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Author: Jennifer Schneider, Structural and Security Glazing Segment Manager, Trosifol

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Cyclone Resistant Glazing Solutions

抗飓风玻璃解决方案

Jennifer Schneider
Structural and Security Glazing Segment Manager | 结构与安全玻璃分部经理

Trosifol
佳氏福

Wilmington, United States
威明顿，美国

Jennifer Schneider is the Structural and Security Glazing Segment Manager for Trosifol. With 13 years of experience in the glass lamination industry, Schneider is involved in the development, commercialization and marketing of interlayers for glazing systems for both the automotive and architectural industries. She holds a Masters of Science in Plastics Engineering from the University of Massachusetts.

Kuraray目前担任结构与安全玻璃分部经理，具备13年的玻璃层压行业从业经验，之前从事过汽车及建筑行业的玻璃系统的夹层的开发、商业化及市场营销工作。她拥有马萨诸塞州大学塑料工程学的理学硕士学位。

Abstract | 摘要

As urban areas become developed in regions prone to severe weather, the risk of financial and human loss increases. Severe weather such as hurricanes, cyclones, and typhoons have caused billions of dollars of damage and thousands of deaths globally. Traditional glazing structures used in buildings are particularly vulnerable to damage by windborne debris. Once the glazing system fails, the building envelope becomes open to water and wind, causing further damage. If the glazing system is designed properly, the damage and potential economic losses are reduced. When Hurricane Andrew hit south Florida in 1992, causing $28 billion in damage, the need for building code revisions became apparent. As a result, building codes were established for glazing systems to withstand the force of a strong hurricane. The building codes in Florida have proven to be very successful in preventing damage from storms and serve as a basis for global codes.

Keywords: Cyclone, Glazing Systems, Hurricane, Interlayer, Typhoon, Wind borne debris

随着易受灾害天气影响地区的城市发展，经济损失与人员伤亡的风险也在增加。飓风、暴风及台风等极端天气已在全球造成了数十亿美元的损失，使得成千上万的人丧命。建筑中使用的传统玻璃结构非常容易受到风力挟裹碎片的损害。一旦玻璃窗遭到破坏，建筑围护就容易受到洪水和大风的伤害，造成进一步的损失。合理设计的玻璃幕墙系统将减少损害及潜在经济损失。1992年袭击了佛罗里达州南部的安德鲁飓风造成了280亿美元的损失，使得建筑规范的修改需求变得非常迫切。因此，为抵挡强飓风的破坏力现已建立了玻璃系统的建筑规范。事实证明，佛罗里达州的建筑规范非常成功地阻止了来自暴风雨的损害，是全球规范的基础。

关键词：气旋、玻璃系统、飓风、夹层、台风、风杂物

Introduction

Typhoons, hurricanes and cyclones are all different names given for the same storm depending on its geography. In the Atlantic Ocean, Gulf of Mexico, Caribbean Sea and East of the International Date Line the storm is a called a hurricane. West of the International Date Line in the Northern Pacific it is a typhoon, and in the far Southwest Pacific Ocean it is a cyclone. Tornados can occur anywhere in the world, however the biggest tornados are seen in tornado alley in the Midwest US. Regardless of the name of the storm, what they all have in common is the ability to generate both dangerous and damaging windborne debris that can cause catastrophic damage to buildings. The glazing system in the building is particularly vulnerable to breakage caused by wind borne debris. Once the glass has broken or the framing system fails, the building will become exposed to water and wind damage. The wind can enter the building and cause an increase in the internal pressure, resulting in even greater damage to the building structure. Despite evidence that hurricanes can cause widespread damage due to impact from wind

引言

台风、飓风和龙卷风都是一种风暴，只是在不同地域使用不同的名字。在大西洋、墨西哥湾、加勒比海和东国际日期线，风暴被称为飓风。在北太平洋的西国际日期线，风暴被称为台风；在遥远的西南太平洋，风暴被称为龙卷风。龙卷风可以发生在世界任何地方，然而最大龙卷风在美国中西部龙卷风带被看到。无论风暴的名字，它们的共同点是具有能生成对建筑物造成灾难性破坏的、危险和破坏性的风夹带碎片之能力。建筑中的玻璃系统特别容易被风载碎片破坏。一旦玻璃或框架系统被破坏，建筑物将暴露在雨水和风损害中。风能进入建筑内并引起建筑内压增加，从而对建筑结构造成更大的伤害。尽管有证据表明飓风能造成由风夹带碎片冲击造成的广泛的损害，直到1994年也没有合适的规范以确保所建建筑能承受高风压及所产生的碎片。当1992年安德烈飓风袭击迈阿密以南40英里佛罗里达霍姆斯特德市后这一切都发生了改变。这是一个建筑物设计和建设方式需要改变的警醒。

borne debris, until 1994 there were no codes in place to ensure that buildings would be built to withstand the high wind force and debris generated. This all changed when Hurricane Andrew in 1992 hit Homestead Florida 40 miles south of Miami. This was a wakeup call that the way buildings are designed and built needed to change.

Hurricane Andrew and the Birth of Hurricane Glazing Codes

In 1992, Hurricane Andrew, a Category 5 hurricane, made landfall 40 miles south of Miami in Homestead Florida with wind gust exceeding 168 MPH (270 KPH) and sustained winds of over 140 MPH (225 KPH). The storm destroyed 60,000 homes and severely damaged 100,000 homes leaving 175,000 people homeless. Total destruction was $26 billion in 1992 which is the equivalent to $44 billion in 2016. At the time this was the most costly hurricane in history. Hurricane Andrew was unique in that it was primarily a wind borne debris event with extremely high gusts of wind. If this hurricane had shifted to the northeast it would have hit Miami, a major urban environment, and the damage and loss of life would be significantly higher.

Insurance claims from Andrew totaled $15.5 billion, an amount which is equivalent to $25 billion today. The insurance companies were not prepared to handle the high cost of claims and as a result there was strong support from the insurance industry for a strengthening and enforcement of building code requirements. Hurricane Andrew was the catalyst that created the changes in the Florida building codes around wind borne debris resistance.

Analysis of the damage sustained by Hurricane Andrew exposed a clear need to have improvements in the glazing systems of the building. Glazing systems failures occurred by both the wind borne debris damaging the glass as well as the strong winds themselves ripping the whole window system off of the building. The openings created in the building caused water to penetrate as well as internal pressure leading to the collapse of the building. It was quite evident from the damage analysis following the storm that improvements in the glazing system design could have helped mitigate the damage.

The first hurricane code was developed by Miami-Dade County. It was specific to the high velocity hurricane zone. It required testing and product approval of the entire fenestration system. If the glass remains intact but the frame fails then the building envelope will be open to water and wind damage. The system approach was adopted so that all components could be evaluated during testing.

The codes for Miami-Dade were implemented in September 1994 and were only in place in Miami-Dade County however Palm Beach County followed shortly after. The testing required was as follows:

- Large Missile Impact Resistance-focus on the first 10 meters from the finished grade. The impact missile was 20 cm in length and weighed 4 kilograms. A pass fail criteria was set to minimize water intrusion and unauthorized entry after the event
- Small Missile Impact Resistance - Extend the debris protection from 10 meters to 20 meters above finished grade. The debris missile used was based on an existing ASTM standard for roof gravel
- Pressure Cycling - The pressure cycling was designed to replicate the advance and departure of a hurricane

It was clear that Florida needed a state wide code and in 1996 the Florida Building Commission was created to develop codes along with a product approval program. In 2002, the Florida building codes were developed. The Florida Building Commission also established a product approval system for building envelope components. All window and door systems were to be tested and approved for use in the State of Florida. For building in Miami or Broward County, the glazing system was to be approved by Miami-Dade County and receive a "Notice of Approval."

The Florida building commission also adopted testing protocols that are required to be used for compliance in the High Velocity Hurricane Zone (Wind Zone 4): TAS 201 impact test procedures, TAS202 criteria for testing impact and non-impact resistant building envelope components using uniform static pressure, and TAS 203 criteria for testing products subject to cyclic wind pressure loading.

In addition to the testing protocols developed by the state of Florida, ASTM standards were developed.

ASTM E1996, Standard Specification of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Wind-borne Debris in Hurricanes and ASTM 1886 Standard Test Method for Performance of Exterior

安德烈飓风和飓风玻璃规范的诞生

1992年阵风风速超过168英里/小时（270公里/小时）、持续风风速超过140英里/小时（225公里/小时）的5级飓风安德烈在迈阿密以南40英里的佛罗里达霍姆斯特德市登陆。风暴摧毁了60,000间房屋和严重损坏了100,000间房屋，造成175,000人无家可归。在1992年总损失为260亿美金，相当于2016年的440亿美金。在当时它是历史上造成损失最大的飓风。安德烈飓风的独特之处在于它主要是一个具有极高阵风速度的风夹带碎片事件。如果这场飓风转移到东北部，它可能会袭击一个重要的大城市迈阿密，造成的损失和生命伤害可能会大大增加。

安德烈飓风后保险索赔总额为155亿美元，相当于今天的250亿美元。保险公司不准备受理高成本的索赔，从而从保险行业促进了建筑规范要求的加强和强制执行。安德烈飓风是佛罗里达建筑规范中关于抗风夹带碎片修编的催化剂。

安德烈飓风持续损害分析暴露出建筑玻璃系统需要改进的明显需求。玻璃系统失效发生在风夹带碎片损害以及大风将整个窗系统从建筑撕裂掉。以此引起的建筑物破损口会造成雨水渗透以及内部压力引起的建筑物倒塌。在风暴过后的损害分析中，玻璃系统设计的改进能非常明显的帮助减轻损害。

第一个防飓风标准由迈阿密戴德县制定。它被特定用于高速飓风区。它要求整个门窗幕墙系统测试和产品认证。如果玻璃完好无损但是框架系统损坏，然后建筑外围护结构将失去对雨水和风损害的防护。采用系统的方法，使得所有组件可以在测试中进行评估。

迈阿密戴德县规范在1994年9月只在迈阿密戴德县开始执行，然而不久棕榈滩县也跟随执行。所需测试如下：

- 大发射物抗冲击测试（PA201测试规程）–专注于被冲击面前10米范围。发射物为20厘米长，4公斤重。通过与否的标准被设置为把雨水入侵减到最低和冲击后未经许可的冲击物进入。
- 小发射物抗冲击测试（PA202测试规程）–从被冲击面起10米至20米范围的碎片防护。碎片发射物选用基于已有的ASTM房屋砾石标准。
- 循环压力测试（PA203测试规程）–循环压力测试被设计来模拟飓风前进和后退。

很显然，佛罗里达需要一个全州范围的规范；在1996年佛罗里达州建设委员会成立，并开始制定一个附带产品审批流程的规范。在2002年，佛罗里达州建筑规范制定完成。佛罗里达州建设委员会还建立了

Windows, Curtain Walls, Doors and impact Protective Systems Impacted by Missile (s) and Exposed to Cyclic Pressure Differentials.

ASTM E1996 defines both small and large missile impact testing requirements and the cyclical portion of the testing. In addition, this standard establishes testing conditions regarding allowable test temperatures, load duration during the cyclical testing, as well as other testing parameters.

ASTME1996

- In most regions, only one impact is required per glass specimen, and no impacts are required on the intermediate mullions
- Defines test failure as an opening 130 x 1 mm or through which a 76 mm sphere can pass
- Requires small missile impact resistance above 9.1 meters in height above grade
- Creates protection zones and additional missile types for users
- Specifies that seeking specific test requirements in ASTM standards must first identify the applicable design wind speed for the location as well as the buildings risk category from ASCE7- See figure below
- Specifies basic and enhanced requirements
- Identifies the missile type and speed required for testing

ASTM E1996 requirements for hurricane impact systems are found in Figures 1 and 2. There are two levels, basic protection and enhanced protection. The enhanced protection covers essential facilities such as hospitals, police stations, fire rescue stations, emergency centers, jails and detention centers and buildings critical to the national defense.

For basic protection, small missile impact requirements need to be met 30 feet and above in the building. For the first 30 feet, depending on the wind zone, missile sizes C to E is necessary.

ASTM standards are used outside the HVHZ region. These ASTM standards are also being adopted in other hurricane-prone countries/ regions such as Mexico and the Caribbean, where windborne debris protection is likely required.

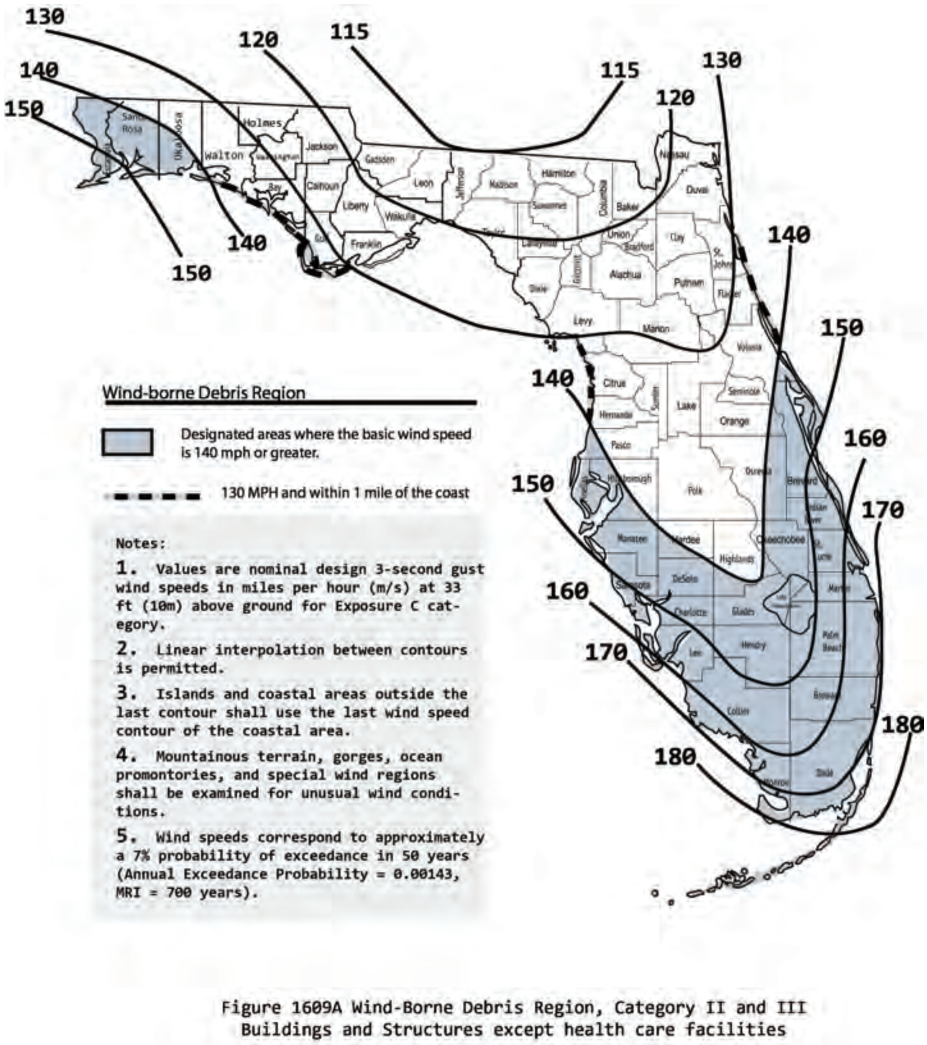

Figure 1. ASCE-7 wind zone map for the State of Florida (Source: Florida Building Code)
图1. ASCE – 佛罗里达州7风区地图（来源：佛罗里达州建筑规范）

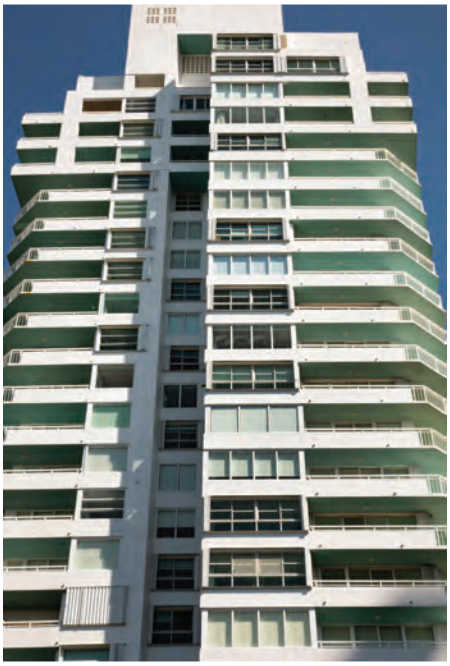

Figure 2. Portofino Tower (Source: Kuraray)
图2. 菲诺港塔（来源：可乐丽）

Figure 3. Brickell City Center (Source: Kuraray)
图3. 布里克尔市中心（来源：可乐丽）

The ASCE-7 Wind Zone maps are used to determine the wind zone and performance level needed for a building depending its location (Figure 3).

针对建筑外围护构件的产品审批系统。使用在佛罗里达州所有的门窗系统需经过测试和审批。在迈阿密或者布劳沃德县的建筑，玻璃系统需通过迈阿密戴德县审批并收到“批准通知”。

The wind zone regions were determined based on information about wind speeds for different categories of hurricanes. The Saffir-Simpson hurricane scale is used worldwide to characterize the severity of hurricanes (Figure 4).

Today there are three options allowed in the state of Florida for protecting the glazing system. The Florida building codes require the use of the following for protection from wind borne debris from hurricanes for glazing systems.

- Plywood, except in areas where the wind is greater than 140 MPH (225 KPH) such as HVHZ
- Approved shutters
- Approved impact resistant windows or doors

The use of plywood or even shutters is not very practical or attractive in tall buildings. Therefore, the use of impact resistant glazing is most commonly used. Quite often there is loss of power during hurricanes and using an impact glazing system will allow natural lighting to enter the building. Hurricane impact glazing systems will use laminated glass to provide impact protection as well as a specially designed frame to withstand the wind forces.

Florida, a Model for Other Building Code Development

Beyond the state of Florida, the International Building Code 2015 has a requirement for impact protection for hurricane-prone regions within one mile of the coastal mean high water line where the basic wind speed is 100 MPH (160 KPH) or greater. Similar to the Florida building code, IBC states that glazed openings located within 9.1 meters of grade would be required to meet the large missile testing requirements, and glazed openings located more than 9.1 meters above the grade would be required to meet small missile testing requirements. Virginia, South Carolina, North Carolina, Rhode Island, Alabama, Connecticut, Louisiana, Massachusetts, New Jersey, and New York all have adopted some type of wind borne debris codes. Texas runs a program through the Texas Department of Insurance (TDI). This program provides insurance when the national or regional carriers elect not provide coverage, which occurs along the coast where the threat of hurricanes making landfall is highest. Primarily, this has been used by residential construction

Figure 4. Brickell City Center glazing (Source: Kuraray)
图4. 布里克尔市中心玻璃系统（来源：可乐丽）

佛罗里达州建设委员会也接受可满足高速飓风区（4风区）使用要求的测试报告。TAS201冲击测试规程，TAS202标准用来测试耐冲击和非耐冲击建筑外围护构件在均布静力荷载下的抵抗力，和TAS203标准用来测试产品遭受循环风压作用。

除被佛罗里达州制定的测试规程外，ASTM标准也被制定。

ASTM E1996，风夹带碎片撞击的外窗、幕墙、门和冲击防护系统标准规范和ASTM E1886，用发射物冲击以及暴露在循环压力差下的外窗、幕墙、门和冲击防护系统性能的标准测试方法。

ASTM E1886 定义了小和大发射物冲击测试要求和测试周期性的部分。此外，此规范还建立了允许测试温度、周期性测试的荷载作用时间以及其他测试参数的测试条件。

ASTM E1996

- 在大多数地区，唯一的影响是对每片玻璃试样的要求，并不影响对中间竖框的要求。
- 当开一个130*1毫米的缝或76毫米球体可通过定义为测试失败
- 要求小发射物耐冲击性高于9.1米高度
- 设立需防护区域和额外的发射物类型
- 指定在ASTM标准寻求特定的测试要求

必须首先确定此位置的适用的设计风速以及从ASEC7确定建筑物的风险类别——见下图

- 指定基本和增强的要求
- 确定测试所需的发射物类型和速度

ASTM E1996飓风冲击系统要求可在下面找到（图1、2）。有基本和增强防护两个层次。增强防护覆盖如医院、警察局、消防站、急救中心、监狱和拘留中心和重要国防基础设施。

对于基本防护建筑物30英尺及以上的部分需满足小发射物冲击测试要求。对于建筑物低于30英尺部分根据风区发射物尺寸C到E是必须的。

ASTM标准被使用在高速飓风区以外的区域。这些ASTM标准也正被使用在其他飓风频发的国家和地区，如墨西哥和加勒比海。在这些国家和地区风夹带碎片测试可能被需要。

ASCE-7风区地图被用来根据建筑位置确定建筑风区和执行防护级别的（图3）。

风区区域是基于不同类别的飓风的风速信息确定的。萨菲尔-辛普森飓风等级被广泛用于描述飓风的严重程度（图4）。

今天在佛罗里达州有3个许可的防护玻璃系统方案。佛罗里达州建筑规范要求选用如下抗风夹带碎片防护玻璃系统。

projects; however, commercial projects can use this as well.

As a result of ASTM standards and the Florida building code, a working group of international experts participated in the development of ISO 16932 Glass in Building-Destructive windstorm resistant security glazing-Test and Classification standard. The development of the ASTM standards, as well as the ISO standard, has paved the road for other severe storm regions to develop regional codes.

11 Years After the Codes Went Into Effect They Were Tested

The building codes in Florida were put to the test when in 2005 hurricane Wilma hit south Florida causing $21 billion dollars in damage and killing 21 people. It was of great interest to the Miami -Dade County Building Code Compliance Office to go out in the field and conduct an assessment of damage to determine how effective these codes were in reducing damage to building structures. The findings are summarized in the Post Hurricane Wilma Progress Assessment report.

Many high-rise buildings in the area were affected by Hurricane Wilma. Investigation showed that none of these buildings that were built under the new building codes sustained any damage to the glazing system. The buildings that were built before the current codes showed damage to the windows, curtain walls and sliding glass doors. Where the damage occurred there was interior water damage and rise in internal pressure inside the building, causing collateral damage such as roof failures. It was also observed that in areas of tall buildings a channeling of the wind occurred, creating an isolated path of damage. This is an important observation to take into consideration when developing urban areas with tall buildings.

The Portofino Towers is an example of a building which was constructed to the new criteria. It is a 44-story building built in 1997 to the Miami- Dade County requirements for HVHZ. After Hurricane Wilma, the building including the glazing system did not sustain any significant damage (Figure 5).

Considerations When Designing the Hurricane Impact Glazing System

In order for a glazing system to be effective in mitigating damage from wind borne debris, the whole system needs to be designed properly. The framing system and how the glass is installed in the framing system are just and important as the impact resistance of the glass. When designing the glazing system for a building, it is important to understand what kind of wind loads the building will experience, and this will determine the design pressure. The type of impact testing required will be determined by the location of the

Figure 5. Secrets The Vine, Cancun, Mexico (Source: Grupo Frel)
图5. 墨西哥坎昆 Secrets The Vine酒店（来源：Frel组）

- 胶合板，除风速超过140英里/小时（225公里/小时）区域（如高速飓风区）
- 被批准的百叶窗
- 被批准的防冲击门窗

在高层建筑中使用胶合板或甚至百叶窗不是很实际或有吸引力的，因此使用防冲击玻璃是最常用的。在飓风中经常会损失电力，使用防冲击玻璃系统将允许自然光进入建筑物。防飓风冲击玻璃系统将使用夹层玻璃提供防冲击保护，以及一个特殊设计的能抵御风力的框架。

佛罗里达州，其他建筑规范发展的模范

除佛罗里达州外，2015国际建筑规范有一项针对沿海平均高水位线1英里范围内基本风速100英里/小时（160公里/小时）或更大的飓风频发区域防护的规定。类似于佛罗里达州建筑规范，国际建筑规范要求离地9.1米内玻璃窗需满足大发射物测试需求；离地9.1米以上的玻璃窗需满足小发射物测试要求。弗吉尼亚州、南卡罗来纳州、北卡罗来纳州、罗得岛州、阿拉巴马州、康涅狄格州、路易斯安那、马萨诸塞州、新泽西和纽约都采用了某种类型的风夹带碎片规范。德州通过德州保险部门（TDI）运行一计划。当国家或区域的运营商选择飓风登陆威胁最高的沿海无保险覆盖地区，这计划将提供保险。该计划首要被用于住宅建设项目，然后商业项目也能使用。

作为ASTM标准和佛罗里达州建筑规范的一个成果，一个国际专家组参与制定建筑玻璃ISO 16932标准（破坏性风暴安全防护玻璃测试和分类标准）。ASTM标准以及ISO标准的制定向其他风暴区制定区域规范铺平了道路。

规范执行11年后被测试

当2005年造成210亿美元和21人死亡的威尔玛飓风袭击南佛罗里达时，佛罗里达州建筑规范得以投入测试。迈阿密戴德县建筑法规合规办公室对去野外并组织用以确定这些建筑规范在减少建筑结构损害方面如何有效的损害评估很感兴趣。可在威尔玛飓风后进展的评估报告总结中找到相关信息。

在该地区的许多高层建筑受到威尔玛飓风的影响。调查显示依据新的建筑规范修建的建筑中没有一个遭受任何玻璃系统损坏。在现行规范之前修建的建筑遭受了外窗、幕墙和平开玻璃门的损坏。破坏发生的地方会造成内部水损坏和造成建筑内部压力升高，从而造成如屋顶坍塌的附带灾

building and the wind zone. The pressure cycling required will be determined by not only the wind zone region but the shape of the building, height of building, location of the building in relation to other buildings and the size of the window itself. This becomes more important in urban settings were the wind loads can increase based on the surrounding buildings, resulting in a tunneling effect of the wind.

Interlayers Used for Hurricane Impact Resistant Glazing

Both Polyvinyl Butyral (PVB) and Ionoplast interlayers have been used in laminated glass for hurricane glazing systems since the codes were in effect. PVB is a soft interlayer and works well when the design pressures and missile size is lower. Because of the low stiffness, laminates using PVB tend to not perform well when the design pressure is high. The high wind pressures can cause the laminate to pull out of the frame during the cycling portion of the test and therefore typically will need better frame design or thicker interlayer and/or glass.

Ionoplast interlayers have been used since 1998 in south Florida and can meet the highest level of performance, which is measured using large missiles D and E along with meeting high design pressures. Ionoplast is a stiff interlayer and provides added rigidity and strength, allowing the laminate to remain intact after high pressure cycling. The high stiffness and rigidity provides the opportunity to down gauge the glass used which can lower cost. Another benefit of Ionoplast interlayers and high stiffness glazing systems is that they can be dry glazed, which reduces the installation cost and timing to install versus traditional wet glaze systems. Dry glazing also eliminates the cost of silicone sealant. PVB is too flexible to be used in a dry glaze system.

Projects in Florida Using Hurricane Impact Glazing

The construction market for tall buildings in south Florida is growing rapidly, with many high-rise condos being built close to the ocean and in some of the highest wind zone regions. Ionoplast interlayers have been used widely in the Florida hurricane market. When large missile impact and high design pressures are needed, Ionoplast has been the interlayer of choice versus traditional PVB. High-rise buildings typically use glazing

害。在高层建筑中也观察到由通风管道引起的孤立的破损路径。这是一个可以用到城市高层建筑区域发展考虑的重要发现。

波托菲诺塔是一个依据新规范建造的建筑案例。这是一座在1997年根据迈阿密戴德县高速飓风区要求修建的44层建筑。威尔玛飓风过后，包括玻璃系统在内的整个建筑没有遭受任何重大损失（图5）。

设计防飓风冲击玻璃系统的考虑

为了让玻璃系统在风夹带碎片中有效的减小损伤，整个系统需设计合理。框架系统和如何将玻璃安装在框架系统上同玻璃具有抗冲击性同样重要。当为一建筑设计玻璃系统时，了解建筑将经受何种类型的风荷载是重要的，这将确定设计压力。所需的抗冲击测试类型将依据建筑所在位置和风区确定。循环压力测试要求将不仅依据风区区域，还需考虑建筑的形状、高度、和其他建筑的相邻关系和其自身外窗尺寸而确定。在城市建设中，由周围建筑导致风的隧道效应而造成风荷载增强变得更加重要。

用于防飓风冲击玻璃的中间膜

自从新规范开始执行以来，PVB和离子性中间膜都可以被用在防飓风玻璃系统的夹层玻璃中。PVB是一种柔软的中间膜，并在压力和发射物尺寸较小时工作良好。由于较低的硬度，在高的设计压力下PVB夹层玻璃表现趋于不好。在循环风压测试中，高的风压会造成夹层玻璃从框架中拉出；因此特别需要更好的框架系统设计或更厚的中间膜（或玻璃）。

离子性中间膜从1998年在南佛罗里达被使用至今，它能达到满足最高设计压力的大发射物D和E级要求的最高级别表现。离子性中间膜是一种硬质的中间膜，提供增加的硬度和强度能让夹层玻璃在高循环压力测试后夹层玻璃仍能完好无损。高的强度和刚度可提供降低玻璃规格的可能，这能降低成本。离子性中间膜的另一个好处是高强度玻璃系统可被干法安装，相对于传统湿法安装系统会降低安装成本和减少安装时间。干法安装也减去了硅酮胶的成本。PVB中间膜由于太柔软而无法被应用到干法安装系统中。

佛罗里达州应用防飓风玻璃项目

在南佛罗里达州的高层建筑市场正快速的增长，其中许多高层公寓正被建造在近海岸和部分最高风区区域。离子性中间膜被广泛的应用在佛罗里达州防飓风市场。当大发射物冲击和高设计压力被要求时；相对于传统PVB中间膜，离子性中间膜是中间层材料的最好选择。高层建筑通常会在建筑30英尺往下部分使用离子性中间膜玻璃系统，在建筑其他部分使用PVB中间膜。

佛罗里达州迈阿密的布里克尔城市中心是一个集商场、办公和公寓一体的开发项目（图6、7）。该项目位于布里克尔金融中心区中心位置，是迈阿密市中心最大的单体项目。该中心包含数个高层建筑。

墨西哥项目

虽然在墨西哥和加勒比海地区没有像佛罗里达州式的强制性规范，开发商们正认识到设计能抵御恶劣风暴建筑的好处。Secrets The Vine是位于具有高飓风风险的西哥坎昆地区的一家豪华酒店。该建筑将离子性中间膜应用在这个建筑玻璃结构中，用以在飓风发生时提供最大限度保护的同时保持高质量的时尚外观。

其他风暴和其他地区

恶劣天气发生在世界各地；如佛罗里达州的情况，通常一个特定的严重风暴会成为建筑规范修订的催化剂。通常会被保险公司为降低未来事件损失而推动。

2012年9月澳大利亚昆士兰遭受风速为181英里/小时（294公里/小时）的5级龙卷风雅斯袭击。雅斯是一个延伸超过2000公里的巨型龙卷风。他摧毁了150间房屋，留下了650间无法使用的房屋。预估损失约36亿美元。澳大利亚已经有关于抵抗风夹带碎片的规范，AS1170 结构设计措施2部分：风力作用；然而“雅斯”龙卷风后这些需被修订以适应更高风速要求。类似于佛罗里达州，澳大利亚被划分为A、B、C、D四个主要区域。A和B为无龙卷风区域，C区域要求能抵御28~32米/秒速度冲击，D区域为最高要求区域需抵御34~44米/秒速度冲击。使用的发射物为一根4公斤重的木棒（截面尺寸：100*50毫米）。

然而不同于佛罗里达州，此规范没有包含整个玻璃系统证书产品审批的规程。防冲击玻璃制造商通常自己组织内部测试，以证明此玻璃具有满足要求的能力。在减轻风夹带碎片损失时框架系统和玻璃一样重要已经得到很好的证明。

systems with Ionoplast interlayer for the first 30 feet from grade level and PVB for the rest of the building.

Brickell City Center located in Miami, Florida is a mixed-use development that includes retail, office and residences (Figures 6 and 7). It is located in the center of the Brickell financial district and is the single largest project in downtown Miami. The center contains several high-rise buildings.

Projects in Mexico

Although in Mexico and the Caribbean there are not any mandatory codes for hurricane glazing like there are in Florida, developers are recognizing the benefits of designing buildings to be resilient in severe storms. Secrets The Vine is a luxury hotel on the beach in Cancun, Mexico, which is a high risk area for hurricanes. This building utilizes Ionoplast interlayers on all the glazing structures to provide the maximum protection during hurricanes while maintaining a high-quality, modern look.

Other Storms and in Other Regions

Severe weather occurs all over the world and, as is the case with Florida, there is usually a specific severe storm that becomes the catalyst for change in building codes. Often times this will be driven by insurance companies to reduce their losses in future events.

In September 2012, Queensland Australia was hit by Category 5 Cyclone Yasi, with winds of 181 MPH (294 KPH). Yasi was a massive cyclone which stretched out over 2000 km. It destroyed 150 homes and left 650 uninhabitable. Damage was estimated around $3.6 billion. Australia already had codes in place for wind borne debris, AS1170 Structural Design Actions Part 2: Wind Actions, however these needed to be modified after Yasi to reflect higher wind speeds. Similar to Florida, Australia is divided in to 4 main zones A, B, C, D. A and B are non-Cyclonic zones, C requires impact resistance 28-32 m/sec and D is the highest requiring 34-44 m/sec. The missile used is a 4Kg piece of timber (100 x 50 mm).

However, unlike Florida there is no product approval process that includes certification of the whole glazing system. Producers of laminated impact glass typically conduct their own testing internally to demonstrate that the glass will be capable of meeting the requirements. It has been well demonstrated that the framing system is just as important as the glass in mitigating damage from wind borne debris.

Figure 6. Secrets The Vine, interior view (Source: Grupo Frel)
图6. Secrets The Vine酒店内部景观（来源：Frel组）

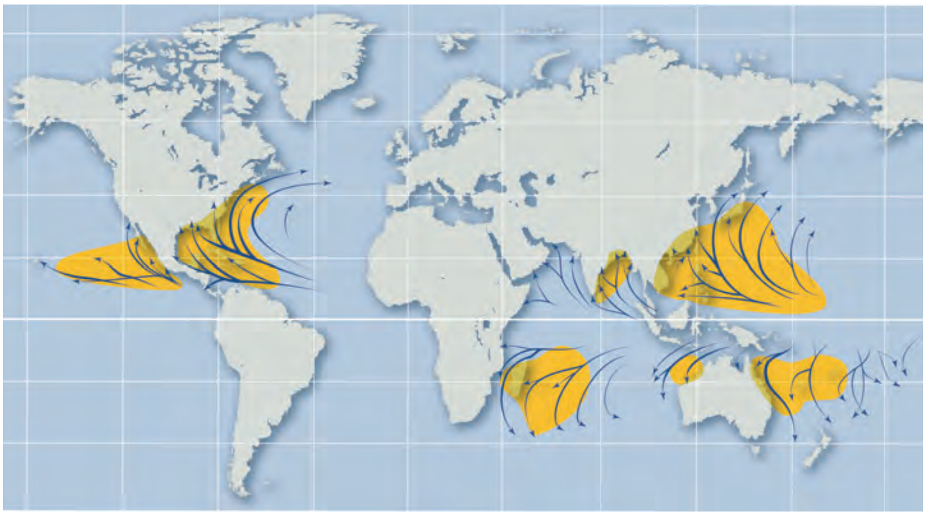

Figure 7. Map of typhoon, cyclone and hurricane regions (Source: Kuraray)
图7. 台风、旋风及飓风区地图（来源：可乐丽）

Conclusion

Since Hurricane Andrew, in recent years there have been a number of very significant storms around the world. In 2008 in North America, Hurricane Ike caused $29.5 billion in damages and killed 103 people, 2005 Hurricane Wilma was Mexico's most costly hurricane at $7.5 billion. Hurricane Katrina cost $96–125 billion.

In the Asia Pacific region, Typhoon Haiyan in 2013 was the strongest ever recorded causing $2.86 billion in damage and killing at least 6,340 people and typhoon YASI caused $3.56 billion in damage and killed three people.

结论

自从安德烈飓风发生以，近几年世界范围内发生了许多的重大风暴。2008年北美艾克飓风造成295亿美元损失和和103人丧生，2005年造成75亿美元损失的威尔玛飓风是墨西哥损失最重的飓风。卡特里娜飓风造成960~1250亿美元损失。

在亚太地区，2013年有记录的历史最强台风海燕造成28.6亿美元损失和6340人丧生；台风雅斯造成35.6亿美元损失和3人丧生。

飓风和台风也正开始在过去不通常见的地区发生。南大西洋并不被认为是一个龙卷风区域，但2004年一个强力风暴在巴西登陆。2008年纳吉斯龙卷风袭击缅甸造成90,000人丧生。美国中大西洋地区不被知道为易受龙卷风袭击区域。近几年，在这局域的发展已经靠近海岸线，但并没有太多抵御飓风袭击的考虑。2013年超级飓

Hurricanes and typhoons are also beginning to appear in areas that have not experienced these types of storms in the past. The South Atlantic is not considered to be in a cyclone region, however in 2004 a strong storm made landfall in Brazil. Myanmar was hit by Cyclone Nargis in 2008, killing 90,000 people. The mid-Atlantic United States is not known to be susceptible to hurricanes. Development close to the shore line has been growing over the years in this region without much consideration for the threat of hurricanes. Super storm Sandy hit the region in 2013, causing $65 billion in damage, which prompted some changes to buildings standards. It is important to consider climate change resilience in buildings. Areas that are not currently susceptible to hurricanes, typhoons and cyclones may need to consider proactively changing their codes as a pre-emptive mitigation measure.

Urban development in areas prone to severe weather has been increasing and this greatly increases the risk of financial and human losses. It is important to learn lessons from past weather events and develop strong codes and standards that make these infrastructures more resilient to severe weather threats to minimize both economic and human losses.

风桑迪袭击了这个区域造成650亿美元损失，并促使建筑规范的部分修订。

在易发生恶劣天气的区域发展城市正在增长，这将极大的增加经济和人员损失的风险。重要的是从过去天气事件中吸取教训；制定确保基础设施更能抵抗恶劣天气袭击，从而最大限度减少经济和人员损失的强有力的规范和标准。

References:

ASTM International, ASTM E1886-13a. **Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials.** Available at: http://www.astm.org/standards/E1886.html

ATM International, ASTM E1996-14a. **Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Wind-borne Debris in Hurricanes.** Available at: http://www.astm.org/standards/astm1196.html

Block, V., Kopec, T. and Rinehart, D. (2008). **A Hurricane by Many Other Names.** Available at: http://www.usglassmag.com/digital/2008/usglass200809-dl.pdf. In-line Citation: (Block, Kopec, and Rinehart, 2008)

Building Code Compliance (2006). **Post Hurricane Wilma Progress Assessment.** Available at: https://www.miamidade.gov/building/library/reports/wilma-assessment.pdf

Magazine, F. (2013, May 13). **Cyclone-rated Glazing: No Room for Compromise.** Available at: http://www.fmmagazine.com.au/sectors/cyclone-rated-glazing-no-room-for-compromise/ In-line Citation: (Magazine, 2013).

N. (2012). **20 Years Later: Insurance Changes Triggered by Hurricane Andrew.** Available at: http://www.insurancejournal.com/news/southeast/2012/08/21/259960.htm. In-line Citation: (*, 2012)

UCAR-University Corporation for Atmospheric Research. (2007). **Hurricanes, Typhoons, Cyclones.** Retrieved May 4, 2016, from http://www2.ucar.edu/news/backgrounders/hurricanes-typhoons-cyclones In-line Citation: (UCAR-University Corporation for Atmospheric Research, 2007)