| | |
|---|---|
| Title: | **The Evolution of Building Evacuation Design in China** |
| Authors: | Fang Li, Senior Vice President, Rolf Jensen & Associates<br>James Antell, Executive Vice President, Rolf Jensen & Associates<br>Martin Reiss, President, Rolf Jensen & Associates |
| Subject: | Fire & Safety |
| Keywords: | Egress<br>Evacuation<br>Fire Safety<br>Life Safety |
| Publication Date: | 2014 |
| Original Publication: | CTBUH 2014 Shanghai Conference Proceedings |
| Paper Type: | 1. Book chapter/Part chapter<br>2. Journal paper<br>3. **Conference proceeding**<br>4. Unpublished conference paper<br>5. Magazine article<br>6. Unpublished |

# The Evolution of Building Evacuation Design in China
# 建筑疏散设计在中国的发展

Fang Li

James Antell

Martin Reiss


**Fang Li, James Antell & Martin Reiss**

RJA Group
JinMao Tower, 24th Floor 2406B, 88 Shi Ji Avenue
Pudong, Shanghai, China
200120

tel (电话): +8621-2890-9735, +(603) 9207 9722,
+ (508) 620-8900
fax (传真): +8621-5049-7119
email (电子邮箱): fli@rjagroup.com;
jantell@rjagroup.com; mreiss@rjagroup.com
www.rjainc.com

**Fang Li** is Senior Vice President of China Operations in China. She has been responsible for the RJA Shanghai Office since 2004. Fang Li was authorized by SFPE to operate the SFPE China Chapter and was elected as the founding Chairman.

李方，美国RJA公司中国营运高级副总裁。从2004年起，负责RJA上海的办公室。李方被美国消防工程师协会授权运营中国分会并被选举为中国分会主席。

**James Antell** is the Executive Vice President responsible for RJA's International Business including offices in Shanghai, Macau, Dubai, Abu Dhabi and Kuala Lumpur. He has over 25 years of fire engineering experience as an advisor on compliance with local and international fire safety codes and standards.

James Antell，负责管理包括上海、澳门、迪拜、阿布扎比和吉隆坡等办公室在内的RJA国际业务的执行副总裁。作为顾问，他拥有超过25年在美国及国际消防安全法规和标准方面的消防工程师经验。

In April 1993, **Mr. Reiss** joined Rolf Jensen & Associates as President. In April 1996, he was elected to the position of President and Chief Executive Officer and as a Director of The RJA Group Inc. During his thirty-year career in the fire protection industry he has founded, managed and served as President or Chairman of companies which he has owned or operated for others.

Martin Reiss，于1993年4月加入了RJA集团，1996年4月，他被选举为总裁和首席执行官，并成为RJA集团的董事。在他30年的职业生涯中，他经历了从创办自有公司到管理并担任他所有的公司的总裁的过程。



## Abstract

As a result of the events of September 11th and other natural and man-made disasters, building owners, designers and fire officials have become increasingly aware of the need to consider a wide variety of scenarios when evacuating tall buildings. As building height and density have increased, so too has recognition that events other than fire could require full evacuation of a high-rise building and adjacent high-rise buildings. These events include acts of terrorism, natural disasters and loss of building power or heat. This presentation will use three case studies – the Jin Mao Building, Shanghai World Financial Center and Shanghai Tower – to evaluate current building evacuation practices that include the total area encompassed by the event. It will also discuss the sequencing of building occupant evacuations from their areas of refuge by the fire service and the staging of the fire and rescue vehicles and command center locations.



**Keywords: Egress, Fire Protection, High-Rise, Evacuation, Life Safety**



## 摘要

在经历了911事件以及众多自然与人为灾难后，建筑业主、设计人员和政府消防官员们开始逐渐认识到，有必要关注高层建筑疏散中的不确定性。随着建筑高度的增长和建筑密度的增加，人们开始意识到，不仅在发生火灾的情况下，而且，当出现包括恐怖袭击、自然灾害和供电、供热故障的突发事件时，也需要对事发建筑和相邻高层建筑进行整体的疏散。本次演讲主要讨论一些正在施行的建筑整体疏散策略，将通过三个案例展开，其中包括上海金茂大厦、上海环球金融中心和上海中心。同时，还将讨论消防队辅助下避难层内人员疏散次序，消防救援车辆的展开及指挥中心的布置问题。



关键词: 安全出口，消防，高层，疏散，生命安全


## Introduction

As a result of the events of September 11th and other natural and man-made disasters, building owners, designers and fire officials have become increasingly aware of the need to consider a wide variety of scenarios with respect to the evacuation of tall buildings.

China's Code for Fire Protection Design of Tall Buildings, GB500045-95, states clearly the principles of high-rise fire safe design. The principle "prevention as priority, cooperating with rescue" includes "self-preservation and self-rescue, reliable precautions and advanced technology applied in a cost effective way". These principles reflect the philosophy that high-rise buildings must be both self-reliant in responding to emergencies and support cooperative efforts with public fire and rescue services. Although the specific fire safety features and strategies for high-rise design have evolved, the principles have remained the same.

As building height and density have increased, it is recognized that a number of foreseeable events could require full evacuation of a high-rise building and adjacent high-rise buildings. These events include acts of terrorism, natural

## 引言

在经历了911事件以及众多自然与人为灾难后，建筑业主、设计人员和政府消防官员们开始逐渐认识到，有必要关注高层建筑疏散中的不确定性。

中国国家标准《高层民用建筑设计防火规范》GB500045-95 (2005版) 中明确高层建筑消防设计的原则。提出了以"预防为主，防消结合"的原则，并且包含"立足自防自救，采用可靠的防火措施，做到安全适用、技术先进、经济合理"等相关内容。该原则反映出高层建筑的设计理念，即同时具备应急自救和外部援救的条件。尽管高层建筑的部分防火特性和策略更新变化，但其原则却是始终不变。

随着建筑高度的增长和建筑密度的增加，人们开始意识到当一些可预知突发事件出现时，需要对事发高层建筑及相邻高层进行整体的疏散。突发事件包括恐怖袭击、自然灾害和供电、供热故障等。

从消防设计的观点看，高层建筑需要一套完整的设计方案，既能够控制火灾的发展，又能保证建筑人员在建筑特定疏散区域的安全。消防设计中必须考虑到以下方面:

disasters – earthquakes or wind – or loss of building infrastructure that would render the building uninhabitable.

From a fire safety design standpoint, high-rise buildings require an approach that controls fire growth and protects occupants in place with only selective evacuation to safe areas within the building. The fire safety design must consider the following:

1. Active and passive fire protection features to control fire growth and to minimize the effects of fire on the structure and its occupants. Active systems include automatic sprinkler protection to control/suppress fire in a small area and smoke management systems to contain and control smoke movement to allow safe occupant evacuation. Passive elements include fire resistant structure and fire barriers to keep fire from spreading.
2. Means of Egress features to facilitate occupant evacuation in the event of a fire. Occupants of the building must be protected from the effects of a fire in the building during their evacuation from the fire area. Fire detection systems are a critical factor in detecting fire quickly and notifying occupants to evacuate. Voice communication systems using both automated messaging and manual messaging by the fire department will help inform occupants of the situation and direct their actions in an emergency.
3. Firefighting operations must be conducted primarily from inside the building, often times in locations remote from fire service apparatus and ground support. Firefighting support systems including vehicle access, firefighter's elevators, fire command center, fire standpipe systems and firefighter communications are incorporated into the building design.

Although evacuation of all of a building's occupants under any circumstances would be a last resort used only when absolutely necessary, total building evacuation could foreseeably be necessitated either by a natural or man-made threat to the integrity of the building structure such as a bomb threat or earthquake or by a loss of some portion of the building's basic infrastructure that would render the building uninhabitable such as a loss of power that would make cooling the building difficult.

Traditionally, Fire Protection Engineers have only been concerned with fire related events and scenarios. Our thinking has evolved with respect to the need for full building evacuation and with this the design of egress systems to facilitate this evacuation has evolved significantly. This presentation will look at past and present evacuation strategies to demonstrate how design changes enabled buildings to better respond to a broader range of evacuation scenarios.

**Three Towers**

Shanghai's Jin Mao Tower, World Financial Center and new Shanghai Tower offer a unique history of high-rise fire safety. The three buildings grouped together in Pudong's financial district and built over three decades each represent advanced strategies and approaches when they were designed and built.

*Jin Mao Tower.* Designed and built in the 1990's the Jin Mao tower at 421 meters in height was the first of the three and a long standing icon of Shanghai. The tallest building in China from 1999 until 2008, the building was designed by a U.S. team led by Skidmore Owings & Merrill, LLP, working closely with Chinese design institutes and builders. The building included many fire safety features that are now considered standard.

1. 主动和被动消防措施: 用于控制火灾发展，并减小对结构和人员的影响。主动消防系统包括可控制或扑灭保护区域内火灾的喷淋保护系统，限制和抑制烟气流动以提供良好疏散环境的防排烟系统。被动消防包括结构耐火和防火分隔，阻止火灾的蔓延发展。
2. 用于火灾情况下进行人员安全疏散的疏散设施。在火灾区域进行安全疏散过程中，疏散人员应能得到有效的安全防护以免受火灾的伤害。自动火灾报警系统在及时探测火情并通知人员疏散的过程中，扮演者关键的角色。具备自动和手动广播的消防广播系统将有助于向疏散人员传达火情并指导其安全疏散。
3. 灭火工作应在建筑内着火区域开展，然而这些展开常常缺乏消防装备及地面等必要的支持。因此，建筑设计需要与消防救援系统有效结合，包括登高场地、消防电梯、消防指挥中心、消防竖管系统和消防员通信等方面。

尽管在任何情况下，建筑内人员整体疏散都是最后的备选方案。但是在一些情况中整体疏散确是必要的，这包括在一些自然或人为灾害发生并危及到建筑结构的完整性的情况，如炸弹威胁或地震，以及建筑内部分基础设施不能正常运转导致不适于人员停留的情况，如停电造成建筑内空气调节失效。

传统意义上，消防工程师仅需要关注与消防相关的事件和情况。但是我们的思维方式已经随着建筑疏散的需要而产生变革，与此同时，安全疏散系统也在其中取得了长足的发展。本次演讲将回顾过去并总结现有的疏散策略，以证明这样的发展，如何能够迎合更为广泛的安全疏散需求。

**三座塔楼**

上海金茂大厦、环球金融中心和新上海中心书写了一段独特的高层建筑消防安全史。三塔集中在浦东金融区内，历时三十载，每座塔楼的设计和建设均代表了当时最为先进的消防安全策略及方案。

*金茂大厦*
设计和建成于90年代的金茂大厦，建筑高度421米，在三塔中是最早建成，且长期作为上海市的地标建筑。在1999至2008年间，金茂大厦稳居全国最高建筑的位置，该建筑由Skidmore Owings & Merrill, LLP设计，并有众多国内设计单位和人员参与其中。建筑中已采用的许多消防设计现在被誉为经典。

金茂大厦是首批综合功能建筑之一。在此之前，大部分塔楼仅仅具有单一的商业或居住功能，当时的规范也没有完全认识到多功能单体建筑的概念。同时，金茂大厦的设计中运用了多层中庭连接近30个楼层的酒店客房和酒店功能区的设计理念。

金茂大厦引入的多项消防安全特征，当前已成为高层建筑设计的标准。该建筑的设计依从了国际建筑标准，并且有效地结合了国内和地方规范。该建筑的建筑与消防设计以中国国家标准《高层民用建筑设计防火规范》GB500045-95为主，Uniform Building Code (IBC的前身) 为辅。

金茂大厦的消防安全策略是利用主动防火系统和被动建筑构件控制火灾的影响，进而保护楼内的人员。在建筑内探测到火灾时，报警系统随即发出警报将指引着火层及上下两层的人员疏散至避难层并等候进一步指示。各楼层办公区和走廊的疏散需要经由通向酒店层中庭的具有一定耐火极限的走廊。走廊连通至具有2小时保护的疏散楼梯，并直接通向避难层。

一旦到达避难层，人员可以在此等待消防员或经过培训工作人员的指导。在必要的情况下，也可以利用疏散楼梯继续疏散。

The Jin Mao tower was one of the first mixed-use towers. Before this time, most towers were single purpose commercial or residential and the prevalent codes did not fully recognize the concept of multiple uses in a single tower. The design also incorporates a multi-story atrium connecting nearly 30 floors of hotel guest rooms and hotel functions.

The Jin Mao Tower incorporates many fire safety features that are now standard to high-rise design. The building was designed following international standards and best practices in combination with local code requirements and local practices. The basis of design was China's Code for Fire Protection Design of Tall Buildings, GB500045-95 supplemented by the Uniform Building Code (forerunner of the IBC).

The fire safety strategy is to defend occupants in place by controlling the effects of a fire using active fire protection systems and passive building elements. In the event of a fire detected in the building, a voice alarm will direct occupants of the fire floor, one floor above and one below to evacuate to the refuge floor below and await instruction. Evacuation from each level is through fire rated corridors in the office areas and corridors open to the atrium on hotel floors. Corridors lead to 2-hour protected exit stairs leading to refuge floors.

Once in the refuge floor, occupants await instruction from fire fighters or trained building personnel. If necessary, they can continue evacuation via exit stairs.

In the office portion of the building – Floors 3 to 50 incorporate refuge floors on Levels 15 and 30. Refuge floors are constructed of 2-hour fire-rated construction and are provided with mechanical pressurization. These areas are directly accessible from both the exit stair enclosures and fire fighter's elevators. Refuge floors on levels 15 and 30 also provide stair interruption in order to reduce the effects of stack effect to 15 floors and to facilitate occupants being able to move to stairs that are not blocked by smoke or by fire fighter operations.

The refuge floors also serve the purpose of subdividing the building into zones so that under alternative scenarios, occupants of an entire zone or occupants of the whole building can be evacuated through alternate exit paths in an orderly manner (see Figure 1).

Levels 56 to 85 are connected by an atrium. Refuge areas are incorporated on every floor connected to the atrium. Additionally, guest rooms are separated from the atrium by fire rated construction in order to facilitate a defend-in-place approach. Refuge areas are mechanically pressurized and connected to exit stairs and fire fighters elevators to facilitate evacuation and firefighting (see Figure 2 and 3).

*Shanghai World Financial Center.* In 2008, the Shanghai World Financial Center overtook the Jin Mao tower as the tallest building in China and the second tallest in the world. At 492 meters in height, the SWFC incorporates a mixed use strategy including office, hotel and observation level with restaurant. It was one of the first supertall buildings designed after the events of September 11th and several features were incorporated into the design.

All of the critical life safety systems including sprinkler/standpipe risers, fire detection alarm & emergency communication system risers, emergency power risers, fire fighters elevators and exit stairs are protected within the robust concrete core of the building, protected from external forces and forces such as earthquakes to enhance the reliability and survivability of these critical life safety systems (see Figure 4).

The SWFC also incorporates three exit stairs into the tower design,

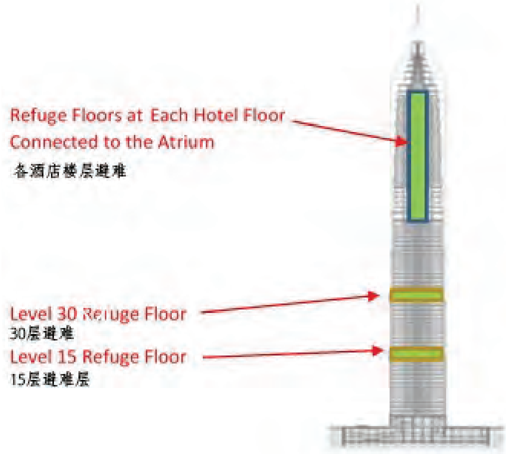


Figure 1. Jin Mao Refuge Floors. (Source: Floor plan courtesy of Skidmore, Owings & Merrill LLP; Modeling courtesy of Rolf Jensen & Associates, Inc.)
图1 金茂大厦避难层 (来源: Skidmore, Owings & Merrill LLP; Modeling courtesy of Rolf Jensen & Associates, Inc友情提供的平面图)

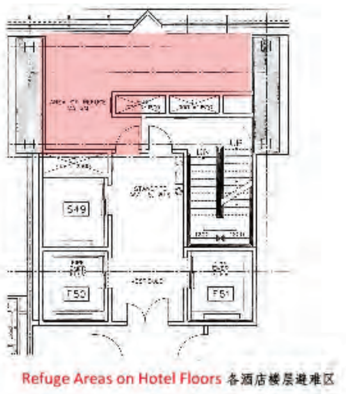


Figure 2. Refuge Area on hotel floors in Jin Mao. (Source: Floor plan courtesy of Skidmore, Owings & Merrill LLP; Rolf Jensen & Associates, Inc. )
图2 金茂大厦酒店层 (来源: Skidmore, Owings & Merrill LLP友情提供的平面图; Rolf Jensen & Associates, Inc友情提供的模型)

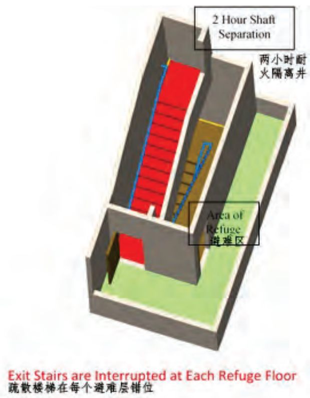


Figure 3. Exit stairs in Jin Mao Tower. (Source: Modeling courtesy of Rolf Jensen & Associates, Inc.)
图3 金茂大厦疏散楼梯 (来源: Rolf Jensen & Associates, Inc友情提供的模型)


Figure 4. Critical Life Safety Systems. (Source: Floor plan courtesy of Kohn Pedersen Fox Associates; Modeling courtesy of Rolf Jensen & Associates, Inc.)
图4 关键的生命安全系统 (来源: Kohn Pedersen Fox Associates友情提供的平面图; Rolf Jensen & Associates, Inc友情提供的模型)

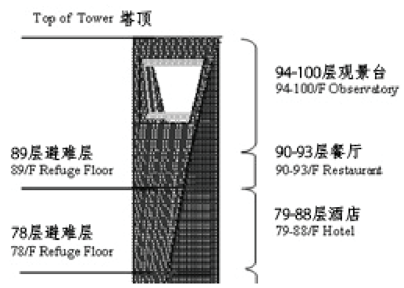


Figure 5. Upper Floors of SWFC. (Source: Building image courtesy of Kohn Pedersen Fox Associates; Modeling courtesy of Rolf Jensen & Associates, Inc.)
图5 SWFC的上层楼层 (来源: Kohn Pedersen Fox Associates友情提供的建筑效果图; Rolf Jensen & Associates, Inc友情提供的模型)

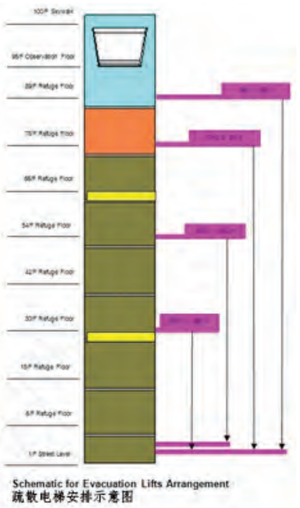


Figure 6. Schematic for Evacuation Lifts Arrangement. (Source: Rolf Jensen & Associates, Inc.)
图6 疏散电梯示意图 (来源: Rolf Jensen & Associates, Inc.)

one more than required for occupant evacuation. This "extra" stair is designed for use by fire fighters during a fire emergency so that firefighting operations do not interfere with occupant evacuation. The 2009 International Building Code has introduced this concept into the high-rise code requirements mandating an "extra" stair (see Figure 5).

The upper floors of the SWFC are used for public assembly functions including a restaurant on Levels 90 to 93 and observatory platforms on Levels 94 through 100. The occupancy of these floors is limited to the capacity of the exit stairs either by the physical layout and seating plan of the restaurant or by timed ticket sales in the observation levels. In order to provide sufficient protection and egress for the occupant load in these assembly spaces, exits from the top of the tower lead directly to a dedicated refuge floor immediately below on Level 89.

The SWFC incorporates refuge area on Levels 89, 78, 66, 54, 42, 30, 18 and 6. The refuge areas are provided with mechanical pressurization to inhibit smoke from entering the area and sprinkler protection. Fire fighters elevators stop at all refuge floors and evacuation elevators stop at selected refuge floors to facilitate elevator assisted evacuation (see Figure 6 & 7).

Although elevators have been used for emergency evacuation in towers such as the Stratosphere Tower in Las Vegas, SWFC was one of the first to use elevators for evacuation in a high-rise building design. The SWFC uses the high speed shuttle elevators normally serving sky lobbies or the observation levels. Shuttle cars SE1 to SE4 are double deck shuttles. During evacuation mode, the upper deck loads occupants of refuge floor 54 and the lower deck loads occupants of refuge floor 30. Shuttles SH2 & SH3 are single deck shuttles serving the hotel. During evacuation mode, they load occupant of refuge floor 78. Observation shuttles GE1 to GE3 load the refuge floor on level 89. In all cases, the shuttles are operated manually from inside the car by trained building staff.

An evacuation model was developed to assess the benefit of incorporating evacuation elevators into the design. The evacuation time with and without evacuation elevators is graphed below (see Figure 8).

Shanghai Tower. The newest of the three Shanghai towers and soon to be completed, the Shanghai Tower measures 632 meters in height. When completed, it will be China's tallest tower. The innovative mixed use design includes a series of perimeter atrium spaces each connecting office, hotel and observation levels.

写字楼部分。在建筑第3至50层区段内，15和30层为避难层。避难层采用2小时的耐火极限并提供机械加压送风，并且可由疏散楼梯和消防电梯直接到达。疏散楼梯在15和30层的避难层错位，以减少烟囱效应对避难层的影响，并方便人员通往未被烟气阻挡或未被灭火救援展开所堵塞的疏散楼梯。

避难层设计还有助于建筑区域的划分。所以，在备选方案中，整个区域或整栋楼的人员可以有序的利用备用疏散路径安全疏散(见图1)。

56-85层利用中庭相连。每个楼层均连接到中庭避难区域。另外，客房和中庭间利用防火分隔以做到就地防御。避难区域采用机械加压送风，并连接到疏散楼梯和消防电梯，以方便安全疏散灭火救援(见图2及图3)。

*上海环球金融中心*
2008年，上海环球金融中心取代金茂大厦成为中国最高，世界第二的超高层建筑。在高度492米的上海环球金融中心内，采用了综合功能的策略，包括办公，酒店和观光层。它是自911事件后首批建成的超高层建筑之一，其设计涵盖了众多独特性设计。

所有关键的生命安全系统的竖向管道，包括自动喷水灭火/室内消火栓系统立管，自动火灾报警系统及应急通信系统立管，应急电源立管，消防电梯和楼梯出口都设在的稳固的混凝土核心筒内，保护不受如地震等的外力影响，以提高这些关键生命安全系统的可靠性和有效性(见图4)。

在上海环球金融中心塔楼还采用了三部疏散楼梯的疏散设计，相比规范要求增加了一部疏散楼梯。这部"额外"的楼梯被设计用于紧急情况下消防队员专用，避免灭火救援行动受到人员疏散的干扰。2009年IBC规范在高层规范要求中将"额外楼梯"的概念列入为强制性条款(见图5)。

上海环球金融中心的顶层部分可作为人员密集场所使用，包括90至93层的餐厅和94到100层的观景平台。这些楼层疏散楼梯的使用，受到建筑布局和餐厅座位布置或观光层定时门票销售的限制。为了在这些人员聚集区域提供足够的安全保障，并有效组织人员的疏散，疏散楼梯可从塔楼顶部直接联通至89层正下方的专用避难层。

上海环球金融中心避难层位于89，78，66，54，42，30，18和6层，避难区域设有阻止烟气进入的机械加压送风系统和喷淋保护系统。消防电梯可停靠所有避难层，疏散电梯可停靠在部分指定的避难层，以便于电梯辅助疏散(见图6 及图7)。

尽管在如拉斯维加斯的云霄塔，电梯已用于紧急疏散，但上海环球金融中心仍是首批在高层建筑设计中使用电梯疏散的建筑之一。在上海环球金融中心采用高速穿梭电梯，一般服务于的高层大堂或观光层。穿梭电梯SE1到SE4是为双层。在疏散模式下，上层供避难层54层使用，下层供避难层30层的人员使用。SH2和SH3是供酒店使用的单层穿梭电梯。在疏散模式，它们将供避难层78层的人员使用。穿梭电梯GE1到GE3供避难层89层使用。在所有情况下，穿梭电梯均由经过培训的人员从车内手动操作。

设计中采用疏散模型评估疏散电梯的实用性。使用和不使用电梯作为疏散工具的疏散时间如图所示(见图8)。

*上海中心大厦*
上海三塔中最新并即将竣工的上海中心大厦，建筑高度632米。建成后将成为中国第一高楼。采用多项创新型综合使用功能设计，包括中庭外廊与办公、酒店层及观光层相互联通等。

从消防安全的角度来看，该塔楼引进了大量创新元素，使其疏散

From a fire safety standpoint, the tower includes a number of innovative features to facilitate building evacuation for a broad range of emergency scenarios. One of the key features designed to facilitate full building evacuation is the use of the high speed shuttle elevators to provide elevator assisted evacuation.

In the event that is becomes necessary to fully evacuate the building, the high speed shuttle elevators are used be trained staff to shuttle occupants from refuge floors and sky lobbies to the ground floor. The elevators do not substitute for stairs, but instead they supplement the capacity of the stairs and significantly reduce the overall evacuation time from the building.

In the event of a fire, occupants of the fire floor and one floor above and below evacuate using the stairs to the next refuge floor below their floor. Once on the refuge floor, occupants await further instruction from fire fighters or trained building personnel. The primary means of evacuation from the refuge floors is for occupants to continue evacuation down the Tower via protected exit stairs and using evacuation elevators.

Designated elevators are designed with a "Lifeboat Evacuation" mode that allows them to be used as an additional means of evacuating building occupants under certain emergency scenarios. Once building management has established that it is safe to begin this evacuation procedure, elevator controls allow fire service personnel or trained security personnel to operate designated elevators. Elevators would be used only as part of an established evacuation procedure (see Figure 9).


Figure 8. Using elevators in evacuation. (Source: Floor plan courtesy of Gensler; Modeling courtesy of Rolf Jensen & Associates, Inc.)
图8 电梯疏散 (来源: Gensler友情提供的平面图; Rolf Jensen & Associates, Inc友情提供的模型)

| Destination Floors 停靠楼层 | Lift Car 电梯名称 | Floors Served 服务区域 | Number 数目 | Speed 电梯速度 (m/s) | Load 承载重量 (Kg) |
|---|---|---|---|---|---|
| Refuge Floor of Area 3 3区避难层（20F） | 3x | Area 3: Office 区段3办公区 | 2 | 5 | 1600 |
| Refuge Floor of Area 4 4区避难层（35F） | 4x | Area 4: Office 区段4办公区 | 2 | 6 | 1600 |
| Refuge Floor of Area 5 5区避难层（50F） | 5x | Area 5: Office 区段5办公区 | 2 | 8 | 1350 |
| Refuge Floor of Area 6 6区避难层（66F） | 6x | Area 6: Office 区段6办公区 | 2 | 10 | 1350 |
| Refuge Floor of Area 7 7区避难层（82F） | 8x | Area 7: Hotel 区段7酒店区 | 1 | 12.5 | 1350 |
| Refuge Floor of Area 8 8区避难层（99F） | 8x | Area 8: Hotel 区段8酒店区 | 3 | 12.5 | 1350 |
| Refuge Floor of Area 9 9区避难层（116F） | OB | Area 9: Observatory 区段8观光区 | 1 | 12.5 | 1600 |

Operating Characteristics of Evacuation Elevators 疏散电梯操作性能

Figure 9. Operating characteristics of evacuation elevators. (Source: Rolf Jensen & Associates, Inc.)
图9 电梯疏散的运行特点 (来源: Rolf Jensen & Associates, Inc)

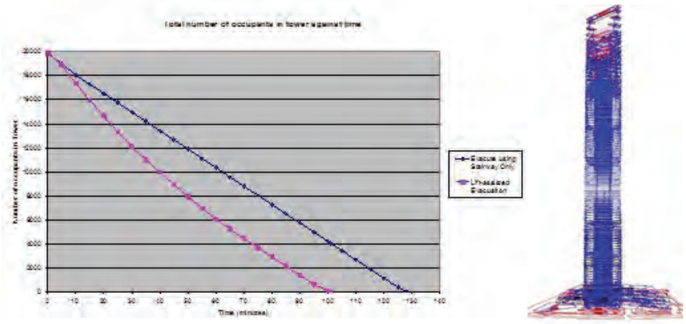

Figure 7. Total number of occupants in tower against time. (Source: Modeling courtesy of Rolf Jensen & Associates, Inc.)
图7 人员数量和疏散时间的函数图 (来源: Rolf Jensen & Associates, Inc友情提供的模型)

能够适用于更为广泛的紧急情况。其中一项关键设计为采用高速穿梭电梯用于电梯辅助疏散，促进了建筑的整体疏散。

在需要整体疏散建筑内人员的情况下，高速穿梭电梯经由受过培训的工作人员的操作，可将疏散人员从避难层和空中大堂转移至首层。但是这并不是说电梯要替代楼梯，而是对楼梯疏散的补充，并减少建筑内的整体疏散时间。

在发生火灾时，着火层及其上下层的人员利用楼梯疏散至下方的避难层。一旦进入避难层，人员将待命等候消防人员或经过培训的工作人员的进一步指示。避难层内人员疏散的主要途径是利用疏散楼梯和疏散电梯继续向下疏散。

疏散电梯均设计有"救生舱疏散"模式，在应急情况下能够被用作疏散建筑内人员的补充手段。一旦管理方确认该疏散方式是可靠的，电梯将交由消防人员或经过培训的保安人员控制操作。电梯将只作为疏散流程的一部分 (见图9) 。

在正常电源和应急电源的条件下，电梯在经过培训的操作员的控制下，可用于建筑整体疏散，搭载人员由指定的临时区域 (避难层) 返回首层 (地面) 。在这种情况下，穿梭电梯通常服务于空中大堂，停靠于避难层。

救生舱疏散电梯将包括以下特点:

- 电梯疏散是建筑应急疏散方案的一部分。电梯由受过训练的人员手动操作。
- 救生舱电梯可在搭载人员控制模式下工作，从而使在电梯内的搭载人员能够控制电梯的所有操作程序。IBC2009和ASME A17.12009中第三阶段的消防人员操作正是针对该条。
- 所有救生舱电梯，在紧急情况下应同时设有应急电源。
- 救生舱电梯应当做到防水。这包括通过大堂地面做坡或在前室提供排水，防止水渗透井道 (见图10) 。

上海中心大厦的另外一项安全功能，就是利用多个额外辅助楼梯分别将八个中庭与其下方的避难层直接联通。额外辅助楼梯的设计，有助于人员在中庭起火或烟气蔓延时的迅速撤离。额外辅助楼梯通向避难层下方的安全区域，在那里人员可以等待电梯疏散或使用的主要疏散楼梯继续向下安全疏散 (见图11) 。

国内已确定和认可的高层建筑整体疏散时间的标准为2小时，其中人员数量根据规范计算得到，并且同时使用楼梯和电梯进行疏散。目前大多数超过100层的高层项目利用电梯进行辅助疏散。一般建议采用多个场景，包括3个疏散楼层、避难层间的区域和建筑整体疏散的模拟，以确定整体的疏散能力，并确定任何阻碍建筑疏散的因素 (见图12) 。

Under both normal power and emergency power conditions, elevators under the control of trained operators can be used to effect a total building evacuation, shuttling occupants from designated staging areas (refuge floors) to the primary return floors (Ground). Under this arrangement the buildings shuttle elevators that normally serve sky lobbies, stop on refuge floors and are available for evacuation.

Lifeboat Evacuation Elevators will include the following features:

- Elevator evacuation is part of the building emergency evacuation plan. Elevators are operated manually by trained building staff.
- Lifeboat elevators have the ability to operate in an attendant controlled mode whereby an attendant within the elevator controls all operations of the elevator. The Phase 3 Fire Fighters Operation currently required by IBC 2009 and ASME A17.1 2009 will be utilized for this purpose.
- All required lifeboat elevators are provided with emergency power to operate simultaneously under emergency conditions.
- Lifeboat elevators are protected from the effects of water. This includes design of the elevator lobbies to resist water infiltrating the hoistway either by sloping the lobby sills or providing drainage in the lobbies (see Figure 10).

One additional feature of the Shanghai Tower is the use of supplemental exit stairs leading from the floor of each of the 8 Atrium spaces directly to refuge floors below. These supplemental stairs are designed to facilitate rapid evacuation of the atrium space in the event of a fire or smoke in the atrium. The supplemental stairs lead to the safe environment of the refuge floor below, where occupants can await elevator evacuation or continue down using the primary exit stairs (see Figure 11).

The benchmark that has been established and recognized by Chinese code authorities is 2 hours to fully evacuate a high-rise building using the building population derived from the code and using both exit stairs and elevators for evacuation. Most current high-rise projects over 100 stories are utilizing elevator assisted evacuation in some capacity. It is often advisable to model the evacuation of the building under multiple scenarios involving 3 floors, building zones between refuge floors and full building evacuation to identify the overall evacuation performance and to determine any impediments to efficient building evacuation (see Figure 12).

It should be noted that most elevator systems in high-rise buildings are designed to evacuate the actual anticipated occupant load in one hour. The building population derived by code results in a higher occupant load as a safety factor in the design of the means of egress.

Elevators designated for fire fighters service are generally not use for general evacuation. They are instead dedicated to firefighting operations and to evacuation of disabled occupants that may not be able to exit to refuge floors by way of stairs.

The use of elevators to facilitate building evacuation has been discussed in depth after the events of September 11th and based on this research, the use of elevators for evacuation of high-rise buildings is recognized in the 2009 Edition of the International Building Code and is allowed as an alternative to 1 of the buildings exit stairs.

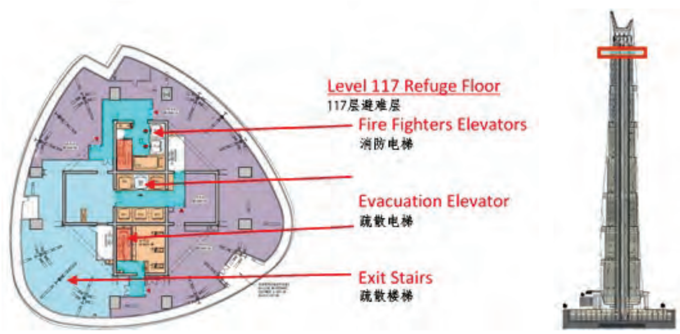


Figure 10. Lifeboat evacuation elevator refuge floors. (Source: Floor plan courtesy of Gensler; Modeling courtesy of Rolf Jensen & Associates, Inc.)
图10 避难层救生舱 (来源: Gensler友情提供的平面图; Rolf Jensen & Associates, Inc友情提供的模型)

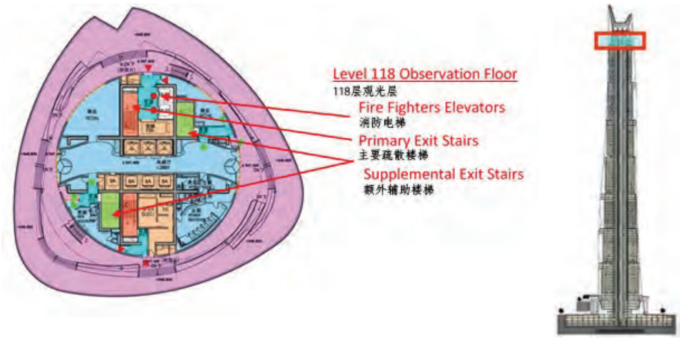


Figure 11. Evacuation observation floor. (Source: Floor plan courtesy of Gensler; Modeling courtesy of Rolf Jensen & Associates, Inc.)
图11 观光层人员疏散 (来源: Gensler友情提供的平面图; Rolf Jensen & Associates, Inc友情提供的模型)

应当指出，大多数的高层建筑内的电梯系统是根据一个小时内实际预期的人员负载进行设计。由于在设计中考虑了一定的安全系数，因此，根据规范计算得到的建筑使用人数一般会比较大。。

消防电梯一般不用于一般的疏散。这些电梯专门用于灭火救援行动，并用于为无法通过楼梯疏散避难层的残疾乘客提供疏散方便。

911事件后，人们已经开始深入讨论电梯疏散对建筑疏散的促进作用，在此基础上，2009版的IBC规范中承认并允许使用电梯作为一处替代的疏散楼梯。

## 应急预案和响应

影响到城市整体或城市部分区域的大型事件的应急管理，一般不包括在建筑法规的强制要求范围内，并且通常也不在城市大型建筑的设计师和业主的考虑范围内。

应急管理需要解决的设计和规划问题包括:

- 建筑的选址应保证当建筑发生突发事件时不会影响到相邻建筑
- 应急车辆可通行的环形车道
- 在人口稠密的地区，合理协调规划邻近建筑间的交通组织，以确保灭火救援展开所需的出入通道及操作场地 。
- 供应急救援的电力、供水及通讯

## Emergency Planning & Response

Emergency management in the context of large scale events that effect a whole city or area of a city is not an area that is generally mandated by building regulations and is generally not considered by designers or owners of large building in dense urban environments.

The critical aspects of design and planning that need to be addressed in emergency management include:

- Siting of buildings so that an event in one building is not likely to affect adjacent buildings
- Provision of emergency vehicle access to and around major developments
- Coordination of fire vehicle access within adjacent properties in dense urban areas to assure proper access and staging areas for fire suppression operations
- Power, water and communication capabilities to facilitate emergency response operations
- Flexible command point so that a variety of scenarios can be managed in dense urban areas
- Assembly points for building occupants that are off site and do not interfere with emergency services operations and that are coordinated with adjacent buildings
- Shelter, sustenance and transportation for building occupants if the event is prolonged

Fortunately, there is some very good guidance in the development of emergency plans for individual property owners found in NFPA 1600, Standard on Disaster Management and Business Continuity Programs and NFPA 1620, Standard for Pre-Incident Planning. These documents provide guidance to building owners and managers on pre-planning for emergencies and for training of building staff for emergency situations. For broader issues of coordination between owners and coordination between private building owners and public emergency services, a collaborative approach and constant communication is needed to be sure that roles and responsibilities are well understood and well-coordinated between neighbors and between public and private entities.

## Conclusion

As a result of the events of September 11th and other natural and man-made disasters, building owners, designers and fire officials have become increasingly aware of the need to consider a wide variety of scenarios with respect to the evacuation of tall buildings.

- 机动灵活的指挥站点以方便在人口稠密地区处置各种突发事件。
- 疏散人员室外集结场地，确保不妨碍到应急操作，并同相邻建筑保持协调
- 如时间持续，需为建筑内人员提供必要的住宿、食品和交通工具

幸运的是，在NFPA1600《灾害/紧急事件管理与商务连续性》和NFPA1620《预防计划的推荐标准》在业主应急方案的制定过程中提供了很好的指导。这些文件帮助业主和管理者制定突发事件的预先规划和培训人员紧急情况时处理方法。对于业主之间的协调关系和私人业主与公共应急部门的协调关系，长期稳定的合作和沟通是非常必要的，进而确保各方理解各自的角色和职责，并充分协调临近建筑之间以及公共和私人单位之间的协调之间的问题。

## 结论

在经历了911事件以及众多自然与人为灾难后，业主、设计师和消防官员已经逐渐意识到考虑各种各样的场景对于高层建筑的疏散的必要。

The smoke movement within an outdoor courtyard and an atrium in this FDS analysis indicates that an equivalent exhaust capacity of 100 $m^3$. s-1 should be able to maintain a tenable condition along the corridors in the modeled tall atrium. In fact, the mechanical exhaust of 40 $m^3$. s-1 can still be able to maintain a tenable condition for 9 to 10 minutes, which is considered adequate for safe exiting through the relatively short corridors in the modeled tall atrium.

## Conclusion

CFD modeling can be utilized to understand the complex patterns and sequences of fire behavior and smoke plume movement within narrow and tall atria. This allows the analysis of the plume at the internal structure (or side walls) of an atrium, and of the smoke re-circulation.

This information can be used to identify cost effective and sustainable design strategies for managing fire and smoke movement within tall, thin atria; thereby helping to create tall buildings which have increased sustainable elements and which can be architectural compelling.

## 研究结果讨论

利用FDS的计算机模拟，对细高中庭内在上述五个排烟方式作用下的复杂烟气流动进行了分析研究。在相同的中庭结构中，比较了三组中庭顶部的机械排烟 (排烟方式#1，#2和#3)，排烟量分别为40m3/s，100m3/s和160m3/s，及两组自然排烟 (排烟方式#4和#5) 的排烟系统功效。需要指出的是，在自然排烟的两组模拟中，中庭顶部的开口于中庭楼面开口同样尺寸(8mx4m)，相当于一个除去顶盖的中庭。事实上，中庭常常被形容为室内的天井或者是带有屋顶的天井。因此，在排烟方式#4和#5模拟研究中的中庭，可以等同于一个细高的天井。

通常，天井中不要求沿回廊设计安装防火卷帘或者玻璃隔断，并且由于天井顶部的开敞，一旦发生火灾，火灾烟气一般不会在天井内大量聚集。中庭 (又被称作室内天井) 内的消防措施、特别是防排烟系统，可以考虑参照相似结构的天井内的排烟功效进行设计。

不同排烟方式和排烟量的FDS计算机模拟研究发现，所有火灾场景 (4 MW"快速火") 的模拟过程中 (20分钟)，尽管温度相对较低的烟气会很快地蔓延至中庭客房层、作为疏散通道的客房层走廊，中庭楼面的烟气温度和 (一氧化碳) 有毒气体均未对安全疏散构成有效的威胁。显然，能见度的下降是这类中庭内消防安全的主要因素之一。需要说明的是，本研究中的中庭疏散线路简单明确，即使能见度受到一些影响，走廊中暴露在火灾烟气的时间也会非常短。

火灾烟气流动在天井和中庭内的FDS计算机模拟研究表明，100m3/s或等量的排烟系统能够保证本研究中的细高中庭疏散走廊内的可耐受环境，满足安全疏散的要求。事实上，40m3/s的机械排烟系统依然能够保证中庭疏散走廊内的可耐受环境，在9到10分钟之内满足安全疏散的要求。考虑到本研究中庭内相对简单明确的疏散路径，这样的时间足够人员通过较短的中庭走廊。

## 结论

计算机模拟用来研究细高中庭内部复杂的火灾烟气流动，包括烟气羽流同中庭建筑结构碰触，以及烟气循环的结果。

利用本研究的结果，可以在细高中庭的建筑设计、特别是消防和防排烟系统的设计中，为选择更为经济、绿色的建筑方案提供有益的帮助。

## References (参考书目):

ICC. 2012. **International Building Code (IBC)**. Country Club Hills, IL: International Code Council

Klote, J. (et al.) 2012. **Handbook of Smoke Control Engineering**. Atlanta, GA: ASHRAE

McGrattan, K. (et al.) 2010. **Fire Dynamics Simulator (Version 5.5) User's Guide**. Washington D.C.: National Institute of Standards and Technology (NIST).

Ministry of Housing and Urban-Rural Development of China (MOHURD). 2005. **Code for Fire Protection Design of Tall Buildings**. Xicheng District, Beijing: China Planning Press

SFPE. 2007. **SFPE Engineering Guide to Performance-Based Fire Protection – Second Edition**. Bethesda, MD: Society of Fire Protection Engineers

SFPE. 2011. **SFPE Engineering Guide – Guidelines for Substantiating a Fire Model for a Given Application**. Bethesda, MD: Society of Fire Protection Engineers