Title: **20 Years of High-Rise Fire Safety: From Jin Mao to Kingdom Tower**

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Subjects: Architectural/Design
Fire & Safety

Keywords: Code Compliance
Elevators
Fire Safety
Life Safety
Performance Based Design
Refuge Areas

Publication Date: 2012

Original Publication: CTBUH 2012 9th World Congress, Shanghai

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 Unpublished conference paper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 Unpublished

20 Years of High-Rise Fire Safety: From Jin Mao to Kingdom Tower
20年高层建筑消防安全：从金茂大厦到王国大厦

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Abstract

This paper will discuss the evolution of fire safety concepts in the recent generation of high rise buildings starting with "early" 1990's designs in China and trace the development of new active and passive features that have followed and are currently in use worldwide. The paper focuses on current technologies in high rise fire safety using case studies.

Keywords: Fire Protection, Fire Safety, Life Safety, Performance-Based Design, Code Compliance, Tall Buildings

摘要

此文将讨论近代高层建筑消防安全概念的演化。 以中国19世纪90年代“早期”设计为起始点，追溯已在世界上运用的新型主动及被动功能的发展。此文也将用案例讨论当代高层建筑使用的消防安全技术。

关键词：防火、 消防安全、生命安全、 性能化设计、 遵守法规、 高层建筑

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Antell先生是负责所有RJA的国际运营的执行副总裁。以超过25年的消防工程经验， 他为设计团队及建筑业主提供咨询帮助其项目达到地方上的以及国际上的消防法规和标准。Antell先生有着涉及全球高层建筑的经验，包括在美国，亚洲和中东地区的最高建筑物。他被视为高层建筑消防安全设计的专家，并且出版了许多此方面文章并对其做了多次演讲。

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High Rise Design Trends

As international design teams have participated in the development of high rise structures in China; many of the concepts of fire safe design first introduced there have become global design standards, applied to projects throughout Asia and the Middle East, Europe and the United States. China has had more experience with high rise design and construction in the last 2 decades than any other country in the world. This experience has put China at the forefront of high rise fire safety over that period of time and provided international designers with a wealth of knowledge and experience.

China's Codes and Building Approval Process

China's building codes and standards are developed and administered at a national level by the State Planning Commission and the Ministry of Public Security with input and assistance from other agencies, experts from the universities and the Fire Research Institutes. Building products used in China are tested to national test standards by approved Chinese testing agencies.

高层建筑设计趋势

由于国际设计团队参与了中国高层建筑的发展，许多初次提出的消防安全设计概念以成为了全球性的设计标准，并用于亚洲、中东地区、美国的项目中。近二十年来，中国拥有比其他国家都丰富的高层建筑设计建造经验。这样的经验让中国位于此时期高层建筑消防安全最前沿，并且向国际设计团队提供了丰富的知识及经验

中国法规及建筑审批过程

中国建筑法规及标准的制定及实施都是在国家级层次上的。其发展是由国家发展计划委员会和公安部联合其他机构，如来自各大院校的专家及消防研究所主导的。建筑中用材都是经过依照中国国家测试机构认证的测试标准经行过测试的。

中国国家建筑标准结合了两个元素

- 描述高层建筑设计和消防安全系统的详细的硬性规定。
- 提供可替代性的并能达到硬性规定意图的性能化设计。

这些元素支持国家鼓励发展建设和创新型建筑设计的目标，同时保证了新建筑达到高水准的消防安全。

建筑审批大多是经由省级消防局。但是作

China's National Building Standards combine two elements:

- Detailed prescriptive requirements that outline requirements for design of high rise building features and fire safety systems.
- Performance based alternative approaches that provide a mechanism to allow alternative design approaches that are deemed to perform at a level equivalent to the prescriptive requirements of the code.

These elements support the country's overall goal of encouraging growth and innovation in building design while at the same time assuring a high level of fire safety in new construction projects.

Building approvals are generally the responsibility of provincial fire authorities, although Beijing, Shanghai & Guangzhou, where much of the high rise construction has traditionally occurred, have "home rule" authority to approve most projects. Compliance with the requirements of the code is the responsibility of the Local Design Institutes (LDI) and the Owner. Although there is no formal mechanism in the National Standards for variations from the standards or for alternate design approaches, China has developed a rigorous design approval process to accomplish this objective. The approval process in China also encourages innovation and the rapid assimilation of new building technologies.

All high rise building designs that are greater than 250 meters in height are required to include a special report prepared by a fire expert that documents the buildings fire safety features and demonstrates the satisfactory performance of the building in foreseeable fire scenarios. The special report typically includes fire modeling and egress modeling studies to validate the performance based approach of the design. The fire engineering report is peer reviewed, typically by one of the fire research institutes or by a recognized expert company, to validate the assumptions and conclusions. Both the special report and the peer review report are submitted to an expert panel consisting of fire service and industry experts for final technical review and concurrence. The final approval of the special report is done by local and provincial fire departments.

The application of performance based design, expert panels, peer review and special studies to validate building performance were first introduced in conjunction with high rise design in China and have evolved into standard practices on high rise structures worldwide.

Passive provisions such as fire compartments, hardened core elements and enhanced structural performance have become standard features of most modern tall buildings. Many of these features are common elements of all high rise codes. Some find their origins in the Chinese standards. Several of these elements are highlighted below:

Refuge Floors

The concept of refuge floors was first introduced to codes in Asia, including China nearly 40 years ago. Since that time, they have been incorporated into high rise designs throughout the world. The concept of refuge floors is to address a number of issues associated with high rise evacuation and fire fighting. These include:

- It is recognized that many building occupants are physically unable to evacuate from upper levels of high rise buildings without rest or other assistance. Refuge floors provide a protected area at intermediate levels of the building for occupants to rest and wait for rescue without danger from fire or smoke.

为高层建筑常建地的北京、上海、广州却有“地方自治”的机构进行项目审批。地方设计研究院（LDI）及业主必须遵守法规要求。 虽然中国法规里并没有制定正规的针对与硬性规定不同的替代性方法机制，中国已发展制定出了一套严格的设计审批流程以完成此目标。中国审批流程同样鼓励创新和快速吸收新建筑技术。

所有的超过250米的高层建筑设计都被要求包含一份由消防专家所撰写的特殊报告以记录建筑的消防安全措施并证明在可预见的火灾场景中建筑表现是满意的。这种特殊报告一般包括了用来验证性能化设计的火灾模拟和疏散模拟。 此消防报告会在同行中进行评审以验证假设以及结论。评审者一般为消防研究所或国家认证的专业公司。特殊报告和评审报告都需提交给由消防局和业界专家组成的专家组做最终审查及批准。特殊报告的最终审批是由地方和省级消防局执行。

运用性能化设计、专家组、同行评审、特殊报告的方式来验证建筑性能的这个方法是在中国高层建筑设计中首次出现的。这已演化成了全球高层建筑项目的标准做法。

被动防火规定，如防火分区、核心硬化构件、加强型结构性能，都成为了现代高层建筑的标准。许多措施都是在各种高层建筑法规中常见的。有些却是可以追溯至中国法规。这些中的一部分将在下面着重介绍：

避难层

避难层这个概念是是与大约40年前引进亚洲的，当然这也包括中国。 自此，这概念也融入了世界各地的高层建筑设计中。此概念解决了几项有关高层疏散和消防作业的难题。其中包括了：

- 这个规范的制定是基于在现实中许多在高层建筑里的人们无法在没有帮助或停憩的情况下成功的逃生。避难层则在建筑的中间层提供了一个受保护的区域，这个使人们在等待救援的同时免受火或烟气的侵害。
- 避难层同样也可阻止火势蔓延。 由于避难层里包含了不可燃物质，无论是在建筑内部还在建筑外部的玻璃幕墙上，它都能有效阻止火势在竖直方向上的蔓延。
- 避难层可用于分隔楼梯井。连接楼层超过40层楼梯井加强了烟囱效应并且使楼梯间加压不能有效的阻止烟气的进入却还会让楼梯间门难以操作。 当避难层用来分隔楼梯井时，避难层实际上减小了烟囱效应并且加强了楼梯间加压防烟的效果。
- 避难层可作为建筑中的人员集散点。 使用经过专门训练的消防人员或建筑管理人员，避难层可作电梯逃生作业准备区。或当某个楼梯被烟气填满或用于消防作业，避难层也可用于指导人们使用其他的楼梯。

虽然各个法规中的要求不尽相同，但是都包含了就地保护人员的规定。表1中展示了几个现今有关避难层的规地。

使用避难层规定可以是多种形式的。双子塔使用空中大堂和天桥作为避难层。 这样一来，如果必要，人们可以从一个大厦转移到另一个大厦里。

金茂大厦在办公用楼层的第15和第30层上设置了避难层。而在宾馆用楼层里，所有的有客房的楼层都被用作避难层。因此避难层是和有人员载荷的楼层共用一个楼层的。疏散楼梯井在大厦的15和30层被分隔开来，相应的人们也被引导至此避难层内。但是楼梯井并没有在第58层和85层隔开来，因为人们并没有重新引导至此两楼层。为了减小烟囱效应，疏散楼梯井在第51楼层进行了转移。

哈利法塔运用了临近建筑机械设备楼层的避难层。 楼梯井在避

Building Feature 建筑参数	Location of Refuge Areas 避难区分布	Size of Refuge Areas 避难区面积
USA 美国	Every floor of a high rise building is considered a refuge area during fire. Floors are of 2 hour fire rated construction with protection of penetrating shafts. 在火灾中，高层建筑的每个楼层均可以考虑成避难层。 避难层的楼板需达到2小时的耐火极限并封堵穿过楼层的竖井的孔洞。	No provision is made for size of refuge areas. Because each floor is considered a refuge area, it is assumed that each floor can accommodate the occupant load from 1 other floor. 因为任何一层楼都可用作避难此并且法规中假设每个楼层都能容纳来自另外一楼层的人员，所以没有对避难层大小作出规范。
China 中国	Current Chinese Code mandates that a refuge floor can serve a maximum of 15 occupied floors. A proposed revision would limit vertical separation of refuge floors to 45 meters (between 10 and 14 floors depending on the floor to floor height). 现在实行的中国法规要求，每隔15层有人员载荷的楼层，均应设置避难层。今后可能会改为每45 m 设置一避难层 （基于楼层高度，可能为10 至14层楼的高度）。	Refuge areas can only share floors with mechanical equipment areas, although refuge areas sharing floors with occupied areas is permitted under some situations. Refuge areas are required to hold the entire population of the floors that it serves at a density of 5 occupants per square meter 避难层通常只能和放置机械装置楼层共用。在某些情况下，法规允许避难层和有人员载荷的楼层共用。 此外避难层需能容纳经每平米5人计算出的人员载荷。
Korea 韩国	Refuge floors are required in high rise buildings. Refuge floors are to be located every 30 floors (they serve 29 floors). Refuge areas may be shared with mechanical equipment floors, but not with occupied floor levels. 避难层必须配置于高层建筑中。每30层需设置一避难层 （为29个楼层提供服务）。 避难层可和机械设备楼层共用，但不能和有人员载荷的楼层共用。	By code, there is no guidance on refuge area size. By practice, refuge areas are to hold a percentage of the population served. At the highest levels, this is as high as 80%. On lower levels, it can be reduced to 40% 法规里并没有对避难层大小的设置提出要求。实践中，往往使用可容纳人员载荷百分比来确定大小。对于服务于最高楼层时的避难层，这个百分比达到了80%。对于服务于低处楼层时的避难层，这个百分比减小到了40%。
Gulf Cooperation Council 海湾阿拉伯国家合作委员会（GCC）	GCC Code Circular requires full refuge floors every 20 floors (serving 19 floors). Refuge floors are required to be full floors with no other occupancy. They can be open to the exterior or mechanically pressurized. GCC法规要求每隔20楼设置一个避难楼层 （为19个楼层提供服务）。 每个避难层需占据整个楼层且不能用于其他功能。避难层可对外部开放也可实施机械加压。	The GCC Circular provides no guidance on occupant load. Refuge areas are required to be full floors and only HVAC equipment that serves only that floor may be located on it. GCC法规里并没有对避难层大小的设置提出要求。避难层需占据整个楼层，此外只有仅服务于此楼此的暖通空调系统可布置与避难层。
India 印度	The National Building Code of India requires refuge areas in high rise buildings located every 15 meters (4-5 floors depending on the floor to floor height) vertically. 印度国家法规要求高层建筑中每15m 需设置一避难层 （基于楼层高度，可能为4至5层楼的高度）。	Refuge areas sized for 0.3m²/per person for occupants of 2 floors. Min. 15.0 m² 避难层大小是由0.3m²/人的系数和两层楼人员载荷总数来计算的，但不得小于15 m²。

Table 1. A number of current requirements for refuge areas
表1. 现今有关避难层的规地

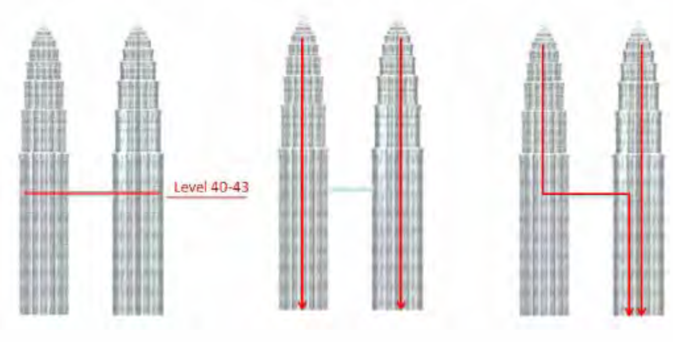

Figure1. Petronas Towers. Sky lobbies and sky bridge serve as refuge areas.
图1. 双子塔：空中大堂和天桥作为避难层

- Refuge floors can act as a fire break. Because they contain no combustible materials, refuge floors can impede vertical fire spread by way of both the interior of the building and the building's exterior curtain wall.
- Refuge floors can be used to interrupt exit stair shafts. Stair shafts connecting more than 40 stories can provide a significant path for building stack effect and can be difficult to pressurize sufficiently to keep smoke from entering while at the same time, allowing easy door operation. When refuge floors are used to interrupt the stair shafts, they reduce the overall impact of stack effect and facilitate protection of the stairs from smoke infiltration.
- Refuge floors can be used as assembly points within the building. Using trained fire service or building personnel, refuge floors can be used to stage elevator evacuation, to direct occupants to alternate stairs in cases where a stair might be blocked by smoke or by fire fighter operations.

The requirements found in various building codes differ substantially, but all include some provision for defending occupants in place inside the building. Table 1 demonstrates a number of current requirements for refuge areas.

Application of refuge floor requirements can take several forms. The Petronas Towers utilize the sky lobbies and sky bridge as refuge areas.

难楼层分隔开来。因此人们能从楼梯间进入避难层，同时楼梯间内的烟囱效应也得以减小。

电梯应急使用

- 消防电梯
  人们很早就认识到电梯可用于高层建筑中的消防作业。
  事实上，电梯是在高层建筑里唯一能让消防员迅速达到较高楼层内展开灭火救援工作的设备。国际上使用的大多数法规都对消防电梯有着相似的规定。
  在高层建筑法规的实际运用中，对消防电梯和疏散楼梯共用前厅的布置上基本保持一致。
  哈利法塔上的消防电梯与疏散楼梯独立并存，并拥有专门的前厅。
- 逃生电梯
  除了消防电梯，在一些紧急情况下，使用逃生电梯也成为一种趋势。目前使用逃生电梯有两种模式 – “救生船”式逃生或自助逃生。在这两种情况下，电梯都是针对紧急情况而专门设计的。 不过其中一种模式需要受过训练的电梯操作人员进行作业。另外一种模式则依靠人群自己操作。
- 救生船逃生电梯
  最新的几个高层建筑，如哈利法塔、上海中心大厦、王国大厦，都使用了“救生船逃生”的模式。在某些紧急情况下，这种模式可被视为额外的逃生方法。一旦建筑管理系统肯定此逃生方式是安全可行的，电梯控制系统会允许消防人员或受过训练的保安人员对指定的电梯进行控制。电梯只能作为已建立的逃生步骤里的一部分。在正常供电和应急供电的情况下，被受过训练的人员控制电梯会对整个建筑的人员逃生，以及输送人员到指定区域，如避难层或空中大堂、地表，产生影响。这种方法可以大大的减少疏散的时间，并且能保证在大多数情况下少于2小时。电梯同时还应防水并配备有应急电源。
- 自助逃生电梯
  IBC2009，第403.5.2节要求除了非R-2类并高于128m 的建筑都应配备有符合IBC2009第3008节的自助逃生电梯或者配备额外的疏散楼梯。 这个要求的宗旨是为了保证人员能畅通地从较高楼层疏散至低处，并且能保证消防人员可避开向下疏散的人群从而进入较高楼层。 自助逃生电梯

This allows occupants from one tower to transfer to the other tower if necessary.

The Jin Mao Building incorporates refuge floors on the 15th and 30th floor of the office portion of the building. In the hotel portion, refuge floors are incorporated on all guest room floors. Refuge areas are shared with occupied floor areas. The exit stairs are interrupted, directing occupants into the areas of refuge at levels 15 and 30, but are not interrupted for that purpose between levels 58 and 85. The exit stairs physically transfer at level 51 to mitigate the impact of stack effect.

Burj Khalifa incorporates refuge areas adjacent to the building mechanical floors. Stairs are interrupted at refuge areas both to direct occupants into the areas of refuge as well as physically interrupted to mitigate the impact of stack effect.

Elevators for Emergency Use

- **Fire Fighter's Elevators**
  It has long been recognized that elevators for fire fighter use are needed in high rise buildings. Elevators are the only practical way for fire fighters to reach the upper levels of a high rise to be able to begin suppression and rescue operations. Most international codes have similar requirements for fire fighters elevators.
  Application of these requirements is fairly consistent in current high rise design with fire fighters elevators and exit stair sharing a common vestibule.
  Fire fighter's elevators on Burj Khalifa are independent of the exit stairs and have dedicated lobbies.
- **Occupant Evacuation Elevators**
  In addition to elevators for fire fighter's operations, there is a

与救生船式逃生很相似，因为电梯同时都是防水的并配备有应急电源。主要的不同点在于自助逃生是在建筑中的每个电梯上实施的，并且是由在每个楼层（而非指定楼层）的人群发起的。 自助逃生电梯只在有电梯烟感应探测器或从消防控制室内人工发起的电梯召回的第一阶段前使用。 此种模式目前用于很多高层建筑项目里。

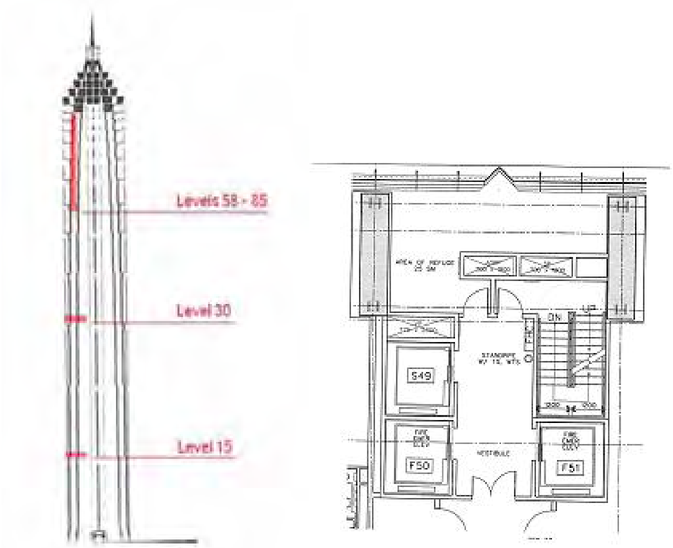

Figure 2. Jin Mao Tower. Building section and plan view showing refuge floors
图2.　金茂大厦：展示避难层的建筑剖面和平面

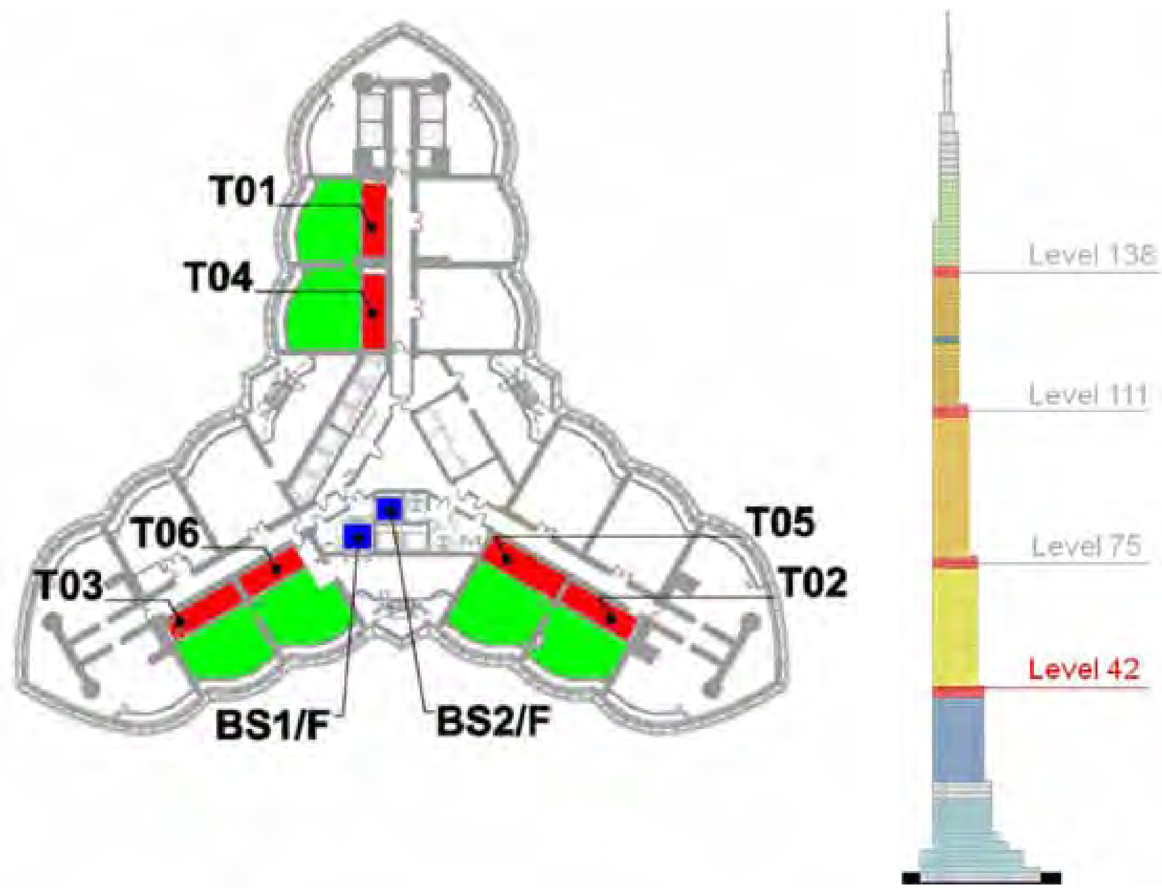

Figure 3. Burj Khalifa: Building section and plan view showing refuge floors
图3.　哈利法塔：展示避难层的建筑剖面和平面

Building Feature 建筑参数	Kingdom Tower 王国大厦	Wuhan Tower 武汉大厦	Burj Khalifa 哈利法塔	Jin Mao Building 金茂大厦	Petronas Towers 双子大厦
Year Complete 竣工年份	2017 (estimated 大约)	2015 (estimated 大约)	2010	1999	1996
Height/Number of Floors 高度/楼层数	1000+m/165	606m/118	828m/163	421m/88	452m/88
Areas of Refuge 避难层	Levels 18, 38, 56, 71, 85, 104, 124 and 144	Levels 4, 14, 24, 35, 48, 58, 69, 72, 87, 103, 116 (层)	Levels 42, 75, 111 and 138 (层)	Levels 15, 30, 58-85 (hotel levels) & Penthouse L2 15, 30, 58-85 层(宾馆楼层) 和 顶层阁楼第2层	Levels 40-43 (层)
Floor Area 楼层面积	Full Floors 整个楼层	Partial floors – area based on population served 部分楼层 – 面积由人员载荷确定	Partial floors – area based on population of 3 largest floors served 部分楼层 – 面积由人员载荷最多的三个楼层来确定	Partial floors – area based on population served 部分楼层 – 面积由人员载荷确定	Full floors – sky lobbies 整个楼层 – 空中大堂
Ventilation 通风	Mechanically Pressurized 械加压	Mechanically Pressurized 机械加压	Mechanically Pressurized 机械加压	Mechanically Pressurized 机械加压	Mechanically Pressurized 机械加压

Table 2. Comparison of refuge floors
表2. 避难层对比

Building Feature 建筑参数	Kingdom Tower 王国大厦	Burj Khalifa 哈利法塔	Jin Mao Building 金茂大厦	Petronas Towers 双子大厦
Year Complete 竣工年份	2017 (estimated)（大约）	2015 (estimated)（大约）	1999	1996
Height/Number of Floors 高度/楼层数	1000+M/165	828M/163	421M/88	452M/88
Primary Fire Water Supply 主要消防供水	Gravity fed to extent possible. Automatically fed fire pumps taking suction from dedicated fire water storage tanks. 尽可能利用重力供水系统。 可自动启用消防水泵从专设的消防水池中取水。	Gravity fed to extent possible. Automatically fed fire pumps taking suction from dedicated fire water storage tanks. 尽可能利用重力供水系统。 可自动启用消防水泵从专设的消防水池中取水。	Basement tank connected to domestic water tank. Two secondary water tanks on L51 and Penthouse with pumps. 地下室消防水池和生活用水池相连。 两个副水池位于第51层和顶层阁楼并并配备消防水泵。	Basement tanks connected to domestic water mains with fire pumps 地下室消防水池和生活用水池相连并配备消防水泵。
Fire Water Supply Duration 消防供水持续时间	Combined Sprinkler & Standpipe system. 2 hour minimum with redundant refill methods. 喷淋&消防栓系统相结合. 至少2小时并提供多种回灌措施。	Combined Sprinkler & Standpipe system. 1 hour minimum with redundant refill methods. 喷淋&消防栓系统相结合. 至少1小时并提供多种回灌措施	Separate sprinkler and standpipe systems. 1 hour for sprinklers, 3 hours for standpipes 喷淋系统和消防栓系统相互独立。喷淋系统1小时，消防栓系统3小时	1 hour for sprinklers 喷淋系统1小时
Fire Pumps 消防水泵	Yes 提供	Yes 提供	Yes 提供	Yes 提供

Table 3. Comparison of water supply systems
表3. 给水系统对比

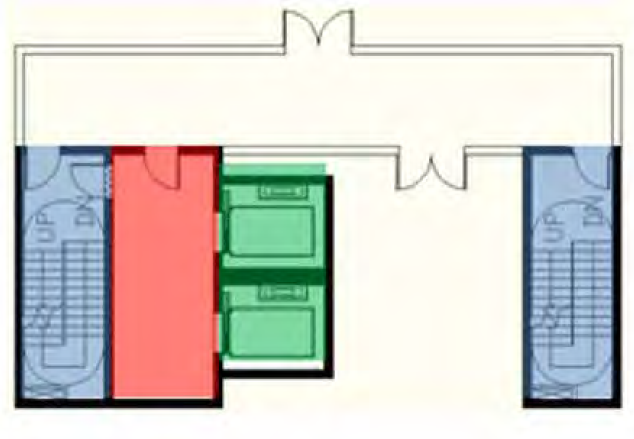

Figure 4. Fire fighters elevator requirements of IBC 2009
图4. IBC2009消防员电梯要求

Figure 5. Burj Khalifa: Typical fire fighters lobby and evacuation elevator lobby.
图5. 哈利法塔：一般的消防员大堂和疏散电梯大堂

trend toward using elevators for occupant evacuation in certain emergencies. There are currently 2 basic modes of operation for these occupant evacuation elevators – "Lifeboat" Evacuation and Self-Evacuation. In both cases, elevators are specially designed to be used under emergency conditions. In one case, they are operated by trained building personnel. In the other they are operated by building occupants.

- **Lifeboat Evacuation Elevators**
  Several newer high rise buildings, including Burj Khalifa, Shanghai Tower and Kingdom Tower 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. 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, usually refuge floors or sky lobbies, to grade. This mode of operation generally uses the high speed shuttles, evacuating from designated assembly points down to grade. The method substantially reduces total building evacuation time, in most cases to less than 2 hours. Elevators are provided with emergency power and are protected from water infiltration.
- **Self Evacuation Elevators**
  IBC 2009, Section 403.5.2 requires buildings other than R2 occupancy and taller than 128 m to have an additional exit stair or occupant self-evacuation elevators in accordance with IBC 2009, Section 3008. This provision is to address both the ability of occupants to exit from the upper floors and the ability of fire fighters to gain access to upper floors without interference of occupants descending. Self-evacuation elevators are similar to lifeboat evacuation in that the elevators are on emergency power and protected from water infiltration. The key difference is that self evacuation elevators are implemented for all building elevators and are initiated by occupants on every floor of the building rather than designated floors. Self-evacuation elevators are only in service until phase 1 recall is initiated by an elevator smoke detector or manual recall from the fire command center. This mode of operation is currently being designed into a number of high rise projects.

Fire Protection Water Supplies

Reliability and survivability of active fire safety systems has also become a key focus of our current designs. It is especially critical that these active systems be simple and easily serviced and maintained as high rise construction in areas of the developing world, not used to designs employing sophisticated levels of technology, continues to accelerate. The use of on-site water storage tanks for firefighting water supplies is common in high rise buildings.

In many current designs, the sprinkler and standpipe systems operate by gravity so that a failure of the fire pumps will not impede the operation of these suppression systems. An example of this arrangement in shown in Figure 6.

Country 国家/法规	Fire Fighters Elevator 消防电梯	Fire Fighting Lobby/vestibule 消防用电梯大堂/前厅
China 中国	1 fire fighter elevator for 1,500 s.m. of floor area. 1 fire fighter elevators for 4,500 s.m. of floor area. 800 kg capacity. 2-hour hoistway enclosure 60 second time to top of building. Emergency Power. Water Protection. 一个服务于1,500平米楼层面积的消防电梯. 两个服务于4,500平米楼层面积的消防电梯. 800 kg 容量 电梯井耐火极限为2小时 60秒内到达顶层 应急电源 防水	Min. 6.0 s.m. Min. 10.0 s.m. where shared with a stair. 2 hour fire rated enclosure. Mechanically pressurized. Water Protection. 最小 6.0 平米 最小 10.0平米与楼梯间相通 耐火极限为2小时 机械加压 防水
BS5588	1 fire fighter elevator & fire fighting shaft (elevator, vestibule & stair) for each 900m2. Max 60m to most remote point. Min. size: 1.1m X 1.4m, 630kg 2-hour hoistway enclosure 60 second time to top of building. Emergency Power. Water Protection. 提供一个消防电梯和消防井（电梯，前厅和楼梯间）。里最远点距离不得超过60 m。 最小面积：1.1m X 1.4m，630kg 耐火极限为2 小时的电梯井 60秒内到达建筑顶层 应急电源 防水	2 hour fire rated enclosure. Min. area: 5m2 Min dimension: 1500mm Mechanical or natural ventilation. Direct access to stair. 耐火极限为2 小时 最小面积：5m2 最小长度：1500mm 机械或自然通风 直接通向楼梯
IBC 2003	1 fire fighter elevator. 2-hour hoistway enclosure Emergency Power. 一个消防电梯 耐火极限为2 小时的电梯井 应急电源	2 hour fire rated enclosure. Mechanically pressurized. Direct access to stair. 耐火极限为2 小时 机械加压 直接通向楼梯
IBC 2009	1 fire fighter elevator. Sized to accommodate an ambulance stretcher. 2-hour hoistway enclosure Emergency Power. 一个消防电梯 电梯可容纳医用担架 耐火极限为2 小时的电梯井 应急电源	1 hour fire rated enclosure. Min. 14 s.m., Min dimension – 2440 mm Direct access to stair. 耐火极限为1 小时 最小面积. 14 m2.， 最小长度：2440 mm 直接通向楼梯
IBC 2012	2 fire fighter elevators. Sized to accommodate an ambulance stretcher. 2-hour hoistway enclosure Emergency Power. Water Protection. 两个消防电梯 电梯可容纳医用担架 耐火极限为2 小时的电梯井 应急电源 防水	1 hour fire rated enclosure. Min. 14 s.m., Min dimension – 2440 mm Direct access to stair. Water Protection. 耐火极限为1 小时 最小面积. 14 m2.， 最小长度：2440 mm 直接通向楼梯 防水

Table 4. emergency elevator codes
表4. 紧急逃生电梯规范

Conclusion

In conclusion, as the community of high rise design specialists, contractors and operators continues to carry out projects around the world, it is important to learn from the shared experience of the recent and unprecedented period of high rise development centered in China, which has helped foster advances in high rise fire safety advances the practice of fire safe high rise design around the world.

消防给水

自动消防系统的可靠性以及生存能力已成为如今设计中的重点。重要的是要保证这些自动消防系统是相对简单的、容易维修的，因为在发展中国家里的高层建筑项目还没有适应系统繁杂的技术。而用于现场的消防水池是在高层建筑项目中常见的。

现在的许多设计里，喷淋系统和消防栓系统都利用了重力供水方式，从而减小对消防水泵的依赖。下图展示了一个这种设计的例子（图6）。

结论

总而言之，随着世界各地不断涌现着涉及各方面的设计人员、施工人员、以及使用者高层建筑项目，从近来以中国为中心的、以史无前例的速度发展的高层建筑增长里学习相关经验显得格外重要。　这些经验促进了全球高层建筑消防安全水平。

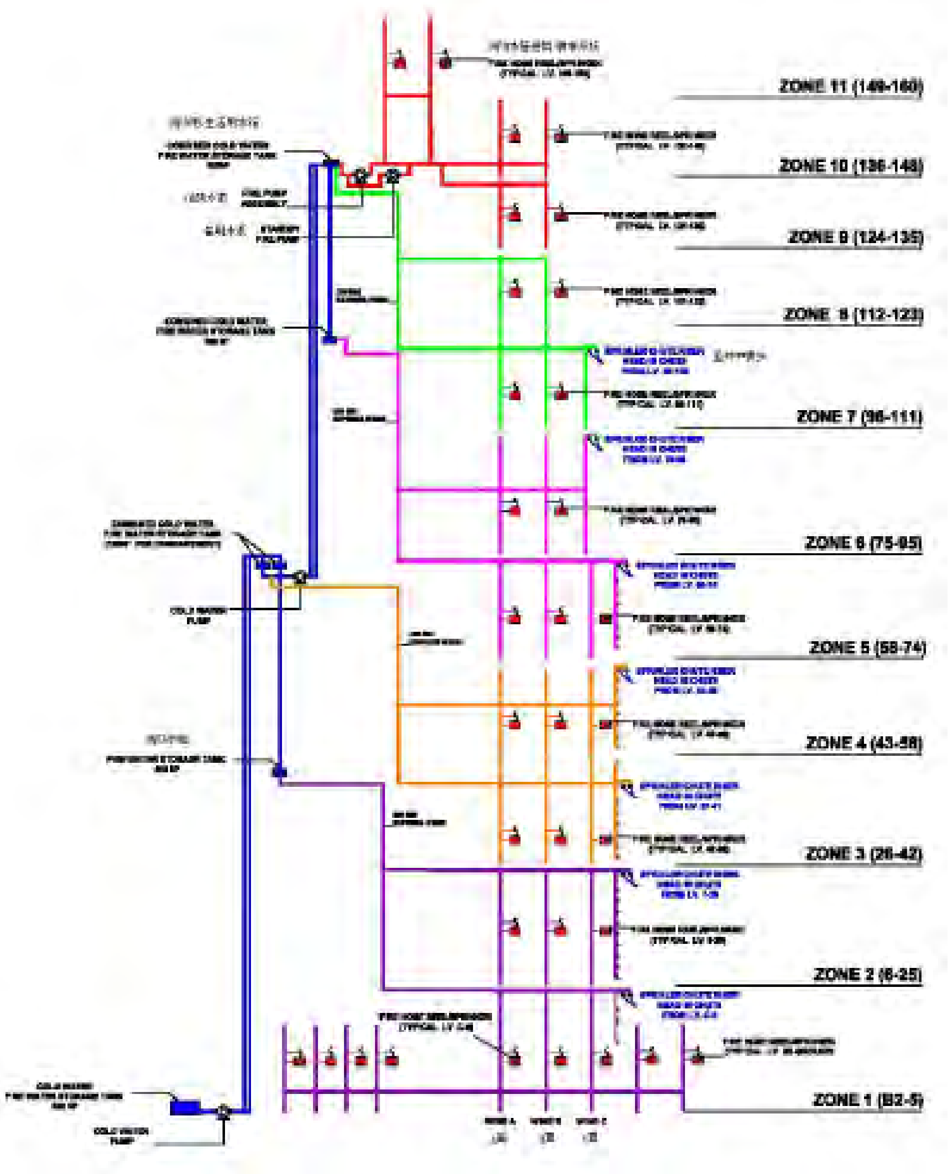

Figure 6. Burj Khalifa: Schematic of fire fighting water supply.
图6. 哈利法塔：消防给水示意图

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Wood, A. 2003. "Pavements in the Sky: Use of the Skybridge in Tall Buildings." **Architectural Research Quarterly (ARQ),** Vol. 7, No. 3 & 4: 325–333. Cambridge University Press.