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Fire & Life Safety Challenges in Sustainable Tall Building Design

可持续高层建筑带来的消防及生命安全挑战

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李方女士是RJA公司管理中国业务的执行副总裁。自2004年以来，她一直负责上海办事处。同时她也担任着美国消防工程师协会中国分会的创始主席。其参与编写的“建筑物性能化防火设计技术导则”被广泛应用在中国的众多高层建筑中，而李芳女士也因此被授予公安部科技进步奖二等奖。对于世界各地独特的超高建筑，李方是知名的消防专家。她拥有伍斯特理学院（WPI）的消防工程硕士学位。

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Reiss先生是RJA公司的总裁兼首席执行官。他在1992加入了“美国国家消防协会”董事会，并从2000年至2002年担任该委员会的主席。此外，他是中国消防协会的第一个外国成员。Reiss先生是一名注册专业工程师，并当选为消防工程师学会最高级别会员。Reiss先生拥有美国麻省理工学院（MIT）的工程科学学士及硕士学位。

Abstract

The movement towards sustainable building design can result in unique fire protection challenges and concerns, especially with tall buildings in relationship to traditional prescriptive code compliance. Specific design features include the fire separations and the fire protection system design. Other fire safety concerns include green roofs, sprinkler water quality and testing, fire department access and areas of refuge. The solutions to these prescriptive code challenges and fire safety concerns can range from simple alternatives to more detailed engineering performance-based design analyses.

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

摘要

在实现可持续建筑设计的过程中可能出现独特的消防难题，特别是处理遵守传统的指令性规范的高层建筑物。具体消防设计包括防火隔离和消防系统的设计。其他消防安全隐患包括绿化屋顶，消防喷淋用水的质量和检测，消防通道和人员避难区。这些针对指令性的法规所提出的挑战和消防安全隐患，可以简单地用替代品来解决，或者需用更详细的性能化设计经行解决。

关键词：消防、消防安全、生命安全、性能化设计、遵守法规、高层建筑

Introduction

The movement towards sustainable or environmentally friendly building design can result in unique fire protection challenges and concerns, especially with tall buildings in relationship to traditional prescriptive code compliance. The solutions to these prescriptive code challenges and fire safety concerns can range from simple design alternatives to more detailed engineering performance-based design analyses (Hofmeister, 2010).

Fire protection design usually does not have a direct impact on obtaining green building certification, however, some alternatives or performance based options will help the design team meet the sustainable goals for the project and influence the certification process.

These issues have been addressed by performance-based design for many types of buildings but the frequency has increased with green buildings. Tall buildings have further increased the magnitude of the spaces involved which require more creative solutions for fire safety and energy saving.

引言

在实现可持续建筑设计的过程中可能出现独特的消防难题，特别是在遵守传统的指令性规范的高层建筑物。这些针对指令性的法规所提出的挑战和消防安全隐患，可以简单地用替代方案来解决，或者需用更详细的性能化设计经行解决(Hofmeister, 2010)。

消防设计通常不会对一座建筑的绿色建筑认证产生直接影响，一些替代方案的运用或基于系统表现性能的设计方案却可帮助设计团队达到该项目的可持续性目标并影响的认证过程。

这些问题已在多种类型的建筑中由性能化设计得到解决。 性能化设计也逐渐越来越多的用于绿色建筑。高层建筑又进一步增加了一个建筑中需提供建设性的消防安全方案及节能设计的空间。

消防设计难题

以下列举了运用指令性规范时的难题以及消防安全隐患 。

防火分区和耐火建筑构件

绿色建筑设计经常采用大量的玻璃及类似的半透明的材料。此类设计可向整个建筑提供自然光照明，同时也向建筑用户提供了美景。基于照明和通风上的考虑而使用

Fire Protection Design Challenges

The following are examples of the prescriptive code challenges and fire safety concerns.

Fire Separation & Fire Rated Structural Elements

Green building design frequently incorporates large amounts of glass and similar translucent materials to provide natural light transfer throughout the building while also provide occupants with scenic views. The desire for large open spaces for light and ventilation results in an increase of atriums and other similar spaces. These spaces can create code compliance issues with the requirements for fire rated separations.

Additional separation and fire related construction issues arise in large mixed-use facilities when the different usage and occupancy areas are considered separate buildings with their individual code compliance requirements for egress. Large shading structures and canopies also create code compliance issues with respect to fire resistance of these structures and fire department access to these elements.

The use of complex curtain walls can create other separation issues (O'Connor, 2011). Restriction of vertical fire spread to the floor of origin is the desired outcome. Double-skin façades for heating, cooling, sound control and lighting efficiency create challenges in preventing a break-through of the flame and smoke into the tall shaft-like space. The choice of fire stop materials and joint system constructions is important in achieving the necessary separations. Another challenge is the growing use of combustible insulation and finish materials for the façades.

Often the issues associated with new sustainable technologies are related to the newness of the technology itself and the lack of familiarity or lack of experience in the use of the technology in tall building design. Many times a hazard analysis is needed to define the hazards associated with sustainable products or materials to quantify the hazards introduced and to determine the appropriateness for tall building design.

The energy saving exterior insulation material for the glass curtain wall requires high performance both for energy savings and for fire safety. When compared to solid exterior walls, glazing materials are more sensitive to exterior temperature changes. The insulation material required by codes needs to be non-combustible while the desired energy saving is for light weight and high insulation performance. Some materials, such as extruded polystyrene board, meet the energy saving goal but have poor fire protection performance with respect to fire spread on exterior walls. Many of the new materials being used for energy savings have not been tested for fire resistant ratings such that the testing protocols need to be updated. This conflict between the energy savings for new materials and fire protection performance is a challenge in how to meet the objectives for achieving the design goals requiring the new technology for both product and updated testing protocols. The lessons learned from some recent fires could be a good source of best practices for updating regulations. The challenge is to encourage new energy efficient materials and technologies while at the same time assuring that building regulations are in place and up to date to maintain fire safety.

Masdar Corporate Headquarters. This notable design is by Adrian Smith + Gordon Gill Architects in Abu Dhabi, United Arab Emirates (see Figure 1).

The building includes several integral cone elements intended to moderate natural ventilation and provide natural light transfer throughout the building. The cone elements support both the canopy

Figure 1. MASDAR Corporate Headquarters Building (Source: AS+GG)
图1. 马斯达公司总部大楼 （来源 AS+GG）

大型开放式空间的概念，让类似中庭等的场所有所增加。这些空间可能使满足法规对防火分区要求更具挑战性。

当大型多功能设施中拥有不同的使用功能区域，且此区域被考虑为单独的建筑并其遵守与其相匹配的疏散规定的时候，额外的防火分离和耐火构件常被用到。大型遮阳结构和檐篷的耐火极限以及通往这些建筑构件的消防通道也可增加达到规范要求的难度。

使用复杂的玻璃幕墙带来了有关防火隔离的挑战(O'Connor, 2011)。最理想的情况是能把垂直蔓延的火势限制在火灾起源的楼层。对加热，冷却，声音控制和照明效率有正面效果的通风式双层幕墙却对防止火焰及烟气进入此井状空间的目标带来了挑战。使用防火封堵材料和防火封堵系统构件是满足防火分隔要求的重要的手段。同时，建筑外墙越来越多地使用可燃保温和饰面材料也被视为另一个新挑战。

有关新可持续技术所带来的挑战往往涉及到其技术本身的新颖性和缺乏在高层建筑设计中使用此技术的经验。多数情况下，必需对引进的可持续性材料进行危害分析。 此类分析将对可持续性材料相关危害给出定义，并论证其是否适合用于高层建筑设计。

用于玻璃幕墙的保温材料的节能和防火性能都有较高标注。与实体外墙相比，玻璃材料对温度的变化更加敏感。法规要求隔热材料需是不可燃烧的。能达到期望的节能标准的材料一般都材质轻、保温性强。某些材料，如挤塑聚苯板，能达到节能目标但是在外墙火势蔓延方面有很差的防火表现。许多用于节能的新材料都没有经过耐火极限测试。因此测试方式应该更新。在新材料的节能与防火性能冲突的背景下，如何取得对产品和测试方法的新技术指标是极具挑战性的。从最近的火灾中吸取的教训，可能是更新法规的最佳来源。如今所面临的挑战是在鼓励新的节能材料和科技的同时需保证建筑法规的及时更新以保持消防安全水平。

马斯达公司总部. 这是位于阿拉伯联合酋长国阿布扎比，由Adrian Smith + Gordon Gill建筑事务所设计的一项引人注目的项目（见图1）。

此建筑包括了几个一体化的核心筒。这些核心筒向整个建筑提供自然通风和自然光照明。他们也支撑建筑上方的檐篷结构以及建筑本身的一部分，因此这些核心筒也是属于建筑结构框架的一部分，这也就意味着它耐火等级受相应法规所约束。一些核心筒同样是中庭的一部分，这又要求其与相邻的有人员载荷的区域实施防火隔离。为了美观，设计团队希望使用暴露的钢架。由于没有防火涂层，这可能对所期望的消防安全目标带来更多的挑战。依照建筑承重构件的不同功能，法规里了供不同的选项，如使用膨胀型的涂层使构件达到1.5小时的耐火极限。使用喷淋系统来作为自动保护措施也是达到法规保护暴露于高温下的钢架的另一种方法。喷淋系统的使用是不允许任何的障碍物阻挡水流作用于可

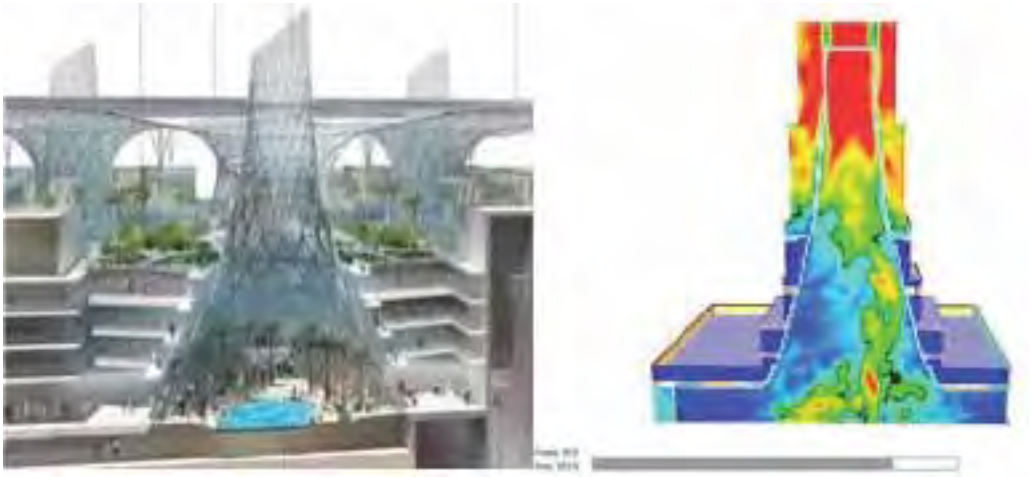

Figure 2. Model Simulation for MASDAR Corporate Headquarters Building (Source: AS+GG and RJA)
图2. 马斯达尔公司总部大楼的火灾场景电脑模拟（来源：AS+GG和RJA）

structure over the building and portions of the building itself. The structure is considered part of the structural frame which would require a fire resistant rating based on the applicable code. Some of the cone elements are also part of the atrium spaces which would also require fire resistant rated separations from adjacent occupied areas. The design team wanted to have exposed structural steel as part of the aesthetics and the challenge was to meet the fire safety objectives without using traditional fire coatings on the steel. The code allows options depending on the structural element function, such as using intumescent coatings for achieving fire ratings less than 1.5 hours. A water based sprinkler systems for active protection is another means of meeting the intent of the code to protect the structure from exposure to high temperatures. The use of sprinklers mandates that no barriers prevent the impingement of the water on the fuel load. The fuel load in the atrium was well regulated and open to the sprinklers. The analysis was based on the most credible fire scenarios for temperature rise and impact on the steel structural performance during the fire.

A performance-based approach was performed that is similar to those taken for these types of atrium issues in tall buildings in order to achieve the intent of the design. The cone elements are designed of structural steel tubes without passive fire proofing. The analysis included a review of the use, fuel loading and potential fire hazards to develop severe-case fire scenarios. Variables considered included fire location and size, effect of sprinklers and the geometry of the atrium space. The analysis used a combination of FDS and SAFIR tools. Working with the structural engineering team members, various designs were fire modeled to develop the appropriate protection scheme (see Figure 2).

Fire Protection System Design & Installation

The design and installation of fire protection systems, such as automatic sprinklers, fire alarm and smoke control are another challenge in green buildings. The challenges can range from the performance-based design of the atrium smoke control system to the placement of devices based on obstructions, local temperatures and glazing locations.

CFD modeling will often allow for either reduced mechanical ventilation requirements or for a natural ventilation alternative. In both cases, the solution would have a positive impact on reducing energy use.

Pearl River Tower. The Pearl River Tower in Guangzhou, China is one of the first green buildings in China. It was designed by Skidmore, Owings & Merrill, L.L.C The building is a mixed-use facility of 310 meters with 71

燃物载荷的。中庭中的可燃物载荷量是被严格要求的并且这些可燃物同样是被要求能被喷淋系统完全覆盖的。设计分析是基于最可能火灾场景下的温度以及对钢架结构的性能影响。

如同解决类似的高层建筑的中庭的消防问题，为了满足法规的宗旨，性能化设计被用于此项目。核心元件是由无防火涂层的管状钢架结构组成。性能化设计设计审核了建筑使用功能、燃料载荷、和可引发严重火灾的火灾危害分析。分析中考虑到的变量包括了火灾位置、大小，喷淋系统的影响和中庭空间的形状。此分析还结合使用了FDS和SAFIR。同时，与结构工程团队成员合作而制定的火灾模拟为不同的设计制定了相应的保护方案（见图2）。

消防系统设计及安装

消防系统（如自动喷淋、火灾报警器和烟气控制系统）的设计和安装是绿色建筑面临的另一个挑战。这些挑战可能来自于中庭防排烟系统的性能化设计，也可能来自于受障碍物，气温和玻璃窗的位置影响的系统装置的放置。

对火灾场景电脑模拟和其他性能化设计工具的使用可对烟气运动提供一个详细的评估，以此为基础，可对人员疏散，疏散距离和耐受条件的做出分析。此评估还可以用以审查机械、自然排烟方案审查的。分析中使用的CFD模拟常常可证明所需机械通风量比设想的要小或者完全可以使用自然通风代替机械通风。无论是哪种情况，解决方案都对节能有着正面的影响。

珠江大厦. 广州的珠江大厦是中国第一批绿色建筑之一。它的设计由Skidmore, Owings & Merrill, L.L.C公司完成。珠江大厦是一个71层、310米高的多功能建筑。 此建筑同时还包括了一个3层楼的裙楼和一个45000平方米的地下设施。这个建筑中所遇到消防挑战是目前许多绿色建筑的典型案例（Li, Antell和Reiss, 2008）。珠江大厦里遇到的消防难题包括了垂直轴风力发电机、太阳能发电板、金属吊顶冷却系统和双重幕墙（见图3）。

其中一个对消防作业的带来挑战是火灾可能起源于风力发电机组。虽然这是一种很少见情况，独立的风力发电机的火灾案例却是实实在在的。因此消防局对在有人员载荷的区域使用此技术和用什么样的策略来保证建筑及人员的安全非常感兴趣。项目中所使用的策略是使用耐火构件将风力电动机外部（主要是机械构件）元件和建筑相隔离。 这样外部的火势无法蔓延至建筑内部。同时风力电动机内部（主要是电气构件）元件放置于防火室中并配备法规要求的针对电气设备的灭火系统。最后，针对这个罕见的个例，为了方便消防作业，项目里也提供了通向风力发电机的消防通道此外，一项运用事故类型方法的分析建立了相应的消防安全设计和和应急预案。

stories, 3 story podium and 45,000 sq. m. below grade. The fire protection issues for this building are typical of those now being emulated in many green buildings (Li, Antell, and Reiss, 2008). The fire protection issues in the Pearl River Tower included the use of vertical axis wind turbines, photo voltaic panels, metal ceiling cooling system and a double curtain wall (see Figure 3).

One particular issue for the fire department was the fire hazard that may be associated with wind turbines. Although rare, there are documented cases of fire occurring in free standing wind turbine structures. The fire department was interested in understanding how this new technology would operate in an occupied high rise building and what strategies could be used to protect the building and occupants. The strategy used was to isolate the exterior (primarily mechanical components) elements of the wind turbine from the building with fire rated construction so that the exterior fire would not spread into the building. At the same time, the interior elements (primarily electrical components) were provide with fire rated enclosure and with fire suppression as required by code for other electrical elements in the building. Finally, access to the wind turbine was provided in the rare case that the fire department would need to access the exterior elements. A fire analysis used a failure mode approach which provided a fire safety design and emergency response plan.

Figure 3. Pearl River Tower Fire Safety Issues (Source: SOM and RJA)
图3. 珠江大厦的消防安全问题（来源：SOM和RJA）

Fire Safety Concerns

Many decisions made by others on the design team can impact the overall fire safety of the project. They include green roofs, sprinkler water supply, building access and areas of refuge.

Green Roofs

The issues of green roofs as a fire hazard are not new. The foliage becomes a source of combustible fuel load in drought conditions or when not properly maintained. In addition to the impact on the building roof, fire spread to other buildings that are in close proximity are a concern. Green roof design may have an impact on airborne evacuation from the roof during fire emergencies which is a requirement in certain countries, such as China. Codes require clearances and area sized for landing such that the area will not have any green growth. Fire officials are concerned about the potential fuel load from the foliage, particularly in high wind situations creating situations that could prevent the landing. The design community needs to be aware of these concerns in planning.

Sprinkler Water Quality & Testing

Water conservation is a major part of green building design. Use of rainwater or other grey water sources as a supply for the sprinkler systems is being considered as another opportunity to conserve water. If implemented, this will increase the risk of corrosion and MIC buildup,

消防安全隐患

许多由设计团队中的任何人所提出的决定，都可能会影响该项目的整体消防安全。这些包括了绿化屋顶、喷淋系统供水、消防通道、以及避难层。

绿化屋顶

绿化屋顶作为火灾隐患并不是一个新概念。树叶在干旱条件下或没有妥善保管时可称为燃料的来源。除了火灾在建筑物屋顶上的影响，火势蔓延到临近的建筑物也是一个消防隐患。在火灾事故发生的时候，绿化屋顶对空降逃生也会因此产生影响。 在一些国家，如中国，是对空降逃生有明确要求的。法规中规定了着陆区域的大小以及不能有植被覆盖。 消防局会担忧树叶是潜在的可燃物载荷。特别是在有大风的情况下，这可能阻止直升机的成功着陆。设计团队应在规划阶段就应意识到这点。

喷淋系统水质及检测

节约用水是绿色建筑设计的重要组成部分。使用雨水或其他灰水作为自动喷淋系统的水源是节水方案之一。如果付诸实施，这将增加管道腐蚀和腐蚀性微生物（MIC）在管道集结的风险，特别是铁质管道。MIC的集结通常由于水中含有不纯净成分。另一个节水方案是限制甚至取消周期性喷淋系统水流量测试。此种方案会影响法规的对系统性能的检测要求。

消防通道

新颖的园林设计是众所期望，特别是在绿色建筑项目里。除此以外，遮阳檐篷常常用于绿色建筑的入口，用来提供对玻璃幕墙以及其他外在元件的遮阳。 但是这些可能会影响到通向建筑或场所消防作业出入口。大型园林设计物件可能成为消防车辆障碍物；减少铺设的路面可影响消防车道。此外，在屋顶上使用的玻璃窗或遮阳檐篷可以干扰消防员出入。具有重量轻和透明特点的玻璃幕墙是现代建筑中常被用到的，但是在火灾事故中玻璃窗可能会破坏和影响消防安全性。许多位于入口的檐篷都是用来保护消防员免受下坠碎片的伤害。但是这又同时限制了消防器材的使用。消防作业需要能让消防车辆出入的一片作业区域。 此区域应该有足够的承重能力、净空高度、以及足够大的作业准备区域。这样的区域对超高建筑消防所需的云梯车更加重要。此外，

particular in steel piping. MIC buildup occurs in water that has impure ingredients. Another consideration for conservation may be to limit or even eliminate periodic water flow testing. This could compromise the verification of system performance that is required in many codes.

Fire Department Access

Creative landscape design around a building is a desired feature in many buildings and particularly with green buildings. In addition, shading canopies are often used in green buildings at building entrances, for shading of curtain walls from solar gain and to cover and shade exterior elements. All of these applications may impact the fire department access to the building or site. Large features can create vehicle obstructions and the desire to limit paving can impact fire lanes. In addition, the use of glazing on roofs or shade canopies over buildings can interfere with firefighter access. The glass curtain wall is the modern desired feature with light weight and transparency; however, during a fire the glass could break and impact the fire operation safety. Many entry canopies are designed to protect fire fighters from falling debris, but at the cost of limiting exterior access for fire apparatus. Fire department operations need an access area for their vehicles with minimum structural road loading, overhead clearances and a staging space. This access is even more critical when aerial trucks are needed for super tall buildings. Strong reflection of sunlight from the glazing can impact fire firefighting efforts and the choice of the site for the staging area by creating light pollution on the ability of the fire fighters to see the building.

Areas of Refuge

This space is part of the culture in many Asian countries. It creates the requirement for a refuge floor every 12 to 20 floors, depending on the local codes. This requirement creates a conflict on efficient space use versus other accepted uses. One of the main reasons for this code requirement is the desire of the fire service to be able to control panic and crowd management with zoned evacuation during a fire emergency. It also provides for a temporary shelter for the disabled.

Conclusion

Prevention of fire in itself is a significant green design feature. The environmental impact of a fire with the release of carbon gasses, destruction of resources and run-off of suppression products can have a greater negative impact than the actual savings in the building design. Application of today's best practices and advances in fire safety design can help to both mitigate a fire disaster from occurring and achieve the desired creative design for the building.

玻璃窗带来的较强反射效果可产生光污染使消防员无法看清建筑，从而影响消防作业以及对消防作业准备区域的选择。

避难楼层

许多亚洲国家，避难层空间是文化的一部分。根据地方法规，每12至20层需配备避难层。这样的要求使得对空间实施高效利用和对空间实施其他使用产生了冲突。使用此规范的另一个主要原因是，消防局希望能在火灾应急状况下对惊恐的人群实施有效管理并实施分区式的疏散。 它同时也对残疾人群提供了暂时的庇护。

总结

火灾的预防本身就是绿色建筑的一个重要设计。因考虑到节约而用的建筑设计可能在火灾时产生更大的负面影响。如火灾中释放的烟气对环境的影响，对资源的破坏，和释放的灭火剂对建筑的影响。 使用当今最佳实践和先进的消防安全设计，既可以帮助减小火灾发生的可能性，也可以帮助建筑达到期望的创造性设计。

References（参考书目）:

HOFMEISTER, C.(2010), Prescriptive to Performance-Based Design in Green Buildings, **Fire Protection Engineering**

O'CONNOR, D. (2011), Fire Safety and Green Building Design, **Fire Protection Engineering**

LI, F., ANTELL, J. , REISS, M. (2008) Pearl River Tower, Fire Protection Strategies, **CTBUH 8TH World Congress Proceedings**