限制，同时为额外机电立管提供更多空间，并将酒店电梯组由三台扩展至四台，以提升运载能力及可靠性。

Conclusion

As ultra high-rise and mixed-use buildings are becoming more of a necessity than just a mere luxury, the demand for expertise and innovation in the construction of these landmark towers will be greatly needed. Not only must the structures and designs change over time to adapt to the environment, but also to satisfy the needs of the people who inhabit them. Extensive collection of experiences in the design and construction of tall buildings is summarized into the following key considerations/challenges from the MEP & VTS design (Vincent & Herbert, 2014) and operation viewpoints:

- Every building is unique; there is unlikely a "one-size-fits-all" design approach.
- Important factors on MEP system design stand point:
  - Regional environment
  - Micro-climate
  - System reliability
  - Green and energy efficiency
  - High tech and state-of-the-art
  - Cost effectiveness
  - Sustainability
  - Flexibility for future changes (operations & maintenance)
  - User-friendliness (operations & maintenance)
- VTS designs should be interactive and harmonised with the following:
  - Brand
  - Architecture
  - MEP
  - Structure
  - Costs
  - Operations

结语

当超高层建筑和综合型发展大楼逐渐成为社会的必需品时，建造这些楼宇所需要的专业技能和革新技术也日趋重要。楼宇的结构和设计须跟随环境和时间而改变，并满足租户的特殊要求。高楼建造中的大量机电及垂直运输系统设计经验可以总结为以下几项 (Vincent & Herbert，2014)：

- 每一幢建筑都是独特的，没有万能的设计方案。
- 机电系统设计方面的重要考虑因素包括:
  - 当地环境的需求
  - 微气候的考虑
  - 系统可靠性
  - 绿色及能源效益
  - 高端科技
  - 成本效益
  - 可持续发展
  - 未来变化的灵活性 (运营及维护)
  - 用户便利性 (运营及维护)
- 垂直运输系统的设计须要项目团队的互动及协调，并应注意以下几项:
  - 项目品牌
  - 建筑设计
  - 机电系统
  - 结构布局
  - 成本及造价
  - 运营及管理

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