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Introduction of MEP Technologies
机电关键技术简介

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This chapter explains that, in addition to Shanghai Tower's peculiar height and unique architectural style, the project also targets a Green 3-Star and a LEED Gold certification. The complexity of its electromechanical system required advanced technology to create sufficient energy for the tower. The chapter endeavors to display the commercial use of the building space and how rigorous solutions to the electromechanical systems are required. Further, the management of system integration control and the application of BIM to electromechanical detailed design is elaborated upon.

本文简单介绍了上海中心大厦项目因其特有的高度和独特的建筑造型，及绿色三星和LEED金奖的建设目标设定，其机电系统的庞大和复杂性，运用了较多的先进机电技术和可持续发展能源; 为确保建筑空间的最大商业化有效利用，对机电系统提出的更高更苛刻要求的解决办法，包括特殊设备制造、系统集成控制管理、机电深化设计BIM运用等。

The project establishes a high and a low energy center. The high energy center area employs a conventional centrifugal refrigeration unit system while the low energy center area is in the form of multi-cold source. This includes cooling-heating-power system, conventional electric refrigeration system, ground-source heat pump system, and ice storage system.

The electro-mechanical system of the Shanghai Tower is particularly complex due to the tower's height and unique architectural style (see Figure 4.1). The design of the electro-mechanical system applies advanced technology to sustainably generate energy because it strives for a Green 3-Star and a LEED Gold Award. The heightened commercial use of the building space puts forward higher requirements on the electro-mechanical system. The introduction mainly includes the design and the manufacturing of ultra-silent: air handling units, ice storage systems, CPMS-Energies Management Systems, cooling-heating-power supply systems, sewage treatment reuse systems, integrated power supervisory systems, special lighting designs, BIM applications of electro-mechanical detailed designs, along with special construction schemes and technologies.

The Design and Manufacturing of Ultra-Silent Air Handling Units

Top grade office floors in Shanghai Tower are located in Zones 2–6. The maximum area of the floors cover 4,600 square meters. The minimum area is 2,400 square meters, and most of the stories are 4.5 meters in height. The depth of beam is about 700mm. There is 150 mm raised flooring setting requiring 3-meter ceiling heights. The space for the electro-mechanical pipeline inside the ceiling is limited. The layout of the core tube is a nine-rectangle-grid, while the effective usable space of office conforms to an annular plane layout. Vertical elevators of each district are set up in a nine-rectangle-grid core tube and the rooms and shafts of electromechanical equipment are intensively arranged along the core tube. Consequently, the core tube limits the space and area reserved for mechanical and electrical equipment. The air conditioning facilities and large office spaces and corridors are separated by only a wall, which saves space. In order to meet the required building's energy efficiency quota, many interventions occurred. For instance, Shanghai Tower maximizes utilization ratios of architectural

上海中心大厦项目占地面积30368平方米，建筑面积574058平方米，其中地上总建筑面积约410139平方米，主体建筑结构高度为580米，总高度632米。项目共设高、低区两个能源中心，高区能源中心采用常规的离心式制冷机组系统，低区能源中心采用多冷源的形式，包括三联供系统、常规电制冷系统、地源热泵系统与冰蓄冷系统等。

上海中心大厦项目因其特有的高度和独特的建筑造型 (见图4.1) ，使其机电系统尤为庞大和复杂，又因建设项目的绿色三星和LEED金奖的目标设定，机电系统设计和运用了更多的先进技术和可持续发展能源，建筑空间的最大商业化利用，对机电系统提出了更高的要求，本次简介主要包括超静音空调箱的设计和制造、冰蓄冷系统、CPMS-多能源控制系统、三联供系统、中水处理回用系统、电力综合监管系统、特殊灯光设计、机电深化设计BIM运用、机电特殊施工方案和技术等。

超静音空调箱的设计和制造

上海中心的高档办公区位于2—6区，其中最大的一层的楼面使用面积约4600平方米，最小一层约2400平方米，大部分层高为4.5米，梁高约700毫米左右, 室内设置150毫米高架空地板，室内净高要求做到

Figure 4.1. The Shanghai Tower has a unique architectural style and significant height, especially compared to the surrounding buildings. (Source: Gensler)
图 4.1 与周边建筑相比，上海中心大厦具有独特的建筑风格与出众的高度（来源: Gensler）

space and indoor story heights, and an all air VAV conditioning system. Since the indoor noise is required to be less than 45 decibels, noise elimination equipment is installed in the machine room and air blast ducts. By and large, the aforementioned measures still fail to meet the requirements of noise elimination. Thus, in the stage of equipment tendering, we put forward a highly rigorous test requirement for the noise of floor air handling units and air conditioning facilities. Also, we instated a more severe manufacturing requirement on the boundary dimensions of air conditioning units in order to also meet the needs for air conditioning room spaces.

We proposed the manufacturing of ultra-silent air handling units too. In the stage of design bidding, we evaluated noise levels of the units by testing the prototype's noise spectrum eight times according to the noise evaluation standard Nc40 values. Jiangsu Feng Shen won this prototype testing that was held as a public bidding process. Jiangsu was then able to manufacture units for the Shanghai Tower. The noise of the ultra-silent air handling unit adopted by Shanghai Tower has been reduced so substantially that they produce no more than 15 db (A).

3.0米，吊顶内留给机电管线的空间十分有限; 核心筒为九宫格布局，办公有效使用面积呈环形平面布局，九宫格核心筒内设置了各区大量的垂直电梯，楼层机电设备用房及竖井只能集中沿核心筒周边布置，留作机电设备用房的空间和面积十分有限; 空调机房与大空间办公室或走廊仅一墙之隔，为超常规设计; 为了满足建筑节能、建筑环境噪声、建筑空间的最大利用率、室内层高等等要求，空调系统采用全空气VAV内外分区变风量空调系统，吊顶回风，设定的室内噪声值要求是达到NC40以下，即45分贝左右; 因层高和空间的限制，导致机房及送回风管路均无法设置通用消声设备，无法满足常规消声要求。故在设备招标阶段，我们对系统噪声的源头即楼层空气处理机组及空调机房的噪声提出了较高的测试要求，对空调机组的外形尺寸等，提出了较为严苛的制造要求，以满足机房有限空间的要求。

我们提出的办公区超静音空调箱的制造和招标要求，是根据噪声评价Nc40标准，制定了机组8倍频谱的噪声值及样机检测要求; 在公开招标的样机检测中，最后的中标商 (江苏风神) 定向加工制造的超静音空调箱设备的各项技术指标已基本达到业主及设计要求。对比国家标准GB/T14294-2008《组合式空调机组声压计噪声限值【db(A)】》，上海中心采用的超静音空调箱机外设备噪声已大幅度降低了约15db (A) 以上。

CPMS-多能源控制管理系统

上海中心大厦作为超高层地标式建筑，体量大能耗大，节能降耗形势严峻，因此，如何降低项目在运行使用中的空调能耗，是我们面临的一个重要问题。本项目采用了中央能源管理控制系统 (CPMS)，有效实现空调负荷的准确预测和最大化的节能运行要求，使得空调各能源系统以运行费用最省、最节能、最优化模式运行，达到大厦整体节能降耗目的。

本项目高区能源中心采用常规的离心式制冷机组，低区能源中心采用多能源空调制冷制热系统，包括冰蓄冷系统、地源热泵系统、二次泵系统、免费冷源系统、三联供、常规离心式制冷机组，锅炉。冷热源设备包括:

- 热水型吸收式溴化锂机组
- 常规离心式制冷机组
- 双工况离心式机组
- 螺杆式地源热泵机组
- 燃气内燃发电机组
- 燃气蒸汽锅炉

CPMS中央能源管理控制系统的运行策略包括以下几个方面:

- 三联供系统的最佳组成及该系统之全年运行策略。
- 蒸汽锅炉及其配套设施的最佳组成，及该系统全年运行策略。
- 常规电制冷系统及其配套设施的最佳组成，及该系统全年运行策略。
- 冰蓄冷系统及其配套设施的最佳组成，及该系统全年运行策略。
- 热泵系统的组成及全年运行策略。
- 冷却塔采用集中控制，能够满足不同的设备的散热租户冷却水系统以及实施过渡季节免费供冷等需求的运行策略。

以上各能源系统、机组，通过能源管理以及冷热源机房监测与控制系统，简称为CPMS系统，对本项目的能源进行集中管理和控制。CPMS系统的控制目标: 其一是系统能稳定可靠地提供大楼各部分需要的冷量; 其二是在此基础上依据各系统特性，实现优化组合，达到运行费用最省的最优策略。系统最终的控制指标是根据不同室外条件、不同负荷需

Figure 4.2. The Shanghai Tower building envelope (Source: Gensler)
图 4.2. 上海中心大厦建筑表皮 (来源: Gensler)

CPMS- Central Energy Management Control System

As a supertall landmark building, Shanghai Tower will have a large volume and even larger energy consumption. The situation of energy-saving and cost-reduction is grim. Therefore, reducing the amount of energy consumption in use for this project is an important challenge that we are faced with. The project uses a central energy management control system (CPMS) to monitor the air conditioning load and forecast management demand. This system optimizes each subsystem's operation to achieve heightened energy-saving and cost-reduction.

High central areas employ conventional centrifugal refrigeration unit systems and low central areas employ a multi-cold source. This includes an ice storage system, a ground-source heat pump system, a secondary pumping system, a free cold-source system, a cooling-heating-power supply system, and a boiler.

- Cold and heat source equipments consist of lithium-bromide absorption heating units
- A conventional centrifugal refrigeration unit,
- A dual operating conditioning centrifugal unit
- Screwing ground source heat pump units
- Gas generating sets with internal combustion
- Gas steam boilers

Operational strategies of the CPMS or the Central Energy Management Control System, includes the following aspects:

- Optimizing the composition of the combined cooling, heating, and power systems with combined operational system
- Refrigeration system consisting of steam boilers with combined operational strategy
- General Electric refrigeration system with combined operational strategy
- Ice storage systems and the optimally combined operational strategy
- The composition of the heat pump system and combined operational strategy

求、不同设备运行效率、不同时段、不同能源价格等因素条件下，力求能源投入与能源产出的最佳效益。

系统招标为系统集成招标，包括双工况离心式冷水机组 (YORK) 、CPMS控制系统 (Johnson Controls) 及深化设计等。

冰蓄冷系统

作为主要调峰填谷手段，上海中心空调系统设计采用了冰蓄冷系统，实现低温送风，节省水风输送系统的投资和能耗，具有应急冷源、空调可靠性高、供冷启动时间短 (只需15-20分钟即可达到所需温度，常规系统约需1小时) 等特点，系统共选用3台空调制冷量为1800RT的双工况制冷主机，总蓄冰容量为26400RTh; 采用间接融冰钢盘管式分量内融冰串联式系统，该系统的特点是节能、易控制; 系统可以实现: 单制冰 (双工况主机制冰) 工况、 单融冰 (蓄冰装置单独融冰供冷) 工况、 单供冷 (双工况主机单独供冷) 工况) 、联合供冷 (双工况主机+蓄冰装置联合供冷) 工况; 乙二醇循环泵采用变频控制，满足各个工况运行要求。冰蓄冷系统的主要运行原则: 低谷电时开足主机制冰，高峰电时不开或者少开双工况制冷主机，并尽可能减少主机的启停次数，确保前一天的蓄冰量能够在次日白天的供冷中全部融完。主机开启时尽可能让其在高负荷率下运行，提高系统效率，具体运行由CPMS系统给出指令。

冰蓄冷控制系统作为一个相对独立的控制系统，可以对整套冰蓄冷系统的所有设备进行控制，完成冰蓄冷各模式的运行与切换，保证按照CPMS发来的指令及要求运行; 可以随时向CPMS系统通过通讯方式提供所有参数，CPMS系统对冰蓄冷控制系统的数据进行采集、显示、存储、分析，并对冰蓄冷控制系统发送系统运行命令。

系统招标为系统集成招标，即包括双工况

- The cooling tower adopts centralized controls of an operational strategy of heat dissipation and water cooling systems that meet the requirements of different equipments, allowing for free cooling in the off-season

All energy systems and units mentioned above monitor and control the systems energy consumption. In short, the CPMS system aims to centralize management and control energy consumption for this project. Control targets of the CPMS system include: providing each part of building with required cold energy, realizing the optimum combination of units and systems, and providing the optimal strategy to reduce operational costs. The basis of the final control indexes are the outdoor conditions. The basis of the control will also control various load demands, equipment operation efficiency, different time frames, and energy prices. The CPMS will always strive for the optimal energy input and output.

System bidding included a dual operating centrifugal chiller (YORK), CPMS control system (Johnson Controls) and deepening design amongst others.

Ice Storage System

The design of Shanghai Tower's air conditioning system adopts an ice storage system. This achieves a supply of air at low temperature, saving investment and water consumption. With the features of an emergency cold source and a high reliability of air conditioning, the set-up time of cooling is short, requiring only 15-20 minutes to reach the required temperature. Typical systems usually take an hour. The systems select from three dual-operating chiller units. The refrigerating capacity of the air conditioner is 1,800 RT with a total ice storage capacity of 26,400 Rth. By adopting an indirect ice-melting steel disc tube component that melts ice internally there is increased energy saving and ease of control. The most efficient operating conditions are created by efficiently pumping ethylene-glycol through an elaborate air conditioning system. Parts of this system include single ice-maker chiller units alongside an ice-melting device. Also included is an ice-storage system teamed with a dual operating conditioning unit. The system in its entirety is primarily operated with low Ebb electricity without opening peak electricity. This system paired with dual operating conditioner units results in less frequent switching on and off ensuring that the previous day of ice could then be melted for the following day of cooling. The CPMS system will then inform the system when operated under a high loading rate, again, improving efficiency.

The CPMS system will allow an ice storage system to operate rather independently. The CPMS will continue to update itself with the latest parameters. It will then continuously collect, illustrate, store, and analyze the data on a regular basis. In turn, the system will always be running at peak efficiency.

System bidding is an integrated bidding system that includes a dual operating condition centrifugal chiller (YORK), ice storage device, ethylene-glycol pump, cooling water pump, transformation chilled water pump, electric and automatic control system (Hua Yuan) and a deepening design.

Cooling-Heating-Power Supply System

In line with the requirements of attaining both a Green 3-Star and a LEED Gold certification, the design of this project utilizes a cooling-heating-power supply system made of two sets of 1.1MW gas internal combustion generating sets in addition to 2 sets of 1000KW lithium-bromide heating unit. Further there are 2 sets of 1300kW grade plate type thermal water heat exchangers, automatic controls and a corresponding auxiliary system. The average annual load

离心式冷水机组 (YORK) 、蓄冰装置 (BAC) 、乙二醇泵、冷却水泵、板换冷冻水泵、电气与自控系统 (华源) 及深化设计等。

三联供系统

根据绿色三星及LEED金奖要求，本项目设计采用了三联供系统，由2台1.1MW燃气内燃机发电机组+2台1000kW热水型溴化锂机组+2台1300kW级板式热水型换热器+自动化控制及其相应的配套系统构成。 系统开机状态的年平均负荷率为95%，系统开机状态的年平均能源利用率为80%左右 (发电效率约40%，余热利用率约45.8%) 。每天按16小时运行，每天启动时间为6:00，每天停机时间为22:00，全年运营335天以上。 系统年均发电量约为1072万kWh ，年均供冷量约为893万KW，年均供热量约为328万KW。年节约标准煤约1098吨/年; 年减排CO2约6277吨/年。

天燃气冷热电三联供又称为天然气分布式能源，在国际上发展迅速，在我国目前天然气分布式能源尚处于起步阶段，建站数量有限，保持三联供设备有效运行的更有限; 其最主要的行业难点是系统集成问题，三联供主要设备发电机的国际供应商仅提供单机设备，不提供系统集成工作，其他配套设备如溴化锂机组、换热器等，大部分为国产化采购，故完整系统的系统集成及控制，需依靠设备供应商或系统集成商来自主研发完成，需要的系统集成能力主要体现在: 系统设计、系统安装、运营管理三个方面，难点主要是需求侧负荷预测，燃料、电、热、冷供给匹配、适用、连续及稳定性等，成为了该系统在能源经济效率、能源利用效率、能源环境效率三方面影响项目成败的关键因素，也直接关系到本项目的三联供系统能否正常、稳定运行。

本项目对三联供系统的另一个专项要求是减震降噪，现系统设备配置的机房内噪声达到<78db (A) ; 机房外及控制室噪声<60db (A) ，已基本满足并超出业主技术规格要求。

三联供系统作为本项目低区能源中心一种相对独立运行的能源使用子系统，需同时与能源中心的CPMS系统保持联系和通讯沟

rate of the system powered on is 95% of the average annual energy efficiency of about 80% (the generating efficiency is about 40% and the waste heat utilization is about 45.8%). The system runs from 6:00 to 22:00, or 16 hours per day, for 335 days of the year. Average annual output of the system is about 10.72 million kWh, with an average annual cooling capacity of about 8.93 million KW. The average annual amount of heating is about 3.28 million KW saving 1,098 tons of standard coal per year and roughly 6,277 tons of Carbon dioxide per year.

Electrically heated and chilled water congeneration, also known as natural gas distributed energy, is developing rapidly in the world. The distributed energy resource of natural gas is still in its infantile stages in China. The quantity for the site is limited. To keep the combined cooling and heating power equipment effectively operating is much more limiting and is the main difficulty of the system integration. The international supplier of CCHP equipment generators only provide a single machine unit. System integration is not available. Other equipment, such as lithium bromide sets and heat exchangers are procured domestically. Therefore, the system integration and control of the complete system is reliant upon the independent research and development of the equipment suppliers or system integrators. The abilities of system integration are mainly reflected in its design, installation, operation, and management. The main difficulty of the system is the load forecasting demand, fuel consumption, electricity, heating and cooling supply equilibrium, application, succession, and stability. These all became the three key factors affecting the project success or not. Further, the economic efficiency, energy use efficiency, and the energy environmental efficiency is also directly related the project's success.

Another requirement for a combined cooling and heating power system in the project is the damping and noise reduction. Now, the noise of the machine room that is set by system equipment reaches to less than 78 db (A) while the noise of outside the room and control room reaches to less than 60 db (A). The noise levels now meet and exceed the technical specifications of the owner.

Combined cooling, heating, and power systems, such as the energy-use subsystem of the lower energy center in the project, are relatively independent operations. At the same time it needs to keep in touch with the energy center CPMS system and communication, supplying heating and cooling according to the CPMS system's instructions. The combined cooling and heating system and the Shanghai Tower's power system adopts an EMC contract energy management mode. The partner is CSIC (Shanghai) new Energy Co., Ltd. (formerly: Shanghai JiYao new energy technology co., LTD.).

Sewage Treatment Re-Use Systems

In order to meet the requirements of the National Green Building Three-Star Standard, the non-traditional water resource utilization ratio of functional areas should not be less than 25% for Shanghai Tower Hotel. Non-traditional water resource utilization ratios of business offices should not be less than 40%. Therefore, the design scheme of Shanghai Tower makes full use of all kinds of high-quality miscellaneous drainages that captures rainwater into a "grey water" system, or a system that captures rainwater to be used only for activities where the water does not come into contact with the human body. Examples of grey water usage would be construction water consumption, basement garage washing after processing, irrigation, toilet-flushing, etc.

The sewage reuse system establishes three sets of waste and raw water treatment. Respectively, 1 set is in the L66 layer and 2 sets are in the B5 layer. The raw water treatment system of the L66 layer is responsible for collecting and processing the recycled and raw water of the L66 - L121 layers. The raw water treatment system of the B5 layer is responsible for the collecting and processing of recycled and raw water from L65-B5 layers. The former deposed water is mainly

通，根据CPMS系统指令供应冷热，并在指定的时段内开启，与其他子系统联合运行。上海中心三联供系统采用EMC合同能源管理方式，合作方是中船重工 (上海) 新能源有限公司 (原: 上海齐耀新能源技术有限公司)

中水处理回用系统

为基本满足国家绿色建筑三星标准要求，上海中心大厦酒店住宿功能区的非传统水源利用率不应低于25%，商务办公功能区非传统水源利用率不应低于40%。为此，上海中心大厦设计方案充分利用各类优质杂排水和全部可收集的屋面、广场雨水资源，作为建筑杂用水水源，处理后回用于地下室车库冲洗、室外水景补水、室外绿化浇灌、冲厕等非人体直接接触用水。

中水回用系统共设三套废水原水处理系统，分别置于L66层一套和B5层两套，其中L66层原水处理系统负责收集并处理L66层—L121层中水原水，B5层原水处理系统负责收集处理L65层—B5层中水原水，前者处理出水主要用作厕所冲洗水，后者1#中水处理系统出水用于冲厕外，还将用于地面冲洗、洗车，2#中水处理系统用于水景补水、绿化浇灌等。

中水处理工艺 (同济建设科技) : 生活污水--消能水池--格栅井--调节池--MBR池--消毒--中水箱--加压至用户; MBR池采用膜分离活性污泥法，材质: PVDF，孔径: 0.4um，外径: 2.8mm。

雨水回用系统共设四套雨水处理系统，分别置于L66层一套和B5层三套，其中L66层雨水处理系统负责收集并处理L66层—L121层雨水原水，B5层雨水处理系统负责收集处理L65层—B3层雨水，前者处理出水主要用作厕所冲洗水，后者处理出水用于冲厕外，还将用于地面冲洗、洗车等。

雨水处理工艺 (同济建设科技) : 雨水收集--消能水池--调节池--盘式过滤器--消毒--中水箱--加压至用户; 盘式过滤器过滤精度: 55um; 清洗方式: 内源反洗; 清洗周期: 2Hr。

电力综合监管系统

Name 名称	Location 位置	Quantity 数量	Illustration 说明
110kV/10kV Main Substation 主变电所	B1/B2	1	Two routes 110KV incoming line 两路110kV进线 Two sets 40MVA main transformer两台40MVA主变
Emergency generator room 应急发电机房	B1	1	10kV, 0.4kV
Combined cooling heating and power generator room 三联供发电机房	B2	1	10kV
10kV/0.4kV	B1		Underground地下: 6个
Substation 变电所	B2		
	B3		
	First section 一区 6F	1	Overground地上: 8个
	Second section二区 20F	1	
	Third section 三区 35F	1	
	Fourth section四区 50F	1	
	Fifth section 五区 66F	1	
	Sixth section 六区 82F	1	
	Seventh section 七区 99F	1	
	Eighth section八区 116F	1	
Wind turbine 风力发电机组			1250kW

Table 4.1. Overview of the power supply system.
表4.1. 供电系统总览

used for toilet flushing water. The water of the latter water treatment system is used for flushing, and will also be used for ground washing, car washing. The number 2 water treatment system will be used for supplementing the waterscape, irrigation, etc.

Technologies of the sewage treatment (source: Tongji Construction Technology) include a domestic sewage dissipation pool, a grille well, a regulating reservoir, MBR pool disinfection, and a sewage treatment tank. The MBR pool adopts: membrane separation and activated sludge processes. The material is PVDF with a 0.4um pore size and an outer diameter of 2.8mm.

上海中心大厦供电系统包括: 110kV/10kV变电所、应急发电机房、三联供发电机房、10kV/0.4kV变电所、风力发电机组等，供电系统采用总变-分变的模式，以减少线缆和强电井的占用面积，从而减少公摊面积 (见表4.1) 。

供电系统的特点是建筑物高、负荷大、设备多、电源多、不同功能竖向分区多; 对电力系统的控制策略、继电保护装置的合理性、多个配电分区的日常运行管理等，提出了较高要求。我们设计并招标采用了大楼电力综合监管系统 (电能管理系统/南京天溯) ，分变电所进行就地控制和区域管理，总变进行集中监管。对高压电力自动化系统进行继电保护、全电量检测、遥控和运行监测等; 对低压电力自动化系统进行全电量检测、遥控、运行监测等; 对ATS、应急发电机控制系统提供决策支持; 对风力发电、三联供、FAS、BAS、泛光照明等预留接口，对综合电能状态、运行状态、控制信号等进行必要的监测。

特殊灯光设计

上海中心大厦除功能性灯光照明设计外，为充分体现建筑形态和特点，在V型槽、各区中庭—空中花园、塔冠设置了泛光照明。

作为地标性建筑，上海中心大厦地处陆家嘴的核心地段，与金茂大厦和环球贸易中心共同成为区域的核心建筑 (见图4.3) ，为在特定时段充分展示上海城市夜景之美和上海的未来发展城市形象，我们选择性的在地面、空中花园、设备层及塔冠设置和预留了为灯光秀演绎所必须的灯光系统和架构，为将来丰富的灯光剧情编组演绎打下了基础。

机电深化设计BIM (BUILDING INFORMATION MODELING) 运用

上海中心的BIM工作是一项集设计、建模、检测、计算、模拟、数据集成等工作为一体的三维建筑信息管理工程，这项工程覆盖于本工程的设计、深化设计、制造、施工管理乃至后期运营管理的建筑全生命周期，上海中心独特的外形、非同一般的复杂结构，加之众多超新理念的机电系统，使机电系统的设计、施工特别是管线综

The rainwater reuse system establishes four sets of rainwater treatment systems. Respectively, 1 set is in the L66 layer and 3 sets are in the B5 layer. The rainwater treatment system of the L66 layer is responsible for the collecting and processing of rainwater and raw water of the L66 - L121 layers. The rainwater treatment system of the B5 layer is responsible for the collecting and processing of rainwater of the L65-B3 layers. The former deposed water will be mainly used for toilet flushing, while the later is used for flushing. It will also be used for ground washing, car washing, etc.

The rainwater treatment process (source: Tongji Construction Technology) will collect rainwater through: a dissipation pool, regulating reservoirs, disc filter disinfection, and a sewage treatment tank that is pressurized to users. The disc filter filtration accuracy is 55um and is cleaned through an endogenous backwash that takes two hours.

Electrical Comprehensive Supervisory Systems

The power supply system of the Shanghai Tower includes a 110KV/10KV substation, an emergency generator room, a combined cooling heating and power generator room, a 10KV/0.4KV substation, and a wind turbine. The power supply system uses the mode variation-dividing to reduce the occupied area of cables and a heavy cable draw pit decreasing the total area(see Table 4.1).

The power supply system of the project is characterized by heavy loads and various vertical partitions of different functions. The relay protection device distributes multiple partitions daily during the operation management. This puts further requirements on the controlling strategy of the power system, the relay protection device, and the daily operation management of multi power distribution partitions. We designed and bid the electrical comprehensive supervision system of the building (electric energy management system/NANJING TIANSU). This includes, but is not limited to, the local control and regional management for transformer substation, the centralized management for total variation, the relay protection for the high voltage electric power automation system, remote controlling, and running the monitoring for the whole power quantity. This is also operated on an automated low voltage electrical power system providing decision support for the ATS emergency generator control system, the reserving interface for wind power generation, the combined cooling and heating power, FAS, BAS, and flood-lighting.

Special Lighting Design

In addition to the functional lighting design, Shanghai tower is equipped with floodlighting situated within the V-groove, district atrium hanging gardens and tower crowns to fully embody the architectural form and characteristic.

As a landmark, Shanghai tower is located in the core area of Lujiazui together with the Jin Mao tower and the global trade center as the core regional architecture (see Figure 4.3). Shanghai Tower will display the beauty of Shanghai and solidify the city's image of future development. Also, we selectively set up a reserve lighting system and framework for light shows on the ground.

BIM Applications for Detailed Electromechanical Design

The BIM system of the Shanghai Tower consist of 3-D building information, management information, and engineering systems. This is then combined with design, modeling, detection, calculation and simulation, and data integration covering the whole life cycle of building.

合，都带来了前所未有的挑战; 设计施工的重点难点部位包括: 高、低区能源中心、塔冠设备区、各区设备层、与幕墙/钢结构配合紧密的极小细节等等; 如没有BIM的三维设计模型，仅靠二维施工图，机电专业工程师是无法想像机电各专业系统之间、机电与土建、钢结构、幕墙之间是如何搭建各种空间关系的，机电的管线综合将寸步难行。通过机电三维模型导出二维深化设计图纸，使深化设计质量得到保证，确保了可实施性。以三维形式的施工交底、以四维形式为基础的工艺安排及施工方案的确立，已经适时地渗透到安装工程的施工管理过程中。同时，以BIM参数化设计为基础的管道预制加工，使得机电安装工程的模块化、工厂化进程也进入了数字化、信息化的阶段。

上海中心项目机电安装单位–上安的BIM团队，在上海中心机电系统的主要运用成果包括

基于BIM的机电协调和技术决策

从境外的方案设计到国内的施工图设计、从深化设计到现场实施、从设备招标采购到供货商设计加工，均是BIM以信息化、数字化的沟通模式，使各个团队以相通的工作模式、相同的工作语言在一个互通的平台上协同作业。机电深化设计正是在这样一个信息交汇平台上，使得设计依据、设计成果更加直接和即时高效; 同时，BIM模型也是一次全面的"三维校审"过程， BIM工程师发挥专业特长发现了大量隐藏在设计中的问题，这点在传统的单专业校审过程中很难做到，经过BIM模型的建立，使得隐藏问题无法遁形; 机电深化设计正是在BIM模型及运用过程中，发现了各机电专业、各系统之间、管线设备与实际空间之间存在的众多设计问题和技术问题，以及可实施性和可建造性等问题，也使得业主与设计、施工之间的沟通更加有效、便捷，使业主/设计/施工等各方面能更快速的找到问题的解决办法、更有效的做出技术决策和统一认知、解决问题的办法也更加准确、顺畅和相互协作。

基于BIM的管线综合

传统的机电管线综合设计都是以二维图纸为基础，在CAD软件下进行各系统叠加。设计人员凭借自己的设计与施工经验在平面图中对管线进行排布与调整，并以传统平、立、剖面形式加以表达，最终形成管

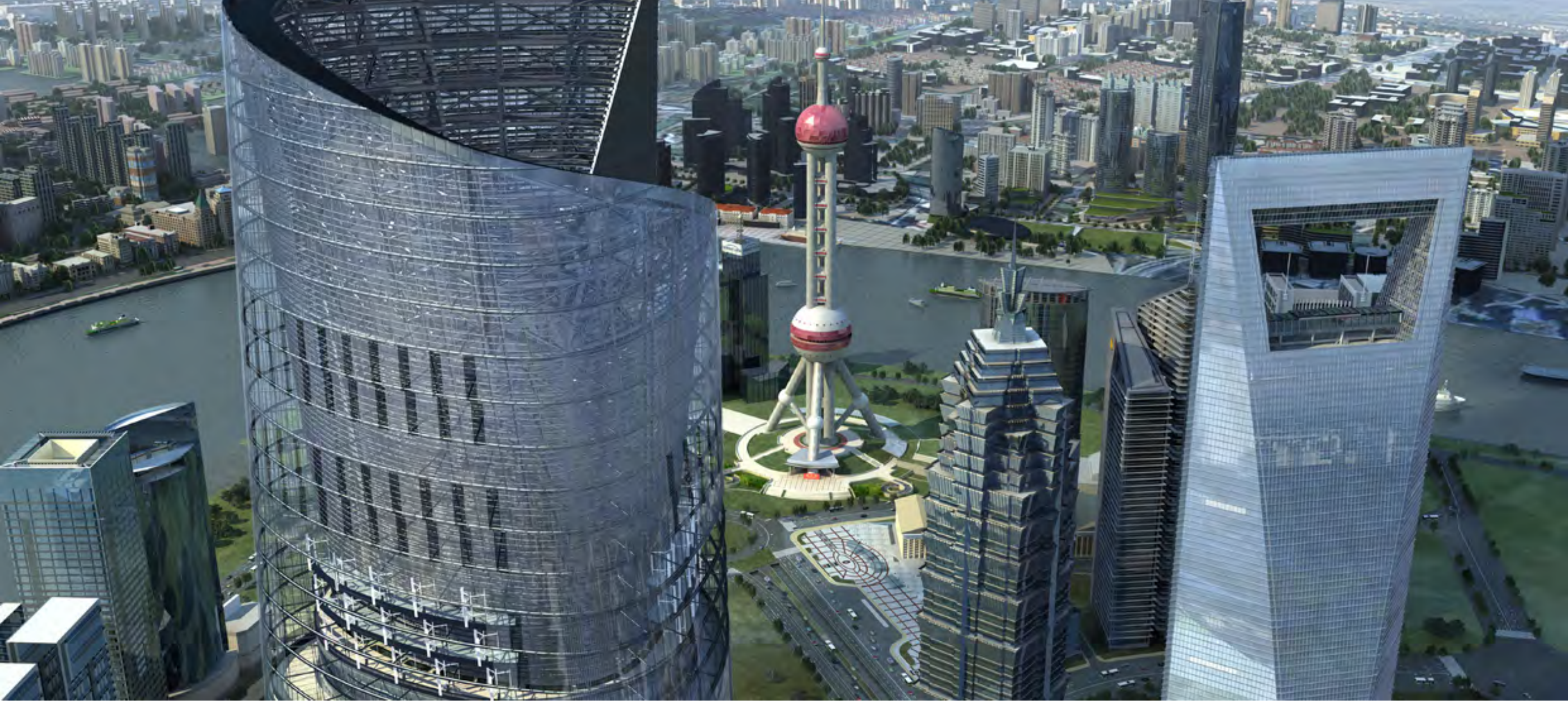

Figure 4.3. The top of the Shanghai Tower acting as a landmark (Source: Gensler)
图 4.3. 上海中心大厦塔顶地标 (来源: Gensler)

The unique appearance and extraordinarily complex structure of the Shanghai Tower, together with many new concepts of electromechanical system, has brought unprecedented challenges in the design and construction of the electromechanical system. For instance, the pipeline integration design and construction includes a high and low energy center, a tower equipment zone, a device net of partitions, and details of coordinating the compactness for the curtain wall and steel structure. It proves a difficult task for electromechanical engineers to address the various kinds of spatial relationships between the electromechanical systems. The electromechanical and civil engineering, the tailored steel structures, and the curtain walls depend on 2-D drawings. This makes it difficult to establish electromechanical pipeline integration. Using BIM, electromechanical 3-D models can export 2-D drawings, guaranteeing quality of detailed designs and ensuring feasibility. Three-dimensional construction details are for technical disclosures and establish construction plans. BIM also processes the specified arrangements on the basis of four-dimensional forms and has been duly infiltrated into the construction management process of installation project. Therefore, based on the BIM parametric design of the piping prefabrication process, modularization and industrialization processes of the electromechanical installation project entered the stage of the digitalization and informatization.

The mechanical and electrical unit installation in the Shanghai Tower project was completed by a Shanghai Installation BIM team applying the results of the Shanghai Tower's mechanical and electrical system.

Electromechanical Coordination and Technical Decision-Making Based on BIM

The process of making the electromechanical system consisted of construction drawing designs, in-situ implementation, and equipment procurement. All steps of the process are based on the ability of each team to quantify and digitize their coordinated operations. This occurred with a communication platform using the same methodology and working language. The in-depth electromechanical design utilized information interchanging, allowing a straightforward and effective implementation of the design. Meanwhile, the BIM model also acted as a method of comprehensive "3-D examination." BIM engineers utilize their expertise and discovered many design problems that were previously unapparent. This is really difficult to achieve in the traditional examination process. Through the establishment of a BIM model, insight into potential problems becomes available. For instance, the electromechanical design is included in the BIM model. The model finds various design and technical problems between the electromechanical sectors, pipeline equipment, and actual spaces, which are then implemented into the building. It also makes the communication between the proprietor and building designers more efficient and convenient thus making it possible for instrumental problem solving.

Pipeline Integration Based on BIM

Traditional electromechanical and pipeline design integration is all based on 2-D drawings consisting of systematic overlays in CAD software. By using a thorough design process and building experience, the designer can make adjustments to the pipeline using traditional graphic techniques. For instance, façades and cut planes would inform the pipeline

线综合设计。这种以二维为基础的图纸表达方式，不能全面解决设计过程中不可见的错漏碰撞问题，影响到一次安装的成功率。同时在一般的深化过程中只对管线较为复杂的地方绘制剖面，但对于部分未剖切到的地方，不能完全保证局部吊顶高度、操作空间等问题。在本项目中，上安的机电深化设计团队，改变了传统的深化设计方式，利用BIM的三维可视化进行设计。在三维环境下将建筑、结构以及机电等专业的模型进行叠加，并将其导入到Navisworks软件中进行碰撞检测，并根据检测结果加以调整。通过BIM三维可视化的特点弥补个人空间想象不足，实现复杂区域管线合理高效排布，确保各深化区域可行性和合理性。

基于BIM的管线优化

在三维环境下，可以通过任意角度的查看模型中的任意位置。所以，通过BIM软件进行方案对比，可以根据实际情况选择最优的管线排布方式，创建更加合理美观的管线排列。在不影响原管线功能及施工可行性的前提下，将机电管线进行适当调整，优化空间，快速解决碰撞问题，管线合理布留。同时，通过高效的现场资料管理工作，即时修改快速反映到模型中，获得一个与现场情况高度一致的最佳管线布局方案，有效提高一次安装的成功率，减少返工。

基于BIM的设计成果检测

BIM技术则通过将各专业模型汇总到一起之后应用碰撞检测的功能，快速检测到并提示空间某一点碰撞，同时可高亮显示、以便于快速定位和调整管路，大大提高了工作效率。本项目中机电深化设计利用Navisworks软件的碰撞检测功能，直观地观察到了管线的碰撞检测情况和位置。然后，返回到Revit软件中根据碰撞的情况将各个碰撞点一一调整解决，调整完成之后再次对模型进行了第二次的检测，如有碰

integration design. This traditional design method was based only on two dimensions and cannot comprehensively solve some problems concealed within the drawings. The process of designing will therefore influence the successful rate of installation. Meanwhile, section planes of the complex parts of the pipeline in the traditional process cannot guarantee the local height of a suspended ceiling, operation space, etc. In this project, Shanghai Tower's specialized electromechanical team strayed from the traditional design method, utilizing BIM's 3-D visualization in order to make design decisions. Using the 3-D approach, designers were able to overlap the model of the constructor with the structural and electromechanical designs. Further, Navisworks software conducted collision examination and made adjustments throughout the entire design process. By using BIM's 3-D visualization, traditional human oversight could be corrected. This aided in the realization of the highly efficient lay-out of complex sections, ensuring the feasibility and reasonability of every in-depth section.

Pipeline Optimization Based on BIM

In the 3-D environment, a model can be examined at any angle. Therefore, by comparison of BIM, software may choose optimal pipeline configurations according to actual conditions, thereby creating rational and beautiful line arrangements. The proposed arrangement will not adversely affect the function and construction feasibility of the original pipeline. The mechanical and electrical pipelines may be adjusted, appropriately optimizing space while quickly solving the problem of collision. At the same time, through efficient site data management, instant modifications can be quickly reflected in the model thereby reflecting the best plan layout which is highly consistent with actual conditions. This immediacy improves the success rate of one-time installations and reduces the amount of repeated work.

Detection of Design Achievements Based on BIM

BIM technology is capable of collision detection by collecting all various professional models together in a single workspace. The software then highlights conflicts to quickly locate and adjust pipelines, greatly improving work efficiency. Designing the mechanical and electrical systems in this project uses the collision detection function of Navisworks. It visually observes the location of pipeline and determines collisions. It then returns to the Revit software solving and adjusting collision points one-by-one according to the collision's data. Then secondary models detect collisions after adjustment. Should a collision remain, it may be modified until, finally, the results of the final test detects "zero" collisions.

Examination of Working Drawings and Confiding Technical Intentions

The BIM model then proceeds to examine working drawings and confides technical intentions by using the design capabilities and visibility of BIM model. This reduces communication obstacles and provides the most convenient, intuitive way of relaying information, so as to improve the work efficiency.

Automatic Prefabrication Processing Based on BIM

Originally, vertical transportation contradictions within super high-rise projects were major issues. Prefabrication provides a vital way to reduce the pressure of vertical transportation. However, it is more practical to prefabricate the interior and exterior framework of the 600-meter-high tower crown and hat truss. Due to the arrangement of the construction process, installation of equipment and pipelines must precede the construction of the curtain wall because of the risks of high-altitude outdoor construction. At the same time, many of the primary system are placed between the mega-truss and the criss-cross with the main system. The narrow construction space makes prefabrication a prerogative. So far, using automated prefabrication processing technology on the mechanical and electrical systems have reduced 30% of the on-site workload in the project overall, reducing 60% of the welding and harmful work. 50% prefabrication rate of pipeline production effectively saved 6% of the labor costs.

撞则继续进行修改，直至最终检测结果为"零"碰撞。

图纸会审、技术交底

利用BIM模型的设计能力与可视性进行机电深化设计图纸会审和技术交底，减少各方的沟通障碍，提供最为便利、直观的沟通方式，从而提高工作效率。

基于BIM的自动化预制加工

历来，超高层工程的垂直运输矛盾是制约项目顺利推进的最大困扰，而工厂化预制则是减轻垂直运输压力的一个重要途径。然而，在600多米高度的塔冠内外八角框架处及帽桁架处的管道预制加工设计则更具实际意义。由于施工流程安排，设备及管道的安装必须先于幕墙施工之前，因此，超高空户外施工的风险是显而易见的。同时，众多的主系统设备安放在巨型桁架之间，与主干线系统纵横交错，施工空间狭小也使得预制加工势在必行。截至目前，机电采用自动化预制加工技术方案已为本项目减少30%现场工作量; 减少60%的焊接与有毒有害作业; 实现50%管道制作预制率; 有效节省6%的人工成本。

基于BIM的施工模拟

针对本项目的特点，大型设备的吊装方案等，通过三维、四维BIM模型演示，管理者能够更科学、更合理地对重点、难点进行施工方案模拟及施工指导，BIM的应用提高了专项施工方案的质量，使其更具有可建设性。利用BIM软件在施工方案模拟的动画中，侧重具体的重点难点部位、施工工序的先后关系及时序，在动画中详细地对各个工序之间的先后关系进行描述，使具体施工人员可以一目了然地了解施工的先后顺序，并准确有效的完成重要节点的施工工作，提高整个施工效率与质量。

机电特殊施工方案和技术运用

上海中心的设备、大宗材料，垂直吊运和设备安装的施工难点和特点包括:

设备和大宗材料吊装和运输的施工量巨大

楼层材料吊装运输4000吨，地下室2000吨。楼层设备3500吨，地下室设备2500吨，总计约有12000吨左右的吊装运输施工工作量。

大型设备吊装高度高，区域分布广，吊装

Construction Simulation Based on BIM
According to the characteristics of the project and the large equipment hoisting plan, the 3-D and 4-D model simulates the key difficulties of the construction schemes and provides construction guidance. The application of BIM improves the quality of the specialized construction schemes, making it more efficient. The construction scheme animation of the BIM software focuses on specific and difficult details, successively revealing relationships between construction processes and time sequences. Also, it illustratively describes, in detail, the relationship of each working procedure allowing construction personnel to clearly understand the construction sequences, and to accurately and efficiently accomplish important nodes of the construction work. This improves the efficiency and quality of the whole construction process.

Special Construction Scheme and Technical Application of Electromechanical

Features of the equipment, bulk material, vertical hoisting, and equipment installation of construction in Shanghai Tower includes:

Large Quantities of Equipment and Bulk Materials were Hoisted
4,000 tons of story materials, 2,000 tons of the basement materials, 3,500 tons of story equipment, 2,500 thousand tons of basement equipment totaling 12,000 tons of construction workloads were hoisted.

Large–Scale Equipment Hoists with Wide Region Distribution
Hoisting and transportation of equipment focused on the first to fifth ground floor, the nine equipment floor areas, and the sixth floor to crown tower. Every 15th layer has two devices. 82 layers of the Shanghai Tower have six sets of 20 ton refrigerators that are lifted into each floor, each with a hoisting height of more than 450 meters. The tower crown equipment hoists each boast a height of more than 600 meters. The height of hoisting construction is affected by weather factors, which dramatically increase the difficulty and risk. The equipment distribution is wide while the protection of the workload remains a great factor even after the completion of the equipment installation. The construction scheme of the hoisting platform is adopted by the construction unit to effectively and smoothly lift electromechanical devices to each area.

Installation of Prefabricated Large-Scale Air Ducts
Air ducts of the project are all commercially produced by in-situ assembly. This accelerates the progress of construction, reducing construction interference of the limited operation site and consequently decreases noise pollution.

Installation of Light Group Hanger
According to comprehensive drawings of the pipeline, on- site piping would use a large amount of light group hangers, all continuously commercially supplied as each unit was finished. This reduced the on-site hanger welding workloads, effectively improving the installation environment, and reducing the total weight of the steel.

Equipment Information
The mechanical and electrical systems of the Shanghai Tower project are categorically large, creating unique challenges. With the sheer quantities of equipment being handled, using two-dimensional coding to input information before the delivery of equipment became invaluable. Equipment based on two-dimensional code made for convenient hoisting transportation, partitioning, and hierarchical classification installation. At the same time, BIM facilitated the efficient future property operation and management in conjunction with all electrical and mechanized units.

难度和风险大。
设备吊装和运输主要集中在地下一至五层，楼面设备层主要有9个区域，从6层至塔冠，每隔15层就有两个设备层。其中82层有6台20吨的冷冻机要吊装进楼层，吊装高度超过450米，塔冠设备吊装高度超过600米。高区吊装施工时受天气因素影响大，更加造成吊装难度和危险性加大。由于设备分布区域非常广，设备就位安装完成后的产品保护工作量大且难度大。 施工单位采用的吊装平台施工方案，有效顺利地将各区大型机电设备吊装至各设备区。

大型风管的预制安装
本项目所有风管均在工厂内生产加工，现场进行拼装。加快了现场施工进度，减少了有限作业场地的施工干扰和施工环境噪声。

轻型组合支吊架安装
根据BIM管线综合图纸，现场管线安装采用了大量的轻型组合支吊架，均为工厂成品加工供货，减少了现场支吊架的焊接工作量，并且有效改善了现场安装工作环境，且减轻了型钢材的总重量。

设备信息
上海中心大厦项目机电系统庞大，设备种类、分类、设备型号、设备数量、安装位置更是各有不同，数量巨大，为便于吊装运输，分区分层分类安装，同时便于今后物业运行管理主要设备、大型设备等，如风机、空调箱等等，在各设备出厂前均使用了二维码对设备进行信息录入，现场安装人员、各级管理人员等，均可根据二维码查询设备关键信息。