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Why Our Façades Are Contributing to Noteworthy Fires
为什么我们的外幕墙会造成举世关注的火灾

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哈珀先生拥有美国马里兰大学的防火工程师学位。他取得专业工程师执照已有25年，在杰森休斯公司工作已长达27年，在此之前曾从事消防员医务工作10年。目前，他是芝加哥副总裁和资深顾问。 杰弗里曾为许多项目提供防火和生命安全服务方案、进行合规性评估并提供替代解决方案。他帮助制定了SFPE指南在超高层建筑消防安全方面相关规定要求，拥有丰富的超高层建筑项目经验，包括哈利法塔和王国塔等等。

Abstract | 摘要

Several recent noteworthy fires in high-rise buildings have drawn international media attention and highlighted a perceived weakness in tall building design. These fires appear to have involved building façades as the principal combustible material contributing to the observed rapid fire growth and development. Because of the orientation and arrangements of building façades, once started, fires involving these assemblies can grow at a significant rate. The typical fire suppression systems in such structures is not designed to mitigate these types of fires. Building designers need to understand the importance of façade material selections and how those selections may contribute to higher risks of fires. This paper will provide information on recent building fires involving the exterior façades, the history of passive requirements outlined in the major building codes that address façade materials, the often confusing world of fire tests, and more.

Keywords: Code Compliance, Composite, Façade, Fire Safety, Fire Test

近期发生的几起广受关注的高层建筑火灾吸引了国际媒体的注意，也凸显了高层建筑设计中的薄弱环节。这些火灾的共同之处，似乎都涉及到建筑物外墙可燃物助长火势快速增长和蔓延的问题。 由于建筑外幕墙朝向和布置的原因，幕墙组件一旦发生火灾，便会显著增长。在这些建筑内的标准灭火系统往往并不是为了减轻此类火灾而设计。

关键词：合规管理、复合、幕墙、消防安全、防火测试

Introduction

To densify our cities and ultimately achieve tomorrow's megacities, architects and engineers must be able to design and specify exterior walls that provide superior climate control performance. At the same time, those very same building skins must also perform acceptably when subjected to a diverse array of fire insults. Several recent noteworthy fires have brought the fire hazards of building exterior walls to the forefront, exhibiting an unacceptable level of fire performance when subjected to a competent ignition source. While the frequency of fires involving façades may be relatively low, the potential for catastrophic results, which often include the displacement of large numbers of people, can be significant (White and Delichatsios, 2014).

In review of the papers published by CTBUH in the Global Interchange Conference Proceedings (2015 New York) on the subject of façades, those papers identified many different and very important performance criteria to which building façades are to be designed – except none of those papers addressed fire performance criteria. Building codes throughout the world regulate the fire performance of building materials and assemblies by imposing minimum performance criteria when subjected to

引言

为了提高城市人口密度，在未来最终实现超级化大都市，建筑师和工程师必须能够设计出在气候控制表现卓越同时，在不同类型的火灾情况下能够拥有良好的表现的建筑外墙。近期发生的受到关注的重大火灾中，建筑外墙在面临能量巨大的火源时表现出的防火性能不能被接受，使建筑外墙火灾危险性越来越受关注。尽管建筑幕墙发生火灾的可能性很小，但是仍然有可能造成灾难性后果，而通常会造成大量的人员疏散移动。（White，Delichatsios，2014）

2015年世界高层都市建筑学会国际交流大会中发表的建筑幕墙相关论文，尽管探讨过建筑幕墙各式各样的重要设计原则，但却都没有提及消防设计应该遵循的原则。国际上的建筑规范，通常是经过特定的耐火试验来规定建筑材料和组件应具有的最低防火性能要求的。在一些未制定建筑规范的地区，主要依靠专业设计师的能力和经验来确定和使用防火性能参数。

近年来发生的火灾表明，伴随不同文化背和社会逐步迈向超级大都市，建筑外包覆材料的选择对于在最大程度上减少火灾向相邻建筑蔓延非常重要（图1、2）。

查阅各种外墙包覆材料的产品资料，发现它们都是很易被误解，购买者需自负责任。

Figure 1. The Address Hotel Fire, Dubai, UAE (Source: copyright)
图1. 地址酒店发生火灾（来源：copyright）

specified fire tests. In areas of the world where there may not be a building code, it is left to the knowledge and experience of the design professionals to establish and enforce fire performance parameters.

These recent fires demonstrate that exterior cladding materials selection is important to maintain the objective of minimizing fire spread from one building to another, as our various cultures and societies move towards creating megacities (Figures 1 & 2).

Review of a variety of exterior cladding manufacturers' product literature shows that it can be easily misinterpeted. Caveat emptor!

Engineers and architects not educated and experienced in fire phenomenon complexities and limitations associated with the wide variety of fire tests used in the built environment are at risk of approving a material for an inappropriate use on or in a building. While this brief paper cannot provide comprehensive instruction on fire testing, it will provide the reader information to facilitate a better understanding of the issues associated with fire tests and the problem involving façades.

Basics of Fire Spread

Fire is a complex, thermochemical chain reaction process, and we are early in developing our own understanding of its behavior and how best to control it. Many factors influence the growth and spread of fire. Those that are germane to the issue of façade fires primarily include weather conditions, as well as the arrangement and orientation of combustibles.

In your mind, envision a single sheet of paper oriented horizontally. How would it burn? The part ignited would show a flame of an inch or more, and would slowly spread across the sheet of paper. The flame height remains relatively constant as it spreads across the paper. Ignition in the corner of the paper would yield flame spread only slightly different when compared to being ignited in the center or the paper. The horizontal flame spread occurs because the flame is preheating the unburned part of the paper to the point that combustible vapors are present, which ignite from interaction with the flame.

Now, contrast that to what happens when the paper is turned vertically and is ignited near the bottom or at some point before the top. Briefly, at the time of ignition, the flame height may be similar to what was observed when the positioning of the ignited paper was horizontal; however, rather quickly, the flame height grows and rapidly spreads up the surface of the vertical paper, ultimately consuming it with fire. The flame spread mechanisms are similar: pre-heating a combustible by the flame. The difference in the rate of flame spread relates directly to the amount of the paper that is preheated to the point of issuing combustible vapors due to its vertical orientation. Also, in this case, the location of ignition will have a rather significant impact upon the flame spread. Igniting the paper near the top will have a completely different outcome than if ignited near the bottom.

This example colorfully describes how the vertical orientation of façades contributes greatly to the spread of fire on the outside of a building. By their very nature, tall buildings are prone to vertical exterior fire spread,

未经培训、对各种建筑环境下耐火试验的复杂性和局限性缺少经验的工程师和建筑师，将有风险批准材料的不当使用或批准材料在建筑内部的使用。尽管本文不能够针对耐火测试进行全面地阐释，但能够使读者更深刻地理解建筑幕墙的耐火测试和消防相关问题。

火灾蔓延的基础

火灾是复杂的化学链式反应过程，我们很早就致力于火灾的特征的认识、研究和火灾控制。影响火灾增长和蔓延的因素有很多，与建筑幕墙关系最为密切的首要因素包括天气情况、可燃物的分布以及方向。

试想沿水平方向点燃一张纸，它将如何燃烧。点燃的部分会出现大概一英寸高的火焰，然后逐渐蔓延至整张纸。在蔓延的过程中，火焰高度将保持相对稳定。点燃纸张的边角和纸张的中心产生的火焰蔓延会稍有不同。火焰之所以会水平蔓延，是因为火焰将还没有燃烧的纸张部分预热至产生可燃气体，并在与火焰的相互作用中点燃纸张。

接下来，对比垂直放置与水平放置时纸张燃烧的不同现象。将纸张竖立放置，靠近纸张底部或顶部的某一个位置将其点燃。最初，火焰高度可能与沿水平方向点燃时相似，但是很快，火焰高度便会迅速增长，并沿着竖直的纸面迅速向上蔓延，纸张也很快就燃烧殆尽。两种情况下，火焰传播的机理很相似，都是通过火焰预热可燃物，而在火焰传播速度方面存在很大不同，主要与可预热释放可燃气体的被点燃的纸张数量有直接关系。

在上面的例子中，纸张的点燃位置对于火焰的传播蔓延影响显著。靠近纸张的顶部点燃与靠近纸张底部点燃将会产生截然不同的结果。

Figure 2. The Address Hotel fire damage (Source: copyright)
图2. 地址酒店火焰伤害（来源：copyright）

especially if the building is clad in a material that will contribute to the fire load on the building exterior.

As our knowledge and understanding of fire behaviors, especially the spread of fire, continues to develop, we come to understand that some of the fire tests used for decades by building codes to characterize fire properties associated with various materials used in specific arrangements are not the appropriate fire tests to be used to understand the fire hazards associated with façades. The exterior skin is the critical barrier that permits engineers and architects to create an interior climate that is comfortable for the building occupants, and it is also a critical element that controls the spread of fire, both within and on the outside of a building, and from one building to another.

Code History

Throughout history, people have been witness to large portions of their cities being consumed by major conflagrations (Baltimore, Boston, Cairo, Chicago, London, Moscow, and Rome to name a few), many of which have resulted in significant life and property loss (Boring et al., 1981). These fires drove the development of building regulations that identified construction types and established height and area size guidelines for both combustible and noncombustible construction types. Other regulations were developed to control the density of and location of different buildings within an urban area. Buildings in urban areas were required to be constructed of noncombustible

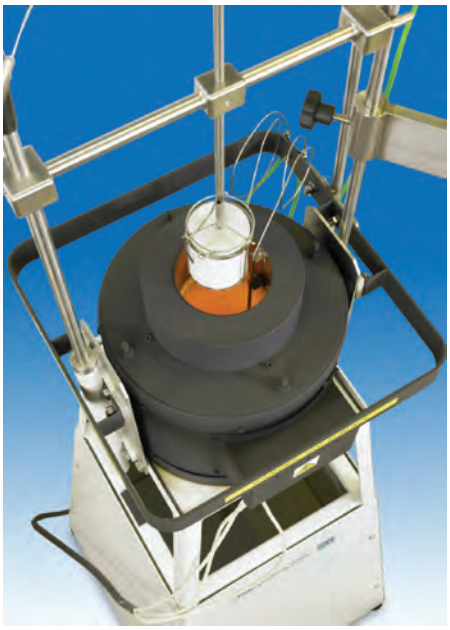

Figure 3. Vertical tube furnace apparatus (Source: copyright)
图3. 垂直管炉装置（来源：copyright）

materials. Early building codes incorporated requirements for exterior walls and roofs on urban buildings to be of noncombustible materials, so that they would be able to withstand exposure fires, thus minimizing the spread of fire from one building to another.

Today, our tall buildings are required by building codes worldwide to be of noncombustible construction. Such a requirement exists because we recognize that:

- The materials used to construct the building should not contribute to the fire load in a building fire scenario;
- The occupants of that building must rely upon the building to stand tall during a fire to effect egress;
- Firefighters need to be protected to be able to fight a fire from within the building.

Material or assembly noncombustibility can be determined using ASTM E-136, BS 476 Part 2, or ISO 1182 fire tests. These tests evaluate material performance under laboratory conditions when the material is exposed to a test apparatus furnace temperature of 750 degrees celcius or more. The test apparatus is often referred to as a vertical tube furnace (Figure 3). Test samples are placed into a pre-heated furnace environment and evaluated for mass loss, sample material temperature rise, and flame extent.

The vertical furnace test to determine material combustibility is, by its very nature and intent, a severe fire insult. Because of the use of plastics and other combustible materials, exterior cladding products cannot pass such a test, and therefore cannot be considered noncombustible.

However, the increasing importance of energy efficiency in tall buildings has rendered the days of masonry exterior walls obsolete. Building envelope technologies evolved with the inclusion of plastic materials and resulted in significant performance improvements in climate control and weather protection. These improvements in building cladding technology have also had a deleterious effect on the fire performance properties of the cladding materials.

Many of the exterior cladding products commonly designed and specified for use on the exterior façades of tall buildings today are relatively light weight, and they have superior weather resistance and energy efficiency performance. The myriad finishes and custom

上例生动形象地说明了幕墙会加剧建筑外立面火灾垂直蔓延。高层建筑尤其是建筑外包覆材料造成火灾荷载增加的建筑，由于其自身性质，更倾向于造成建筑外部火灾垂直蔓延的发生。

基于对火灾特征的认识和理解，特别是对火灾蔓延的理解仍在继续发展，过去数十年中，建筑规范中针对各种材料火灾特性参数测试的耐火试验，并不适合于理解幕墙的火灾危险。建筑的外表皮是阻碍了工程师和建筑师为人员提供舒适内部环境的意图，也是建筑表面、建筑内部以及建筑之间火灾蔓延控制的一个重要因素。

规范研究现状

历史上，人们曾经亲眼目睹自己的城市被大火吞噬，比如，巴尔的摩、波士顿、开罗、芝加哥、伦敦、莫斯科以及罗马，大多数火灾都造成了生命和财产的巨大损失（Boring等人,1981年）。这些火灾推动了建筑标准规范的制定，这些规范标准用于确定建筑类型、可燃和不燃建筑的高度和面积，另一些规范则规定了在城市范围内，如何对不同类型建筑的密度和位置进行控制。规范规定建筑应采用不燃材料建造。早期的建筑规范要求外墙和屋顶采用不燃材料，因此建筑能够抵抗外部火灾，尽量减少火灾在建筑间蔓延。

如今，国际上建筑规范均要求超高层建筑采用不燃结构。所以有这项要求，是因为我们意识到：

- 建筑材料不应增加火灾荷载；
- 内部人员需要在火灾疏散时保持直立行走；
- 消防队员进入到建筑内部灭火时应受到保护。

材料或构件的不燃性可以通过ASEMTE-136,BS 476 第2部分或ISO 1182 火灾测试确定。将材料暴露于温度在750℃或以上的试验炉，并在该实验条件下测试材料的性能。测试装置通常是一种被称为立式炉的装置（图3）。测试样品被放入预热的炉内，评估质量损失、样品材料的温升和火焰范围。

应用立式炉测试判断材料可燃性，从其本质和目的上来说，是将材料暴露于严重的火灾中。由于使用了塑料及其他可燃材料，建筑外包覆产品通常无法通过该项测试，因此也不能被认定为不燃物。

然而，超高层建筑能源效率日显重要，使砌体外墙的时代成为了过去。伴随塑料材料的发展，建筑围护结构技术也在不断发展，为气候控制和气象防护带来了重大性

Figure 4. Design flexibility with MCM panels (Source: copyright)
图4. 设计灵活性，MCM面板（来源：copyright）

forms make them extremely appealing to the building designer and owner (Figure 4).

Driven by the need to improve energy efficiency, modifications of building code requirements permitting the use of combustible materials in traditionally noncombustible construction began to occur in the 1980s. The list of "exceptions" built into modern building codes to permit the use of combustible exterior cladding materials is bewildering.

Here is a summary of some of the currently permitted exceptions for the use of combustible materials in the exterior wall of a "noncombustible" building:

- Plastic insulation (not including foam plastics) having a flame spread rating of 25 or less;
- Plastic insulation having a flame spread rating of 100 or less and sandwiched between layers of noncombustible materials without an airspace;
- Combustible exterior wall cladding materials are permitted on noncombustible buildings subject to area of coverage and height of installation limitations (which usually are limited to the reach of the local fire department), with additional limitations on ignitability (the amount of energy required to result in material ignition) for very short fire separation distances (such as distances to the next adjacent structure);
- Foam plastics used as thermal insulation when having a limited potential heat density (heat energy per unit area) and separated from interior spaces by thermal barriers;
- Plastic veneers are permitted up to specified heights above grade, in limited areas of application, with separation requirements between panels of veneers.

These stop-gap building code exceptions have been introduced into the codes principally by manufacturers who have a keen economic interest in the widespread use of a specific product. This summary of exceptions does not include the number and extent of details to be followed in constructing these various assemblies. The extent of details and requirements to be achieved for some of these exceptions leaves much room for error during design, construction, and oversight of the installation.

Consequently, fire tests used to evaluate the fire performance of exterior cladding have evolved as well.

Fire Testing 101

Fire tests are designed to evaluate specific fire performance attributes of a material or an assembly of materials. A materials' reaction to fire will be different if it is tested individually than if it is tested as part of an assembly of components. The tested assembly will also behave differently in a building fire than it did in the laboratory test fire. Laboratory fire

能改进。这些进步却给建筑外包覆设计防火带来了不利影响。

如今，超高层建筑外幕墙所采用的外包覆产品，大多数相对较轻、环境抵抗能力出色、能源效率卓越。装饰和定制形式多样，使它们对于建筑设计师和业主非常具有吸引力（图4）。

鉴于能效改善提高的需要，从二十世纪八十年代开始，建筑规已经允许在传统的不燃建筑中使用可燃材料。而现行规范中一些除外条款，关于建筑外包覆材料允许使用的可燃材料则令人困惑。以下是关于建筑不燃外墙允许使用的可燃材料的归纳：

- 火焰传播速度小于等于25的塑料绝缘体（不包含泡沫塑料）；
- 夹在不燃材料之间、无空腔且火焰传播速度小于等于100的塑料绝缘体；
- 可燃外墙包覆材料是否被允许在不燃建筑使用取决于覆盖面积和安装高度的限制（通常是限制在消防救援能够达到的范围），另一个限制其可燃性的因素（需要的能量会点燃材料）是建筑间过小的防火间距（例如，与相邻建筑的间距）。
- 用于建筑保温，潜热密度（单位面积的热能）有限，且采取措施与内部空间进行隔热的泡沫塑料；
- 塑料胶合板的使用受限于地面上以上设定高度、使用面积、板面分隔要求。

以上这些用于鉴别和允许包覆层使用可燃材料的例外条款，大多是由厂商引入到规范中的，因为他们迫切期望产品被广泛使

Figure 5. Steiner tunnel fire test apparatus (Source: copyright)
图5. 斯坦纳隧道（来源：copyright）

tests are conducted within carefully controlled conditions. This permits results of the test to be repeatable, and thus comparisons of material performance can be made across a variety of materials.

Fire test results are not precise indicators of how a material will perform in actual fire conditions encountered in real buildings because the tested material or assembly will interact with other building components and furnishings, which ultimately impacts the fire chemistry and physics. However, when materials and assemblies are tested in the manner in which they are expected to be used within a building, the results of those tests can provide insight into how that material may (or may not) contribute to the growth and spread of fire within a building that may involve that material.

Understanding the fire test apparatus, test sample attributes and test procedures used to determine a materials' fire performance rating is critical to understanding if the performance rating given will provide any predictive insight. The two primary tests used in building codes to establish fire performance criteria for exterior walls containing combustible materials are tests to determine flame spread rating and full scale exterior wall assembly fire tests.

Flame Spread Tests

Common tests used to determine flame spread are ASTM E-84, used by the International Building Code (IBC), and BS 476 Part 7, used predominantly in British and European codes. The ASTM E-84 test apparatus (Steiner Tunnel) used to determine flame spread ratings is depicted in Figure 5 (Figure 5).

The objective of the flame spread tests is to determine how quickly a flame moves across a test specimen. In the ASTM E-84 apparatus, the test specimen is oriented in an upside down, horizontal manner, and the fire source is then introduced to one end of the test specimen in a wind aided test chamber. The fire test operator starts the ignition source and then tracks the time at which the flame front on the test specimen reaches predetermined distances.

This ultimately results in a flame spread rate determination. The ratings are calculated and indexed compared to that of red oak flooring (flame spread index of 100 on a scale of 0 to 200). Flame spread indexes lower than 100 are indicative of materials exhibiting flame fronts that do not move as quickly as the flame front on red oak flooring.

Many plastic materials (whether or not impregnated with fire retardant chemicals) melt when subjected to the fire source, and molten plastic drips to the bottom of the test chamber. As the plastic material melts, the edge nearest the fire source retracts from the fire until it no longer melts. Flaming is likely to occur in the melted pools of liquid plastic on the bottom of the test chamber. There is often very little flame front movement down the plastic test specimen. Consequently, plastics are able to achieve relatively low flame spread indexes, which are usually considered a favorable fire performance rating.

However, plastics used on exterior walls are typically not installed in a horizontal orientation; therefore, using a flame spread rating of 25 determined by the ASTM E-84 apparatus is not an adequate fire performance parameter for a plastic material or assembly to be used in an exterior wall configuration.

用以创造巨大的经济效益。以上总结不包含部件的数量和范围应该遵循的具体内容，而这些允许条件的具体范围和要求的实现，为设计、施工和施工监理留下了很大的犯错空间。

因此，规范也引入了包覆层耐火性能测试要求。

耐火试验101

耐火试验用于评估检验一种材料或多种材料组合的火灾属性。一种材料单独测试的效果，与含有这种材料的组件整体测试的效果会有所不同。被测试组件在建筑火灾和实验火灾情况下的表现也不同。试验条件被严格控制以便于重复进行，从而能够对比各种不同材料的性能表现。

火灾试验并不能完全预测一种材料在真实建筑火灾中会发生何种变化，在真实火灾中，被测试的材料或组件会与建筑构件和内部陈设发生相互作用，进而影响火灾的化学和物理现象。但是，以材料或组件在建筑中预期的使用方式来对其进行测试，可以使我们深刻理解当其应用于建筑中时会如何影响火灾增长和蔓延。

熟悉材料耐火极限试验装置、测试样本属性以及测试过程，对于深刻理解耐火极限是至关重要的。规范中主要有两种试验是用于制定外墙可燃材料的耐火性能标准的，一种是确定火焰蔓延指数，一种是外墙组件的全尺寸试验。

火焰蔓延测试

火焰蔓延测试通常包括国际建筑规范采用的ASTM E-84以及英国和欧洲规范主要采用的BS 476 第7部分。ASTM E-84中用于确定火焰蔓延指数的测试装置（斯太纳管道）见图5（图5）。

火焰蔓延测试旨在判断火焰如何沿着试样迅速蔓延。在ASTM E-84装置中，试样分别被倒置和水平放置，在一个风辅助试验箱引入火源，点燃试样的一端。测试操作员首先点燃试样，并记录火焰在试样端燃烧至到达一定距离的时间。最终能够确定火焰蔓延速度。蔓延指数通过计算，并与红橡木地板火灾蔓延指数比较确定（火焰蔓延指数100规模的0 – 200）。火焰蔓延指数低于100，表明材料火焰前沿蔓延速度没有红橡木地板快。

在塑料材质的测试中（添加或未添加阻燃剂），塑料被火焰融化，熔融塑料滴落在试验箱底部。随着塑料的融化，最靠近的火源的边角发生收缩，直到它不再融化。燃烧可能出现在试验箱中液体熔融塑料池

"Full Scale" Fire Testing

In regards to façades with combustible components, fire testing has evolved to undergo "full scale" tests when evaluating the performance of an assembly as it is to be installed. These full scale fire tests use test specimens that will span two or three stories of a standardized building having a floor-to-floor height that is more reflective of what may be constructed in real buildings (three to four meters in story height).

A number of full scale test apparatuses have been developed for the purpose of testing exterior wall assemblies that incorporate combustible elements (White and Delichatsios, pp 44 – 61). One example of a full scale fire test standard, first published by the National Fire Protection Association (NFPA) nearly 20 years ago, is NFPA 285, currently in its third edition (2012). Figure 6 is the NFPA 285 test apparatus (Figure 6).

In these full scale fire tests, the fire insult is typically introduced to a full-sized installation of the exterior wall assembly as a fire coming through a window opening, lapping up the side of the building. Measured fire performance varies from one test to another, but the various full scale tests are used to evaluate the following:

- Limitations on temperature rise in the wall assembly at measured points above the fire;
- Limited vertical flame spread above the window from which the test flame arises;
- Limited horizontal flame spread on the exterior of the wall;
- Limited horizontal and vertical flame spread within the wall assembly;
- No flaming in the room located above the test room;
- Limited temperatures in the room located above the test room.

These full scale fire tests have been expressly developed to evaluate the impact of combustible materials used in non-load bearing façades. Unfortunately, conducting full scale fire tests is costly, and not all of the manufacturers have published data showing they are able to pass these tests. Assemblies that are not capable of passing a full scale exterior wall fire test should not be employed on a tall building.

Figure 6. NFPA 285 test apparatus (Source: copyright)
图6. NFPA 285测试仪（来源：copyright）

的底部。火焰前锋通常很少沿塑料试样向下蔓延。因此，塑料的火灾蔓延指数非常小，能够表现出良好的耐火性。

但是，外墙使用的塑料往往不是水平安装的，因此，采用ASTM E-84 装置所确定的火焰蔓延指数25来确定建筑外墙结构所用的塑料或其组件的耐火性能有失准确。

全尺寸火灾试验

对于采用了可燃构件的幕墙，倾向于采用全尺寸试验评估其安装的组件整体的燃烧性能。这些试样将有两至三层楼高（标准楼层高度），以便更好的反应出真实情况（例如，层高为3至4m）。

为了测试外墙可燃构件的燃烧性能，目前已开发了许多去全尺寸试验装置（White and Delichatsios，44 页 – 61页），例如，20年前发布的NFPA285（2012）第三版全尺寸试验标准。图6为NFPA285试验测试装置（图6)。

在全尺寸火灾试验中，火焰沿窗口进入到建筑内部，被引入点燃全尺寸安装的建筑外墙整体组件。测试耐火性能的试验多种多样，但是全尺寸试验将用于评估以下问题：

- 火源上方各测量点位墙体构件的温升边界；
- 限制火焰在其出现的窗口向上竖直蔓延；
- 限制外墙火焰水平蔓延；
- 限制火焰在墙体构件间的水平和竖直蔓延
- 实验室上方的房间内禁止出现明火；
- 限定实验室上方房间的室内温度。

这些全尺寸火灾试验可以非常清楚地呈现非承重外幕墙中如果使可燃材料会带来哪些影响。但是不幸的是，进行全尺寸火灾试验成本高，而且并非所有厂商都可以证明自己能够通过这项测试。不能通过外墙全尺寸火灾试验的组件将不能用于超高层建筑中。

展望

据统计，外墙包覆层很少发生火灾。但是，为了提高建筑能效，建筑外墙组件中引入了可燃材料，如果火灾确实会发生，则后果将会是灾难性的，也会造成营业中断的严重影响。

Figure 7. City density of Hong Kong, China (Source: copyright)
图7. 城市密度 – 香港（来源：copyright）

Figure 8. City density of Kuala Lumpur, Malaysia (Source: copyright)
图8. 城市密度 – 吉隆坡（来源：copyright）

Going Forward

Statistically, fires involving exterior wall cladding occur infrequently; however, because of the presence of combustible materials within the exterior wall assemblies (to improve energy performance), when fires do occur, they are catastrophic. Business interruption is usually significant.

Architects and engineers designing exterior walls for new construction should be specifying materials and assemblies that meet one of the contemporary full scale exterior wall fire performance tests, even if these tests are not required by locally applicable building codes. Façades that pass full scale fire tests for exterior wall assemblies are more expensive and therefore often value engineer an assembly that does not meet such criteria to reduce construction costs. Buildings codes must be changed to remove fire performance criteria that is not germane to the manner in which the materials are used.

More importantly, what if anything should be done with buildings constructed in the last 25 years that have combustible materials in the exterior wall assemblies that have not passed NFPA 285, or an equivalent? The growth and spread of a fire is impacted by a myriad of factors and there is no singular answer. A thorough fire hazard risk analysis will identify key weaknesses, which should be able to inform mitigation options.

We (owners, developers, architects, engineers, and contractors) all have responsibilities to ensure that a simple fire incident will not result in a conflagration such as those that dot the history of many large cities in existence today. As our megacities continue to grow and expand, adjacencies and proximities between buildings will be reduced (Figures 7 & 8). Designers must be cautious and aware when selecting and approving the exterior façades of tall buildings, so that they will have acceptable fire performances as well as the desired energy efficiency.

新建建筑的外墙设计师和工程师应说明材料和组件满足现行的全尺寸耐火试验，即使当地建筑规范未做此要求。通过全尺寸试验的建筑外幕墙组件价格更高，因此，通常装配不合标准的组件来减少建设成本。建筑规范必须改变，移除与材料使用方式无关的性能标准。

更重要的是，对于在过去的25年里建造的，外墙组件可燃材料未通过NFPA 285测试的建筑物，有什么可以做的或其他替代方案吗？火灾的增长和蔓延受各种因素并非单一因素的影响。严谨的火灾风险分析应识别出能够减轻的关键薄弱环节。

不管是作为业主、开发商、建筑师、工程师，还是作为供应商，我们都有责任防止小火酿成大祸。由于我们的城市仍在增长和扩大，建筑物间的邻接和贴临将会减少（图7、8）。设计者在选择和批准超高层建筑外幕墙设计时必须小心谨慎，以保证在满足能效目标的同时，实现可接受的消防安全水平。

References:

American Society of Testing and Materials (ASTM). (2009). **ASTM E-84: Test Methods for Surface Burning Characteristics of Materials.** West Conshohocken, PA: American Society of Testing and Materials.

Boring, D., Spence, J. and Wells, W. (1981). **Fire Protection Through Modern Building Codes.** Washington, DC: American Iron and Steel Institute (AISI).

National Bureau of Standards (NBS). (1975). **Thermal and Flow Characteristics of the ASTM E 84 Tunnel Test Method.** Report Number NBSIR 75-705. Gaithersburg, MD.

National Fire Protection Association (NFPA). (2012). **NFPA 285: Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load Bearing Wall Assemblies Containing Combustible Components.** Quincy, MA: National Fire Protection Association.

White, N. and Delichatsios, M. (2014). **Fire Hazards of Exterior Wall Assemblies Containing Combustible Components.** Quincy, MA: The Fire Protection Research Foundation.

Wikipedia. (2016). **Conflagration.** Available at: https//en.wikipedia.org/ (Accessed 13 May 2016).