Title: **Wuhan Center – A Sustainable Design Exploration for Skyscrapers**

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Subjects: Architectural/Design
Façade Design
Sustainability/Green/Energy

Keywords: Energy
Integrated Design
Mixed-Use
Sustainability

Publication Date: 2012

Original Publication: CTBUH 2012 9th World Congress, Shanghai

Paper Type:

1. Book chapter/Part chapter
2. Journal paper
3. **Conference proceeding**
4. Unpublished conference paper
5. Magazine article
6. Unpublished

Case Study: Wuhan Center – A Sustainable Design Exploration for Skyscrapers

案例分析：武汉中心——超高层可持续设计的探索与实践

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Weiping Xu, National First-grade Registered Architect, Chief Architect in ECADI. His honors include the Global Young Chinese Architects Awardand the Asia Architecture Promotion Award. Recent projects include National Electric Power Dispatching Center, China Hua Neng Group Headquarters, Beijing Hua Mao Center, JW Marriott & the Ritz-Carlton, Shenzhen Bauhinia Resort. Currently, he designed Wuhan Center at 438 meters high.

徐维平国家一级注册建筑师，教授级高级建筑师，华东建筑设计研究院有限公司总建筑师，曾荣获亚洲建筑推动奖、全球华人青年建筑师奖等。主持并完成了一些较有社会影响力的建筑作品，其主要代表作品为：国家电力调度中心，中国华能集团总部大厦，北京华茂中心办公楼，华茂JW万豪酒店与丽思卡尔顿酒店，深圳紫荆山庄等项目. 如今,他正从事高达438米的武汉中心大厦的设计工作。

Xiaoqiong Ma, PhD, Senior Engineer. In 2008, she finished her PhD thesis on 'Building Comprehensive Evaluation for Healthcare Facilities' at Tongji University. Dr. Ma has participated in several projects, such as Hongqiao Integrated Transport Hub, Expo-axis of Shanghai World Expo 2010, the Bin Hai CBD (Yu Jiapu), and Wuhan Center. Her work and research are primarily concerned with issues relating to sustainable skyscrapers, and the integration of building physics and computational technologies within the architecture and regional planning field.

马晓琼博士，高级工程师，2008年毕业于同济大学并获得工学博士学位，进入华东院以来参与多项重大工程的绿色建筑咨询和科研，包括虹桥综合交通枢纽、世博轴、天津于家堡金融区、武汉中心等。她的研究课题主要集中在可持续性超高层建筑的设计，及如何将建筑物理与计算机技术整合到建筑和区域规划设计当中去。

Abstract

Embodying the "sail" concept, Wuhan Centre will be mixed-use, with urban retail spaces at the base, a unique mix of office, residential, and hotel with a visitor's observatory at the 88th level, soaring 438 meters (1,427 feet) above Mengze Lake in Hunan Province. This paper analyzes several sustainable design features of Wuhan Centre, such as tower facade, integrated energy core and observation deck. It also explores architectural design optimization methods according to several skyscrapers designed by ECADI, not only depending on the techniques of sustainable building design technology, but also acceptable costs and considers the future increment.

Keywords: skyscraper facade, integrated energy core, observation deck, large spaces, sustainable design

摘要

由华东院原创设计的武汉中心，以引领CBD扬帆起航为设计理念；作为集办公、公寓、酒店、商业和观光于一身的超高层综合体，建筑塔楼采用折叠式玻璃幕墙单元、高区能源芯筒、多功能观景层等一系列高性能化设计，旨在体现超高层综合体的可持续建筑设计和资源有效配置，从而提高建筑的经济效益。

关键词：超高层建筑表皮，能源芯，高区多层观光平台，高大空间气流组织，可持续设计

Concept and Layout

Soaring 438 meters above Mengze Lake, Wuhan Center embodies the concept of "sail," just as an ancient Chinese poem said, "Heading to the sea in full sail, braving the wind and the waves," so the elegant building is named as "sailing vessel city." As the flagship of Yangzi River, this light, simple and modern design style adds a bright new star to the city's skyline. The plan is a sleek square, with two chamfers along the whole building, creating two bright epidermises. Folding glass curtain façade forms a digital epidermal mechanism, which complement the landscape of Mengze Lake. The cutting part atop the tower will be the crowning point meant to lead the entire CBD sailing (see Figure1). The sailing vessel hauling upon the wind with hope and power represents the developer marching forward courageously in the wave of economic development. The project construction commenced in 2009, and pile foundation work completed by 2012. The main tower structure is going to be completed in 2013 with the building opening for operation in 2015.

建筑理念与空间布局

武汉中心临水傍湖，形若帆船，寓名帆都，承直挂云帆济沧海之意。作为黄金水道上的旗舰，轻盈简约现代的风格为城市天际线增添一抹夺目的色彩。建筑平面以方形为原型，四边圆滑处理，几乎对称的导角使建筑自然形成两个光亮优美的表皮，折叠式单元式幕墙形成数码表皮机理，与波光粼粼相得益彰，顶部切削处理亦为点睛之笔，引领整个CBD扬帆起航，见图1。造型优雅、意喻为"帆都"的武汉中心，寓意大厦与建设方犹如迎风张满风帆的航船，满载希望与力量，在经济浪潮中乘风破浪勇往直前。建筑主体结构预计将2013年完成，大厦将在2015年正式投入使用。

建筑布局将438m高主塔楼前置，直面南侧梦泽湖，靠近城市道路交叉口，最大化利用道路便于车流人流出入的组织流线；裙房后置，面向地下交通枢纽，其商业空间围合市民广场；多种绿化形式相结合，形成多层次的景观网络结构。整个规划和设计尺度营造出空间与人的和谐共存，见图2。设计在有限的基地范围内营造出最佳的外部空间环境，平衡建筑密度与功能空间的关系，达到适度集中和合理开发。建筑塔楼由底层商业、26层高级办公、32层

Figure 1. Renderings
图1. 建筑效果图

The relationship between the tower and urban infrastructure has been considered. The Tower is located beside the main road in Wang Jiatun commercial district, near Youth Road to the east, next to Mengze Lake and Jianshe Avenue to the south, and convenient for traffic stream and organizations streamline. It is twenty-one kilometers away from the Tianhe International Airport, and less than two kilometers from Hankou Railway Station. The podium is next to the underground public transport hub, and the central public square is surrounded by retail spaces. Green features form a landscape network including roof garden and vertical greening. The scheme and design scale create a harmonious coexistence of building and environment (see Figure 2). A comfortable external environment is designed within the limited site, which balances the relationship between building density and functional space, achieving a moderate concentration and rational development. As a typical landmark urban complex building, the tower function is vertically divided into five parts. Wuhan Centre will be mixed-use, with 5-story urban retail spaces at the base, a unique mix of office, residential and hotel with an observatory at the 88th level. The main part of Wuhan Center consists of an office area from the 6th level, a 32-story residential section, and a grand hotel below the observation deck. Its construction area is about 370,000 sq m (3,980,000 sq ft) and the percentage of usable dwelling area is greater than 70% (see Figure 3).

High-rise towers can influence the environment around the local region, including wind, light, acoustic and thermal environment. It is heat and moisture in summer, and cold in winter along the middle-lower Yangzi River, so a series of building physical problems exists, such as block glare, too large wind speed, limited visibility, and heat island effect. Ecological considerations also include the supply of urban energy, emergency issues, high-density district, and surrounding low-rise buildings. Those factors have been fully considered during the design process.

Building Skin

Wuhan Center's design uses a simple, elegant, monolithic mass, created by lofting the square plan with curved corners vertically. Two slotted sides run through the tower, helping to reduce the wind pressure on the facade. The oblique roof atop the skyscraper makes the tower more slender (Xu, 2011). The initial design concept was to

酒店式公寓、24层星级酒店和位于88层的多功能观光阁组成，一次得房率70%左右，总建筑面积约35.6万m^2，见图3。

高层塔楼在建造前后势必会对其所在区域风、光、声、热湿环境产生不同程度的影响。项目地处长江中下游的夏热冬冷地区，存在夏季热湿、冬季阴冷、街区眩光、局部风速过大、能源输配不均衡、可视度受限、热岛效应、区域热量和污染等一系列问题，同时还包括城市能源供给、人员生命安全保障、突发事件处理预案、高密度建筑之间正负效应、独栋高层塔楼对周边低层建筑的影响。这些因素在设计伊始即被考虑，从而形成现在的建筑形态和功能定位。

建筑表皮设计

武汉中心塔楼原形设计采用简洁、优雅的独石式体量，在方形平面上以鼓边轮廓沿曲线放样，彰显灵动意境，两侧的开槽处理贯

Figure 2. Siteplan
图2. 建筑与场地布局

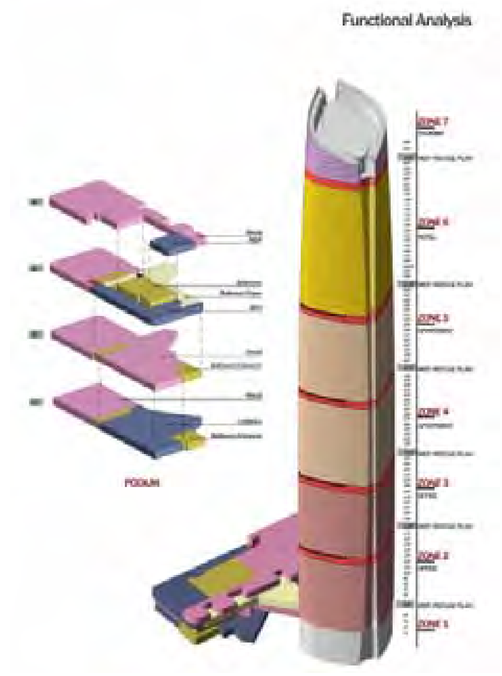

Figure 3. Function diagram
图3. 建筑功能分区

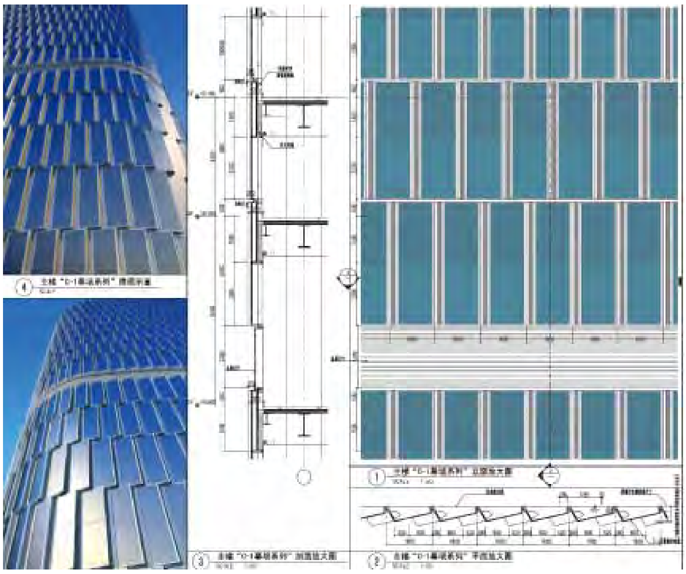

Figure 4. Facade System
图4. 幕墙体系

develop a skyscraper depictive of "sail" as a sustainable paradigm, so the façade is not only affects appearance and the lake landscape, but also indoor environmental quality and building performance.

The tower facade is composed of three types of envelop: micro oblique cascading style at the top, folding curtain wall unit in the middle, and stone vertical texture on the base. The middle part fits 1600mm horizontal modules of the skin, through staggered joint, cantilevering, and other methods. The podium uses horizontally textured skin, which maintains a visual balance with the tower. Fully glazed and sealed curtain wall systems represented the initial design concept initially.

Solar radiation can affect indoor natural lighting and thermal comfortable through the façade. Fully glazed and sealed curtain wall systems let in more light but increase the solar heat gain. Indoor comfort and natural lighting are influenced by building envelope and different solar elevation angles depending on the season. Skyscraper envelope occupies the major surface area of the tower, so envelope properties will influence building heat gain and loss greatly. If energy consumption can be cut by 10% compared to standard model which was designed according to GB 50189-2005, then the envelope contributes about 3%, during simulations. Facade materials not only relate to building appearance, but also influence the indoor environment with relation to solar gain and shade. The window to wall ratio is around fifth-five percent in this project, which was determined by the solar elevation angle and building heat gain, as well as by envelope windowsill height.

Folding curtain wall units can be the sun-shading itself, avoiding adverse effects of high-rise architectural forms to the indoor environment. In the optimization process of façade shading performance, several factors were considered, including shading effects in different direction, unit modulus, and the relationship between solar elevation angle and windowsill height (see Figure 4). Compared with smooth curtain wall, folding curtain wall units reduce the indoor heat gain and air conditioning energy consumption greatly in summer, ensuring adequate natural lighting in the winter, as shown in Figure 5 (Xu, 2011). The solar radiation accumulated on the façade will be reduced about 50% by using folding curtains in summer, especially on northwest facade (see Figure 6). It will be installed and replaced easily, and form high-light changes on the surface in the sun.

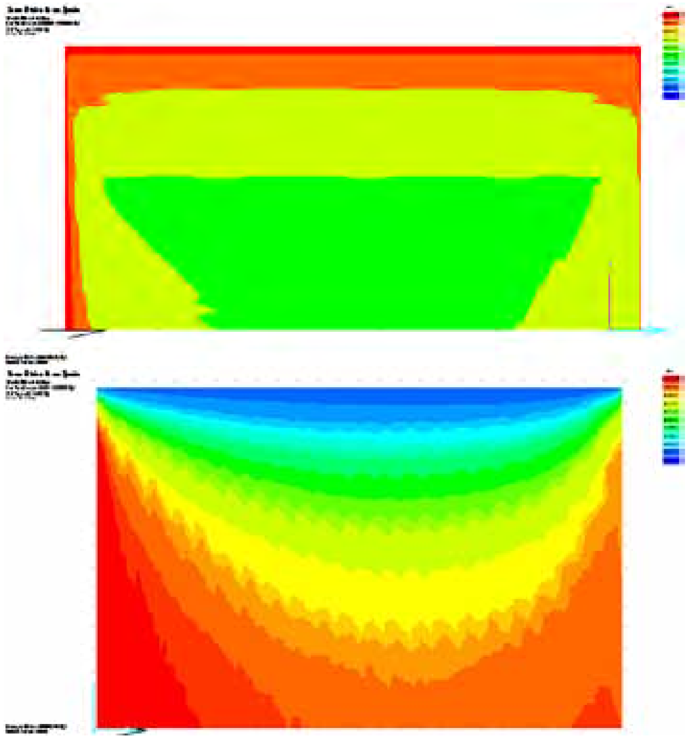

Figure 5. Solar radiation compares (Source: Xu, 2011)
图5. 局部幕墙的太阳辐射量（出自：徐维平2011）

通塔身，这一设计利于降低风压对超高层建筑的不利影响，顶部的斜截设计使建筑造型更显修长（徐维平，2011）。最初以“帆”为设计理念，充分考虑塔楼与周边景致的意境相容，可谓建筑造型到环境融合的最佳呈现。

塔楼表皮由三种类型组成，包括塔顶观景区的微斜层叠式样，中段的空间折叠式幕墙单元和选用石材为主竖向机理的基座。其中中段主体部分以错缝、错台、悬挑、退台拟合成1600mm水平模数的表皮。裙房采用水平向机理，与塔楼保持视觉上的平衡，张弛有度。塔楼的光滑全幕墙形式也进一步体现风帆的初期创作理念。

建筑室内环境从采光和热舒适两个侧面受到太阳的影响，太阳高度角的季节性特征影响采光，建筑表皮得热与室内舒适度也有很大关系。超高层立面占据绝大部分的建筑表面积，围护结构表面性能对建筑得热和热损失影响很大。在相比国标参照建筑节能10%的条件下，围护结构对节能率的影响达到约3%。立面材料的使用不仅关系到建筑外观与表现形式，还会与日照、遮阳等一同影响着建筑室内环境。本项目塔楼窗墙比基本在55%左右，窗台高度根据室内太阳光入射情况确定，以保持在有效高度上得到自然采光。

塔楼采用折叠式形体遮阳，避免超高层建筑形态对室内环境的不利影响。在对幕墙体系遮阳性能的优化过程中，充分考虑了不同朝向的遮阳效果、单元模数的立面效果、太阳高度角与内部空间窗台高度的关系，见图4。与光滑幕墙相比，现有幕墙形式大幅减小了夏季通过玻璃幕墙的建筑立面太阳累计得热量，见图5，同时冬季保证获得充足的光照（徐维平，2011）。使用折叠式幕墙，夏季表皮太阳累计辐射量可减少约50%，见图6。这一设计首先从太阳得热方面大大降低了建筑内部空间的热负荷，从而降低空调能耗，其次达到自然光与人工照明的最佳配置，同时在阳光照射下形成有趣的高光变化，动感夺目。鳞片状表皮便于安装更换。

核心筒的综合利用

在采用适宜气候特征表皮的同时，武汉中心的核心筒设计也旨在

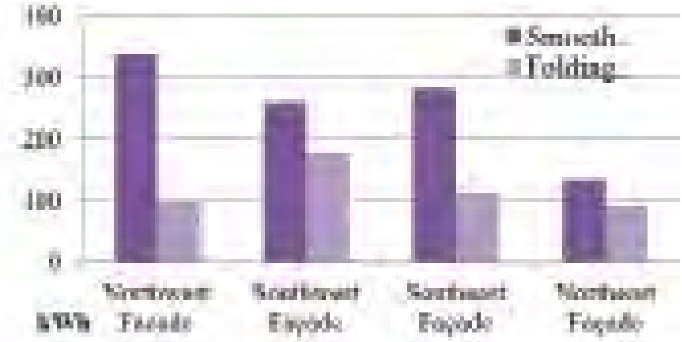

Figure 6. Solar radiations accumulated on façade in different directions
图6. 不同朝向光滑与折叠幕墙的太阳辐射累计值比较

The Multi-Functional Core

The core design of Wuhan center aimed at super-tall building utilization and efficient space layout. As an extremely important part of the skyscraper, it will be the main structural support, and accommodate a variety of vertical transportation and mechanical rooms. Through operating data investigations by several high-rises designed by ECADI, it indicated that the challenge to achieving sustainability is the energy consumption used for vertical transportation, HVAC, lighting and equipment related to the core. The tower core contains elevators, HVAC heat and cold sources, ducts and water pipes, and electricity supply lines which covers about 30 percent of the floor area. It becomes an important design element, which can be affected by design intention and functions.

The lateral force resisting system uses pillar framework, outrigger truss system, which form the cross aisle. It forms corridor public space or combined area by inside and outside corridor easily in standard floor, which can increase the second gain rate to 70%, see Figure 7. Vertical transportation systems are arranged in different regions of the core, which divide into several different groups separating hotel from others and allowing people to arrive at the observation deck through a direct shuttle elevator. Three elevators shuttle run from different refuge levels to the ground floor.

As the tower height increases from bottom to the top, core area reduces gradually, and indoor public space on hotel floors will have nearly 300 square meters free. Considering the structure cost, space utilization, air distribution and security risk problems, this part will be designed to be an energy supply and maintenance circulation space called the "Integrated energy core," instead of atrium. This optimal design concept used the remaining space of the core tube in upper zone to arrange mechanical, electrical and auxiliary systems in a shuttle elevator lobby, and the core periphery and corners. This layout was conductive to equipment maintenance. In early operational period, office and hotel occupancy rates should be around or less than fifty percent, energy consumption per area up to 400 kWh per square meter according to high-rise energy consumption data monitoring. Based on the above factors, "Integrated energy core" had been created during the overall core barrel design process. After several optimization and selection studies, a previous section of mechanical and electrical equipment in the podium moved to the high core excess space, forming more than 10 floors of device core.

"Integrated energy core" comprises of water supply and drainage processing rooms, four layers of hotel dedicated substation from the 76th level, six layers of HVAC plant room below the substation, and a control room at the 65th level. This energy core serves the hotel and the observation deck. It can save mechanical room space in the

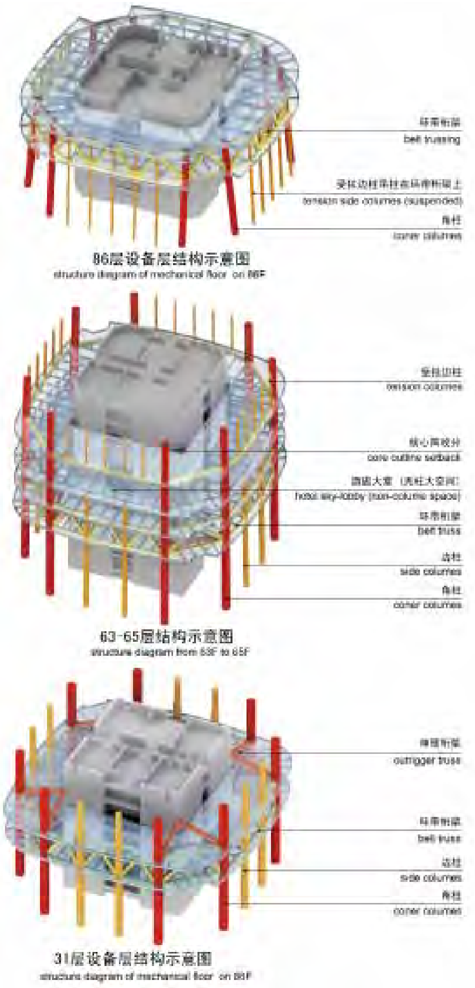

Figure 7. Structure Diagram
图7. 结构概念示意

最大可能提高建筑利用率和空间布局的高效。核心筒作为超高层建筑中极为重要的核心部分，不仅需要承担大部分的结构支撑，更需要容纳超高层建筑内部各种垂直运输以及机电辅助功能，是整个超高层建筑能够顺利运转的重要因素。根据华东院的超高层建筑设计经验，核心筒内垂直交通、暖通设备、照明设施、用电设备等耗能用户的高效运作是保证高层建筑能源有效利用的重要因素，占建筑平面面积约30%的核心筒涵盖这其中多个方面，并包含系统冷热源、管道管路、输配线路等能量传输设施，其设计的差异性在于设计环境与初始条件、建设技术、建筑高度、功能业态类型和数量、建造时间以及建筑轮廓等诸多方面。核心筒成为受设计意图和功能影响的一个重要设计元素。

武汉中心塔楼抗侧力体系为巨柱框架-核心筒-伸臂桁架体系，其内部结构体系使其形成十字形走道系统，易于在标准层形成内廊式或内外廊结合式的公共系统，提高二次得房率，见图7。垂直运输系统布置于核心筒的不同区域，通过电梯分组转换至不同区域，88层观光层配有直达穿梭电梯，在不同避难层亦有3组快速穿梭电梯协助人员疏散。

随着超高层的不断向上延伸，核心筒的需求面积逐步减小，内部公共空间面积在高区酒店多近300m²的内核空间。不同于普适做法，在考虑结构造价、空间利用、安全风险等各方面因素后，这部分区域不设置内部中庭，而设计成设备芯。超高层建筑由于需要克服重力运送能量以供给建筑能源需求，这使得运输代价高，对整体节能、经济性不利。在办公出租率或酒店入住率不高的运营前期，据我们实地的部分超高层建筑能耗数据监测统计，单位面积能耗最高可达400kWh/m²。基于上述因素，在武汉中心核心筒和内部空间的整体设计中，设计团队萌生了将裙房部分机电设备

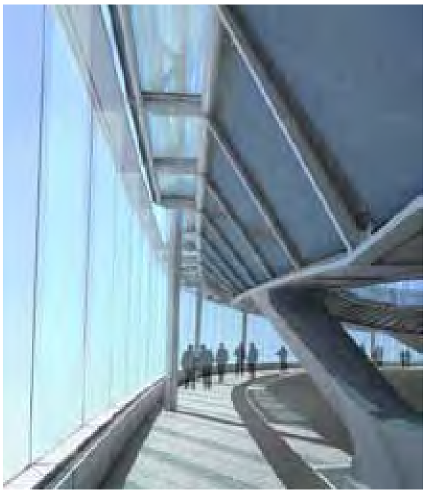

Figure 8. Observations deck
图8. 观光层室内效果

podium, reduce transportation energy consumption greatly, and avoid high energy consumption during early operation.

The building heating and cooling systems compose of centrifugal chillers, gas steam boilers and a cold-beam system with energy efficiency contained heat pump and water storage, which are divided into two parts, podium and energy core. Fresh air deals with dual-wheel heat recovery dehumidifier units. Water supply and drainage processing room in "integrated energy core" have intermediate water system to supply flushing water. The power distribution system uses multiple-line mode and three-independent power in each group.

Observation Deck

At the height of nearly 400 meters, the "Central China's first high" observatory is the most distinctive part of the tower. Tourists can see beautiful landscape in Yangzi River through the large observation deck on the 88th level with 18 to 42 meters high ceilings, which can accommodate 560 people in almost 4,000 square meters of building area. The observation deck can be divided into three independent units, including glass curtain wall system, double layered tourist area, and deck core. The tourism area has two layers along the façade, and tourists can see landscaping on the bridge platform from 5 meters above 88th level (see Figure 8). The inner region in this floor withstands the external steel frame conductive power and meet the vertical transport function. Tourists can also enter into inner region of the core to see outside, but it is separated into small rooms for private use.

The air distribution of the double layer observation area creates a comfortable indoor environment through a multi-way airflow, such as reusing exhaust as stratified air conditioning supply, three-way supply air through the bridge's internal space, and return air outlet located near the core. Three diffident air distribution modes were arranged and simulated, as shown in Figure 9 and Figure 10.

The first mode derived from the bridge, which has two diameters of 700mm and 450mm spaces internally according to structural engineers. Those spaces can be used to arrange ducts. The air distribution mode is upper supply along the envelope through the bridge's internal space to the improve thermal comfort for people on the bridge, upper supply along the envelope through 88th floor elevated levels, and return air to bridge's internal space though the bridge's inside edges. With this air distribution, supply air speed must be increased and people may feel a draft from the bottom.

The second mode is to change upper supply along the envelope through the 88th floor elevated levels to a downward supply outlet.

移至高区核心筒多余空间的想法，最终经过方案比选优化，形成纵深超过10层的设备芯。

设备芯的配置将整个建筑的能源利用分成两部分，高区酒店区域和观光阁均由核心筒内设备芯的机电设备供能，办公、公寓、商业区域由裙房设备机房供能。主机房中含有具节能效应的冷梁系统（含地源热泵和水蓄冷），设备芯内给排水处理机房（含中水系统）位于最上部可利用重力节省水泵扬程，酒店专用变电所从76层开始向上4层，之后为6层的暖通空调机房，弱电间位于最下面。机电机房的分区布置适应于超高层建筑不同时期的利用率，在资源输送能效、内部空间利用、检修查漏、运行风险等方面具有很大优势。

空调冷源按主冷冻机房（服务地下室、裙房、办公、公寓）及酒店区冷冻机房分别设置、各自独立，主冷冻机房采用常规电动离心式冷水机组、水蓄冷和地源热泵结合的冷源形式，从供能位置上分为裙房和塔楼设备芯两部分。能源芯还内含有水处理机房重力式消防给水系统及酒店专用变电所。电力分布系统采用了多线模式，每个群组都含有三个独立的电源。

多功能观光层

离地面400m堪称“华中第一高”的观光阁是建筑最有特色的部分，见图8，18m至42m的高大空间设计可容纳560人远眺长江美景，建筑面积达4000m²。建筑单元体以结构逻辑为核心，分为三个相互独立的单元，最外侧为玻璃幕墙系统，中部为玻璃幕墙支撑构架及其形成的双层观光内部空间，内部为建筑核心筒，承受外部钢架传导力并满足竖向交通功能。观光者亦可进入内部核心筒区域向外观景，所不同的是，这些观景区域被划分为小而私密的房间。

高大空间的多方式气流组织营造出舒适的室内观景环境，如顶部排风回用作高位分层空调、利用桥架内部空间三向送风、靠近核心筒的下回风等等，见图9和图10。内部立面分区的可伸缩式遮阳，保证观光客在充分享受江城美景的同时，避免夏季受到过多的太阳直射。

第1种气流组织形式，利用桥架空间内部，布置直径为700 mm和450 mm的风道作为送风风管。风口分布为沿幕墙边界下上送风结合沿芯筒边缘的下回风，这种气流组织形式利用桥架和88层下部空间，但人员可能会感到较大下吹风感。

第2种气流组织形式是将1中的88层下送风改为桥架向内外两侧下送风，充分利用桥架空间内部，但由于桥架内部空间有限，送风量不够。

第3种气流组织形式，保留1中的送回风布置方式，并在88层芯筒上部增加送风口，这里送入室内的空气为室内排风再利用，形成高大空间上下分层的效果，冬季充分利用排风热量，夏季亦可与芯筒内部空间共享冷量。

现在顶部空间的气流组织优化正在进行当中，目前优化的第3种形式优于前两者，见图10。观景层主入口的穿堂风也将在今后的模拟中得以考虑，同时高大幕墙引入的大量太阳辐射热也将通过部分内部遮阳措施的优化得以解决。

考虑到超高层建筑在武汉市的成长速度，在不久的将来，武汉中心周边会出现更多更高的建筑综合体，从而失去其高度优势，这时观光阁的使用功能就有可能发生变化。在建筑设计中，我们也对未来室内格局的改变做出了前瞻性设计，可将现有的大空间分成数个小空间，作为会所和餐厅使用，以保证顶部观光层的可持续利用。

小结

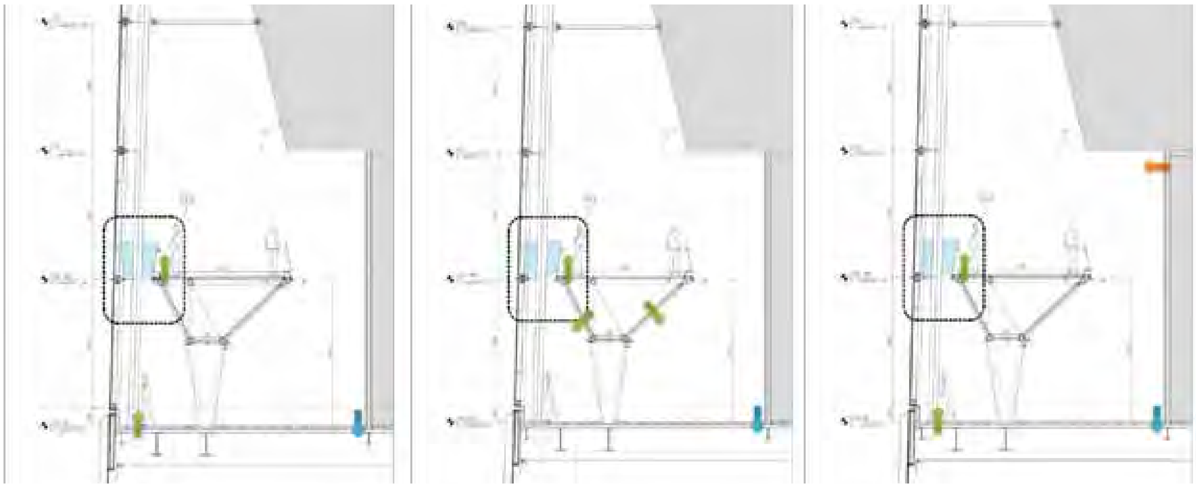

Figure 9. Three diffident air distribution modes
图9. 三种不同形式的气流组织形式

The space can get good thermal comfort, but the bridge internal space is limited, supply air volume is too large to design the proper air duct, so the second one isn't viable.

The third one is to reduce the total amount of supply air, and continue to use the first mode, and add stratified air ventilation from the core. Stratified air ventilation uses exhaust air from vents at the top of observation area to add its supply air volume in winter, and share the cool air with private rooms of core inner region in summer.

Now the optimization is in progress, it will be a better air distribution method compared to the other two conditions. The result is shown in Figure 10. The draft from the main entry to the observation deck is also being considered. Retractable shades on the internal façade are designed to maintain thermal comfort for tourists against the sun.

Taking into account the growth of high-rise buildings in Wuhan, there will be more skyscrapers in the next decade. Wuhan center may lose its height advantage, and the function of observation deck will be changed. This space can be used as clubs and restaurants instead of observation in the future, which maintains a sustainable use. The design blueprint has been drawn within the whole progress, which represents an design innovation from forward-looking perspective it is expected to achieve.

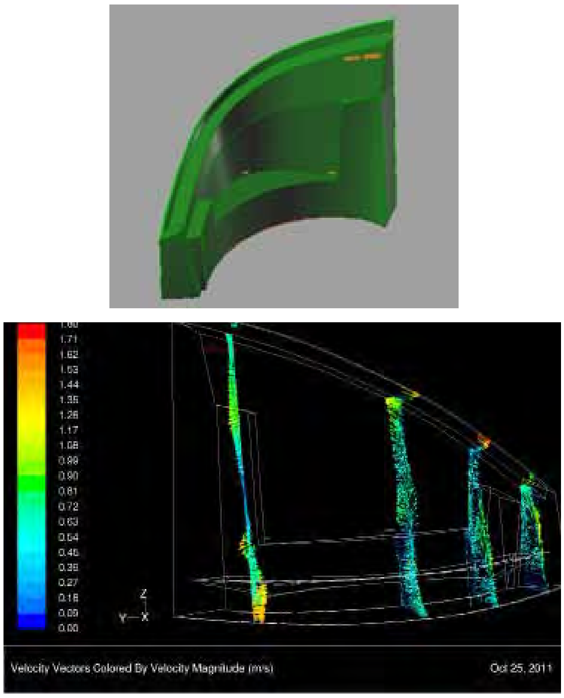

Figure 10. Air distribution
图10. 观光层气流组织

Conclusion

The super-tall building is not only related to itself but also to urban culture. Skyscrapers bring high density of land use, urban expansion, and regional economic stimulation, but consume large amounts of energy. The architectural design of Wuhan Center embodies the sustainable concept, combines architectural modeling and façade technology together, and uses efficient mature resources according to urban scale. Folding curtain wall units, integrated energy core with mechanical and electrical equipment, and a multi-functional optical observation deck are the main sustainable design points. With acceptable costs and technology, it will be our faith to design high performance and sustainable high-rises by considering the future increment.

超高层建筑的设计建造不仅关系到自身的性能，也与城市文化脉络密不可分，它带来了高密度土地开发和城市有序扩张，同时也消耗着大量资源。武汉中心的建筑设计充分体现了建筑理念与表皮技术的完美结合、建筑功能与资源能源的高效配置、成熟技术最有效利用、与自然环境的融合性设计。折叠式单元幕墙、核心筒能源芯和多功能可变换的顶部空间等是其现阶段的主要可持续理念贯穿点。没有使用高造价、高费用的新型能源，为区域发展预留了合理的未来空间，真正意义上体现了超高层建筑的可持续设计。

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