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Initial Research of Technical Essentials in Core Design of Skyscrapers

超高层建筑核心筒设计技术要点初探

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Abstract

The design and research of high-rise building cores have always persisted throughout the design circle of each supertall building. Based on skyscraper projects the authors have worked on in recent years, there are several key points which should be considered in the core design of skyscrapers. Starting from vertical transportation, planning organization, fire exiting, and MEP pipeline arrangements, this paper analyzes the related contents on core design of supertall buildings in order to provide a reference for supertall building design strategies.

Keywords: Supertall Buildings, Core, Elevator Organization, Fire Evacuation, Pipeline Arrangement

摘要

在每一个大厦设计周期内，核心筒的设计研究都是贯穿始终。笔者根据本人最近几年所接触的超高层项目，梳理出关于核心筒设计需要关注的几方面要点。从电梯的竖向及平面组织、消防疏散及机电管线组织入手，分析超高层建筑核心筒设计的相关内容，为超高层建筑方案设计决策提供参考。

关键词：超高层建筑、核心筒、电梯组织、消防疏散、管线布置

Introduction

Today, supertall buildings are rapidly developing in Asia and height records are repeatedly being broken. It is reported that some design firms have started a supertall building design with building height over 1000 meters. The core, closely linked to the regular operations of the tower, acts like the artery of the skyscraper and is also closely related to the standard floor usage of the tower. Therefore, the design and research of the core have always persisted throughout the design process of each supertall building. This is done to achieve a comfort and evenness of the cores and to obtain the highest efficiency for spatial utilizations. Based on previous skyscraper projects in recent years, this paper will summarize some essential elements in supertall building core design that designers should pay close attention to.

According to various forms of standard flooring, supertall building plans can be generally divided into three types – point, bar shapes, and irregular shapes (see Figure 1). There are two principles of core design arrangements. The first is providing effective

引言

如今超高层建筑在亚洲地区飞速发展，而高度也屡创新高。据悉已有设计公司开始进行高度超过1000米的超高层设计。在超高层建筑中，核心筒如同超高层建筑的生命动脉，不仅与大厦的正常运转息息相关，也与大厦标准层使用率紧密相连。因此在每一个大厦设计周期内，核心筒的设计研究都是贯穿始终，以尽力达到核心筒使用舒适顺畅，空间节约且使用率达到最佳状态。笔者根据本人最近几年所接触的超高层项目，梳理出关于核心筒设计需要关注的几方面要点。

超高层建筑根据标准层的不同形式可大致分为点式、板式及异型三类，与此相对应，其核心筒布置也有单核，双核和多核等不同类型。请见图1。核心筒的布局原则一是提供有效便捷的竖向交通，二是提供完整灵活及尽可能具有均好性的使用空间，同时也能与结构体系相适应。不同核心筒类型会有不同设计要点，本文主要注重于单核设计要点。

电梯组织

电梯是超高层建筑中唯一的高效移动手段。大量使用面积叠加在有限的范围内，

Figure 1. Single-core Plan (Standard Floor Plans, The Skyscraper in commercial center of Nanshan, Shenzhen), Double-core elevator Plan (Standard Floor Plans, Tianjin Tianchen Tower), Multi-core elevator Plan (Standard Floor Plans, Beijing TV Center)
图1. 单核平面示意（深圳南山商业中心区超高层标准层平面），双核平面示意（天津天辰大厦标准层平面），多核平面示意（北京电视中心标准层平面）

and convenient vertical transportation systems; and the second is creating intact, flexible, and consistently high-quality spaces that can be occupied which can be adapted into the structural system. Different core types have different design element requirements. This paper primarily focuses on single-core design features.

Elevator Arrangement

Elevators are the only highly efficient way to move vertically in supertall buildings. Since many occupiable areas are overlaid in limited areas, it is extremely important to integrate elevator organization into core designs.

Vertical Organization of Elevators

Normally, there is a high running efficiency of elevators within a height of 50 meters. In supertall buildings over 150 meters, the elevators are usually arranged in groups, running in zones, or adding to the sky lobby to maximize elevator efficiency. With the development of elevator technology, double-deck elevators have been extensively used in elevators traveling through all the floors and ones traveling through individual zones to greatly increase efficiency. In order to solve problems in elevator connections and transitions between upper zones, lower zones, and composite patterns running in segments in the sky lobby, the proposals are as follows:

- Upper section reduced zone layout method: for instance, the first segment (the lowest section) of the elevator is divided into high, middle, and low zones; the second segment divided into high and low zones is vertically located above the elevator shafts of the middle and low zones of the first segment; the third segment divided into high and low zones is also vertically located above the elevator shafts of the high zone of the first segment as well as the low zone of the second segment to avoid conflicts between upper and lower dimensions. This proposal is characterized by requiring more entrances on the first floor than other options (see Figure 2).
- Two reverse running sections method: the first segment is divided into high and low zones rising from the first lobby; the second lobby is located in the middle of the second segment. The elevator going up from the second segment is arranged above the high zone elevator shafts of the first segment and the elevator going down from the second segment is arranged above the low zone elevator shafts of the first segment to avoid conflicts between upper and lower zone dimensions. This proposal is characterized by an opposite movement that

使电梯组织在核心筒设计中显得尤为重要。

电梯的竖向组织

通常电梯在高度50米左右的范围内运行效率较高，因此在高度超过150米的超高层建筑中，多采取电梯成组群控布置，分段运行或增加空中大堂复合电梯分段运行的模式，以达到电梯效率最优化。随着电梯技术的发展，双层轿厢电梯也在穿梭电梯和区间电梯中广泛运用，大大提升电梯效率。在空中大堂复合电梯分段运行的模式下，为解决上下区间电梯交接问题，可有如下解决方案：

- 上段减一布置法：如，第一段（最低一段）电梯分高、中、低三个区；第二段电梯分高及低两个区，位置在第一段中区及低区电梯井道的垂直上方；第三段电梯也分高及低两个区，位置在第一段高区及第二段低区电梯井道的垂直上方；这样就避免了上下尺寸的冲突。此方案特点是首层所需出入口数量较其他方案为多（请见图2）。
- 上段反向两分运行法：第一段分高及低两个区，从第一大堂向上运行；第二段大堂设在第二段区域中部，在第一段高区电梯井道的上方布置第二段上行电梯，在第一段低区

Figure 2. Elevator Zoning Law 1, drawn by Lijie
图2. 电梯分区法示意一 （出自：作者自绘）

Figure 3. Elevator Zoning Law 2, drawn by Lijie
图3. 电梯分区法示意二（出自： 作者自绘）

passengers might not be accustomed to (see Figure 3).

- Utilizing mechanical floor heights and refuge floors: since custom elevators do not need a stop on mechanical or refuge floors, this space can be used as an elevator overrun, mechanical rooms, and an elevator pit. To meet the requirements, the sum of the heights of the mechanical and refuge floors should be approximately twelve meters. This proposal is characterized by high floor-to-floor height for mechanical floors and refuge floors which are also adjacent to each other (see Figure 4).
- Proposal four utilizes all double-deck elevators. This organization method not only reduces the quantity of elevator shafts, but it also reduces the quantity of first floor entrances. However, the application of this system will cause a more stringent limit for the standard floor height of the tower and requires maintaining a small variation for each floor height with the current elevator technology. Furthermore, the connection between odd and even-numbered floors is also inconvenient. Although the operating efficiency of a full double-deck elevator system is relatively high during rush hour, the operating and maintenance cost will also be quite high the rest of the time.

Comparing multiple elevator arrangements in a 74-story, 400 meter-high supertall building, proposal one illustrates its requirement of at least five entrances on the first floor but reduces the number of elevators needed where the sky lobby placement is not necessarily combined with the refuge floor. Proposal two reduces the number of entrances required on the first floor but needs a higher transference space with no elevator stop to overlay the elevator zones. Due to the utilization of the integration of double-deck shuttle elevators and single-deck zone elevators, proposal three can reduce the quantity of elevator shafts used which takes full advantage of double-deck elevator benefits. Proposal four reduces the number of elevator shafts and first-floor entrances because all of its elevators are double-decked. If only the double-deck elevator system is utilized, there will still be problems that need to be resolved (see Table 1).

Elevator Surface Arrangements

The surface arrangement of elevators can be divided into these types:

Figure 4. Elevator Zoning Law 3, drawn by Lijie
图4. 电梯分区法示意三（出自：作者自绘）

电梯井道的上方布置第二段下行电梯。这样就避免了上下尺寸的冲突。此方案的特点是乘客可能不习惯反向运行(请见图3)。

- 利用设备层及避难层高度：由于乘客电梯在设备层及避难层不需要停层，所以可以利用这个空间布置电梯的缓冲、机房及底坑。一般设备层与避难层高度之和应在12米左右才能满足需要。此方案的特点是需要避难层与设备层相邻而且高度高（请见图4）。
- 方案四全部使用双轿厢电梯，不仅是梯井数量最节省的组织方式，同时也可减少首层出入口数量。但全部使用双轿厢系统对于塔楼标准层层高限定较为严格，在目前电梯技术下要求各层层高变化幅度很小。另外是单数层与双数层间联系较为不便。同时，虽然在高峰期全双轿厢系统运行效率较高，但平时非高峰期电梯运行成本及维护费用均较高。

某超高层高400米，74层，在其电梯组织多方案比较中可看到：方案1中，首层需要至少5个出入口，但电梯数有所节省，且空中大堂位置不必与避难兼设备层相结合。；方案2中可节省首层出入口数量，但区间电梯叠摞时所需转换空间较高，且转换区间电梯没有停站。方案3由于使用双轿箱穿梭梯和单轿厢区间梯相结合，节省了梯井数量并可充分利用双轿厢电梯的优势。方案4全部使用双轿厢电梯，不仅可节省梯井数量，同时也减少了首层出入口数量。但全部使用双轿厢系统尚有多种问题有待解决（请见表1）。

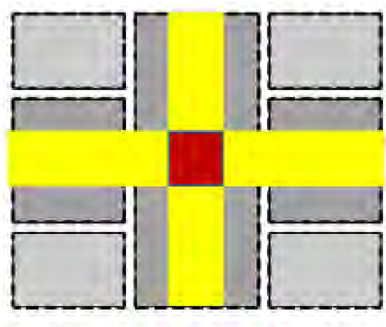

Figure 5. Cross-pattern Arrangement of Core Tubes, drawn by Lijie
图5. 十字型核心筒布局示意 （出自：作者自绘）

			Proposal 1 方案一	Proposal 2 方案二	Proposal 3 方案三	Proposal 4 方案四
The Layout Of Elevator Arrangements 电梯组织形式	Sky Lobby 空中大堂	Quantity 数量	Two Sky Lobbies 两个空中大堂	Onw Sky Lobby 一个空中大堂	Two Sky Lobbies 两个空中大堂	One Sky Lobby 一个空中大堂
	Elevator Shaft 穿梭电梯	System Format 系统形式	Single-Deck Elevators 单层轿厢	Double-Deck Elevators 双层轿厢	Double-Deck Elevators 双层轿厢	Double-Deck Elevators 双层轿厢
		Number Of Groups 分组数量	Two Groups 两组	One Groups 一组	Two Groups 两组	Two Groups 一组
	Zone Elevator 区间电梯	System Format 系统形式	Single-Deck Elevators 单层轿厢	Single-Deck Elevators 单层轿厢	Single-Deck Elevators 单层轿厢	Double-Deck Elevators 双层轿厢
		Number Of Groups 分组数量	Three Groups+Two Groups+Two Groups 三组+二组+二组	Three Groups+ Three Groups 三组+三组	Three Groups+Two Groups+Two Groups 三组+二组+二组	Three Groups+Two Groups 三组+二组
Total Number Of Passenger Elevator 载客电梯总数量			56	50	51	34
Number Of Passenger Elevator Shaft For First Floor 首层载客电梯井数量			32	34	27	27
Number Of Elevator Lobby Entrance For First Floor 首层电梯厅入口数量			5	4	5	4
Note: 备注			Index: 10 square meters/ person, attendance rate is 100%, the load factor during morning rush hour for five minute is 15%, during lunch rush hour is 12%, the average waiting times is 25s to 30s 指标：10平米/人，出勤率100%，早高峰5分钟运载率15%左右，午餐高峰5分钟运载率12%左右，平均等候时间25秒～30秒			

Table 1. Comparison of Different Elevator Arrangements
表1. 不同电梯组织方案对比 （出自：作者参与项目内部资料）

a cross pattern, an I-shaped pattern, a grid pattern, and a hybrid pattern.

The plan arrangement of cross-pattern elevators is characterized by the cross axis of the elevator lobby where the central point of the cross is designated for transportation space only. With the extension of the elevator arrangement, its four corners are used as subsidiary spaces. The advantage of the elevator hall facing the four directions is to have a better centrosymmetric and adaptable arrangement (see Figure 5).

Due to the different arrangements of subsidiary spaces on the four corners, the cross transportation plan of the standard floors' corridor arrangement can generate a ring-shaped pattern and an H-shaped pattern. In order to reduce as much unnecessary corridor area as possible within a whole floor of open offices, an H-shaped arrangement is preferred. Due to different elevator placements, there could be other orientations of H-shaped corridors on different standard floors. Different orientations will influence door opening directions that are needed in the four corner subsidiary spaces on each floor to limit and decrease the efficiency of the four corner spaces. Therefore, the best plan is to have the elevators traveling through their designated zones arranged in pairs to ensure that the occupiable floor corridors are oriented in the same direction to improve efficiency (see Figure 6).

I-shaped elevators are arranged side-by-side based on an I-shape to save spaces designated for corridors only at the crossing point with a compact arrangement. This saves more space than a cross-pattern and is also more economic. It is quite easy for the core to develop in a rectangular pattern because the evacuation stairs, subsidiary spaces, and adjacent elevator lobbies are arranged side-by-side. Since the elevator lobby and subsidiary spaces can only open toward two directions in an I-shaped core arrangement, the corridor arrangement on the standard floors are developed as an H-shape which can save space. This pattern of core arrangement requires more attention in the organization of equipment rooms and the tube well to avoid narrowing equipment pipes and over-occupying height space (see Figure 7).

Figure 6. Different Types of Cross-pattern Arrangement of Core Tubes, drawn by Lijie
图6. 十字型核心筒的不同组织方式（出自：作者自绘）

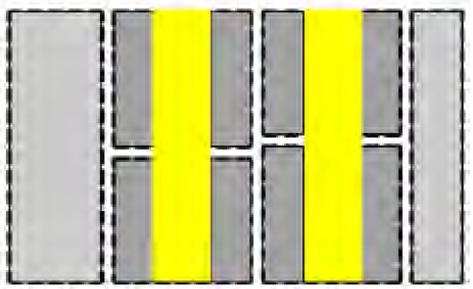

Figure 7. Different Types of Cross-pattern Arrangement of Core Tubes, drawn by Lijie
图7. 一字型核心筒布局示意（出自：作者自绘）

The grid-pattern elevators are arranged on a three by three into a nine square grid, in which a connection between each other is not necessary while the upper section can be transformed into a cross-pattern arrangement to keep the structure stable. The grid-pattern arrangement can provide the bottom lobby with enough elevator entrances that are independent of each other. The plan arrangement is frequently centrosymmetric for a strong adaptability. Since the thoroughly arranged elevators occupy larger areas on the first floor as well as the low and middle zones, this pattern is appropriate for the projects with higher height and large standard floor areas (see Figure 8).

For an efficient utilization of cores, designers should place shorter distance elevators at the border of the tube wells so that the space above these elevators can be converted to effective occupied areas after traveling. The hybrid-pattern combines the characteristics above like a T-shape so the elevator arrangement is non-centrosymmetric and relatively flexible (see Figure 9).

Evacuation and Fire Safety

The evacuation and fire safety inside the core tube mostly consists of the arrangements of exit stairs and fire elevators. When placing exit stairs, the vertical continuity of the exit stairs from different functional

电梯的平面组织

电梯的平面组织大致可分为以下几种类型：十字型、一字型、井字型及混合型。

十字型电梯布局特点是电梯候梯厅呈十字交叉，在此形式中，十字交叉的中心点为纯交通空间。跟随电梯布局的延展，其四角形成附属空间。其优点为电梯厅朝向四个方向，各朝向均好性较好，且基本中心对称，适应性强（请见图5）。

十字交通平面在标准层时，由于四角附属空间布局的不同，其走道布局可产生环形和工字型两种布局方式。在整层为开敞办公的条件下，为尽可能减少不必要的走道面积，我们更倾向于工字型走道布置方式。由于电梯组布置的位置不同，在不同的标准层可能出现不同朝向的工字型走道。而不同朝向必然影响四角附属空间在不同层需要在不同朝向开门，制约了四角空间并使其使用效率有所下降。因此我们建议区间电梯组成对布置，以保证使用楼层的走道总保持在一个方向，提高使用效率（请见图6）。

一字型布局的电梯厅呈一字型并排而列，从而节省了十字交叉点的纯走道空间，布局紧凑，较十字型核心筒更为节省面积，经济性更强。但因为疏散楼梯、附属空间紧贴电梯厅并列排布，因此核心筒较易发展为长方形格局。一字型核心筒由于电梯厅及附属空间仅朝向两个方向开口，因此标准层走道布局为“工”字型，较为节省面积。此种类型核心筒应注意设备机房及管井的组织，避免设备管线出线宽度过窄而过度占用层高（请见图7）。

井字形布局的电梯呈九宫格排列，相互可不做联通，且在上部可收分成十字形布局平面，结构稳定性好。井字型布局可为底部大堂提供足够多的电梯厅入口且相互独立。平面布局一般呈中心对称，平面适应性强。但由于所组织的电梯组数较多，首层和中低区会占用较大面积，适合电梯分区多、高度高、标准层面积大的项目(请见图8)。

为了核心筒的使用更加高效，设计者会将行程较短的电梯靠近筒外布局，以便在其行程结束后其上空间能够迅速转化为有效使用面积。混合型结合了以上几种的特点，如T字形等，电梯组织非中心对称。布局相对灵活(请见图9)。

Figure 8. Grid-pattern Arrangement of Core Tubes, drawn by Lijie
图8. 井字形核心筒布局示意（出自：作者自绘）

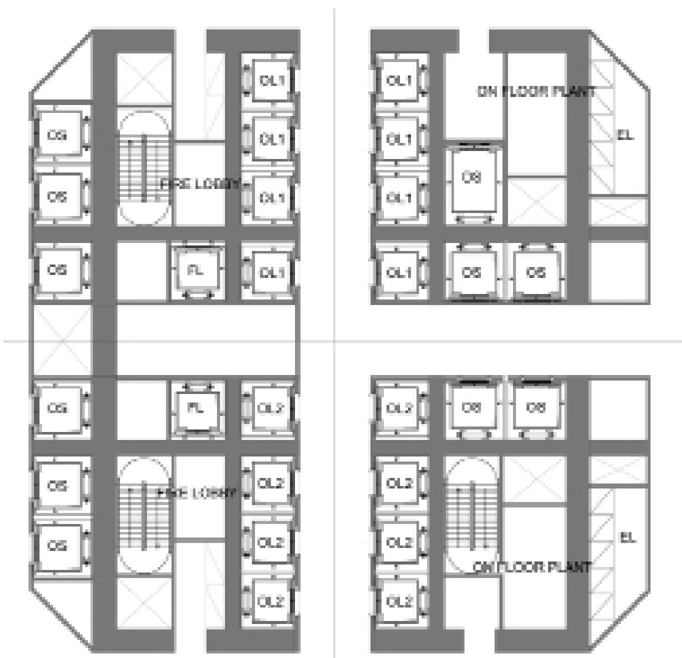

Figure 9. T-shaped-pattern Arrangement of Core Tubes, drawn by Lijie
图9. 丁字形核心筒布局示意（出自：作者自绘）

Figure 10. Stair Conversion in the Refuge Floor, the Skyscraper in Commercial Center of Nanshan, Shenzhen
图10. 深圳南山商业中心区超高层避难层楼梯转换（出自：作者参与工程）

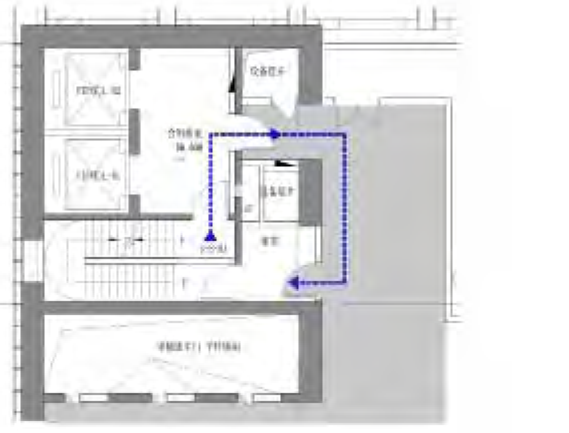

Figure 11. Stair Conversion in the Refuge Floor, Tianchen Tower
图11. 天辰大厦避难层楼梯转换（出自：作者参与工程）

areas should be noted. The exit stairs in the refuge floor can only travel through the refuge zone while no stairs in the other floors should transfer through the floors. It is beneficial to place exit stairs next to the elevators because people are familiar with the circulation and use it frequently in the event of a fire. Therefore, arranging exit stairs close to the elevator can naturally combine frequently used circulation and fire emergency circulation in order to generate a fast and safe evacuation.

In the initial design process, there should be a focus on the exit stair options on the refuge floor to rise or fall by a dislocation on the same floor or through the refuge zones. If the mechanical floors with the high ceiling also serve as a refuge floor, designers might consider arranging the exit stairs in the refuge area. In this case, the ceiling height of the refuge area should exceed the minimum height that a four-run stair requires (see Figure 10).

If additional transfer stairs are required due to the floor height not meeting requirements, consider the following:

- Build an enclosed wall in the stairwell and arrange the vestibule of the stairs separately so that traffic must pass through refuge zones (see Figure 11).
- The locations of stairs can be relocated in the refuge zone. For instance, a hotel located in the upper part of the Shanghai Financial Center has two exit stairs added in the evacuation stair position while one exit stair in the refuge floor in the core is removed.

When a fire occurs in the building, the vertical shaft serves as the main path of vertical extension of fire draft. In tall buildings, the cross-sectional area of the pipe and cable shafts and the access panel area are all quite small. According to GB50035 5.3.2 and 5.3.3, an access panel to pipe and cable shafts is required in order to achieve a Level C for fire doors, and "in tall buildings with height less than 100 meters, every two to three stories' pipe and cable shafts should be divided on the floor slab by non-combustible materials as a fire partition; these shafts have equivalent requirements as the fire resistance of the floor slab." Based on this guideline for fire safety, the large cross-sectional area of an elevator shaft (about four to seven square meters each), the large quantity of shafts (more than 20 in some cases), the vertical perforation in the shaft, and the large area of the elevator doors (common size is 900-1200 millimeters wide and 2100-2400 high) should have stricter requirements for elevator doors and a higher fire resistance level than the access panels of cable and pipe shafts.

疏散及消防安全

核心筒内的疏散及消防安全主要包括疏散楼梯和消防电梯的设置。疏散楼梯布置时，应注意不同功能区的疏散楼梯垂直方向的连续性。除了在避难层疏散楼梯应通过避难区方可上下之外，其余部位楼梯不应转换。疏散楼梯布置在靠近电梯间的位置是较为有利的。因为发生火灾时，人们往往首先考虑熟悉并经常使用的电梯所组织的交通流线。当靠近电梯设置疏散楼梯时，就能使经常使用的路线与火灾时紧急使用的路线有机的结合起来，有利于迅速而安全的疏散人员。

疏散楼梯在避难层需要同层错位或经避难区方能上下。在方案初期应重点考虑。当设备层兼避难层，且层高较高时，可考虑在避难区设置转换楼梯。即需要避难区层高大于4跑所需最小高度。请见图10。

当层高不满足另设转换楼梯时，则可考虑：

- 在梯井处封墙，并分设楼梯前室，使人流必须经过避难区（请见图11）。
- 楼梯可在避难区转换位置。如环球金融中心上部酒店疏散梯位置增加了两部疏散梯，并在避难层取消了核心筒中部的一部疏散梯。

当建筑物发生火灾时，竖向管井是火势上下蔓延的主要途径，而且也是拔烟火的通道。高层建筑的电缆井、管道井截面的面积较小、检查门的面积也小，但是GB 50045、5.3.2条及5.3.3条对电缆井、管道井的检查门均要求达到丙级防火门等级，而且要求“建筑高度不超过100m的高层建筑，其电缆井、管道井应每隔2～3层在楼板处用相当于楼板耐火极限的不燃烧体作防火分隔；建筑高度超过100m的高层建筑，应在每层楼板处用相当于楼板耐火极限的不燃烧体作防火分隔”。按照这个防火指导思想，由于电梯井道截面积大（每个井道约4～7平方米），井道数量多（多时可达20多个），又上下贯通，电梯层门面积也较大（常用开门尺寸为：宽900～1200毫米，高为2100～2400毫米），电梯层门更应该严格要求，其耐火等级应高于电缆井、管道井所配检查门的防火等级。

竖向管线的合理安排

在核心筒的组织设计中，还有一项内容不容忽略：竖向管线的组织。在核心筒设计中，若将设备机房及竖井布置在核心筒内，会带来大量设备管线穿剪力墙的情况，给结构设计增加了难度且降低核心筒结构刚度。因此在条件许可的情况下应尽量布置在核心筒外围，减少管线穿越剪力墙。另外，竖向管线常常会跟随电梯转换而更改平面位置，因此需考虑管线转换所需要的空间，尽量避免设备与电气机房紧邻布置而造成的管线交叉而占用更多层

Appropriate Arrangement of Vertical Pipelines

In the design of core arrangements, another area that cannot be ignored is the arrangement of vertical pipeline shafts. In core design, arranging equipment rooms and shafts inside the core will bring large amounts of equipment pipelines through the shear walls which can increase the difficulties in structural design and decrease the stiffness of the core. Under allowable conditions, these rooms should be arranged at the periphery of the core in order to decrease the cuts through the shear walls. In addition, vertical pipelines frequently change their positions following elevator conversions, so considerations should be made for the conversion space that the pipelines need in order to avoid crossings and extra floor height caused by arranging the equipment room adjacent to the electrical room. Therefore, convenient outlets of equipment rooms and shafts should be seriously considered in order to save floor height.

In conclusion, various mixed issues in core designs require thorough investigations in order to obtain various possibilities of the most appropriate project arrangement to create a careful balance. Each proposal has its merits which also require architects and owners to find project integration elements from practical and economic perspectives. An in-depth research on core tube wells in the early phase of the supertall building design process will lay a solid foundation for the constructability of the entire building in order to avoid issues of being stuck with an unchangeable shape of the core while no comprehensive research has been done on it yet but all structural design has been confirmed.

高。机房与竖井应充分考虑出线方便性，尽量节省层高。

总之，在核心筒设计中，各种问题往往交织在一起，需要耐心研究各种不同的可能性，并从中权衡判断出最适合与本方案的核心筒布局。也许多种方案各有千秋，这就需要建筑师与业主共同在实用性和经济性中找到适合的方案结合点。在超高层建筑设计早期就应该进行深入的核心筒设计研究，这样才能为方案的可实施性打下良好基础，也不会因发生如结构方案都已落定，而核心筒尚未研究透彻却已不可更改等类似问题而留有遗憾。

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