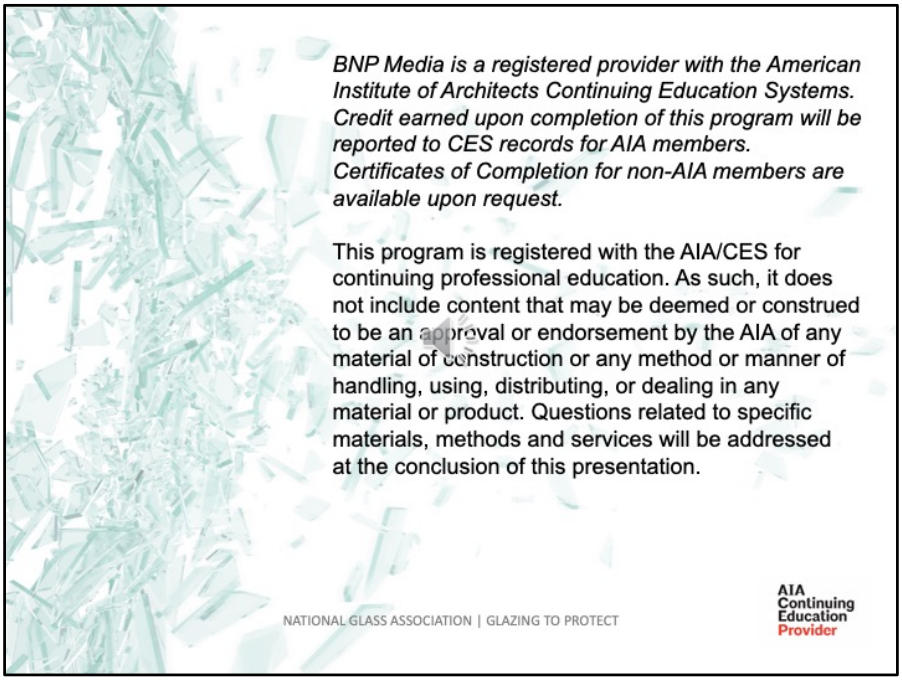
Welcome to NGA's AIA presentation – Glazing to Protect: Design Considerations and Performance Characteristics



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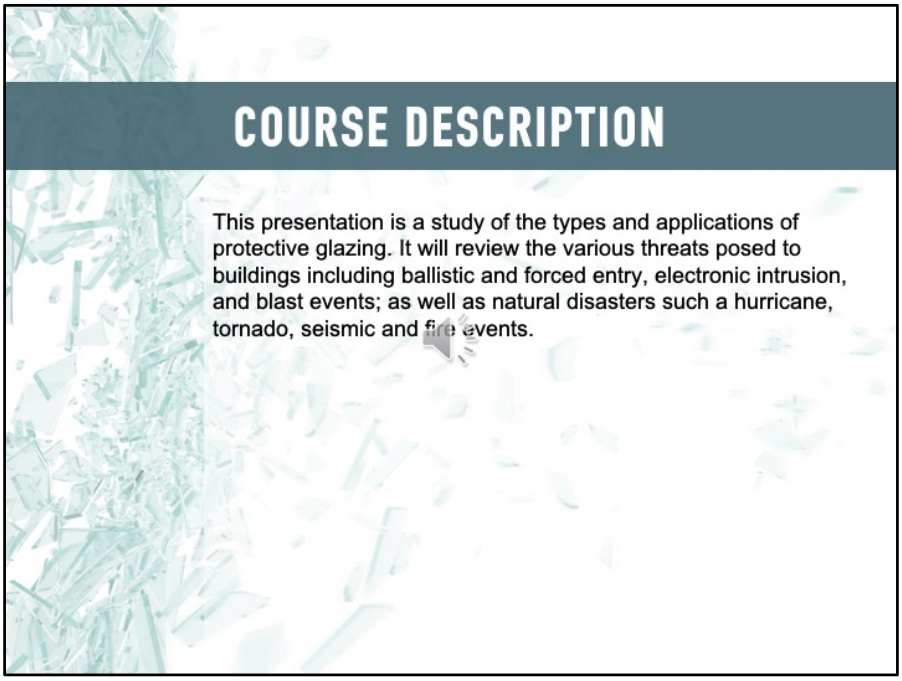
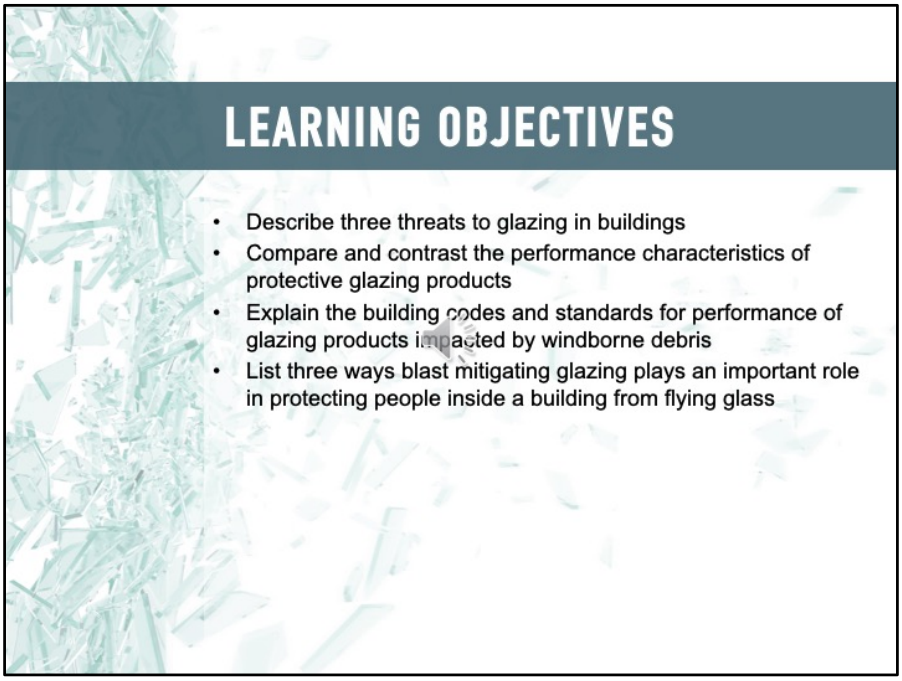


This presentation is a study of the types and applications of protective glazing. It will review the various threats posed to buildings including ballistic and forced entry, electronic intrusion, and blast events; as well as natural disasters such a hurricane, tornado, seismic and fire events.

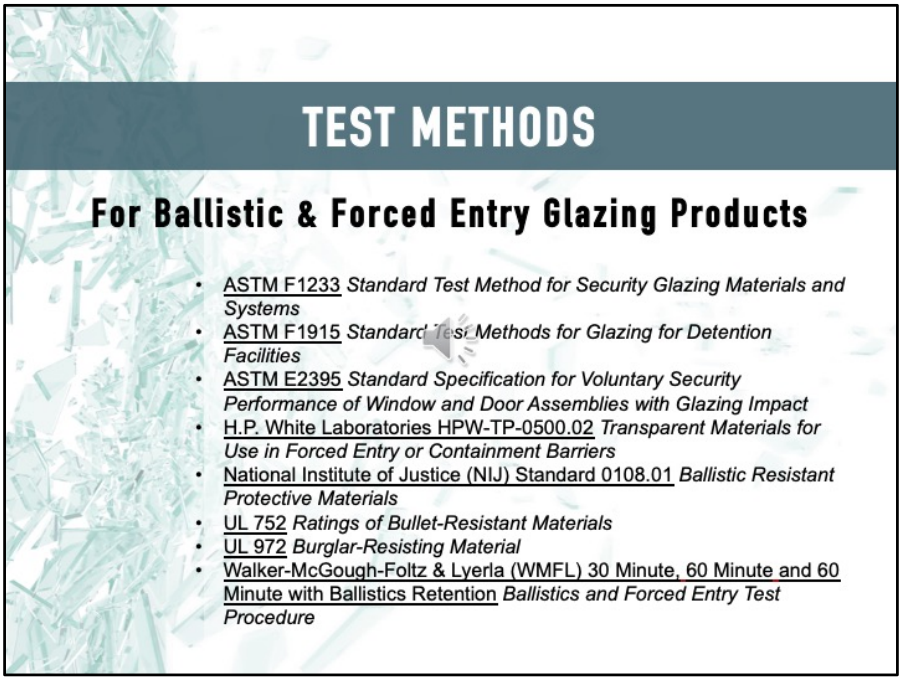


The Learning Objectives for this course are to:

- Describe three threats to glazing in buildings
- Compare and contrast the performance characteristics of protective glazing products
- Explain the building codes and standards for performance of glazing products impacted by windborne debris
- List three ways blast mitigating glazing plays an important role in protecting people inside a building from flying glass

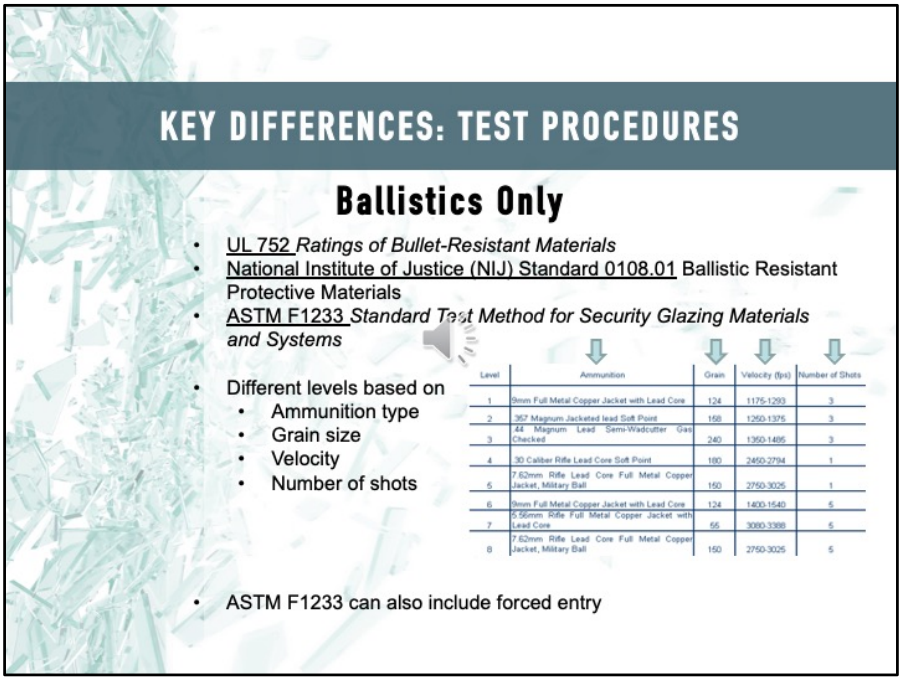
This presentation addresses the use of protective glazing in buildings that require a specified level of security performance. The threat may be from bullets, forced-entry, natural disasters such as hurricanes and earthquakes, blast, or fire.

First, let’s address the test methods and glazing types for ballistic and force entry applications.



There are several test methods used to assess the performance of glazing used for ballistic and forced entry protection. The first test method utilized for ballistic and force entry testing was developed by the H.P. White Test Laboratories. Modeled after the H.P. White Test Procedure. ASTM F1233 also offers the option of ballistics, physical attack, or a combination of both. The WMFL test, developed by the architectural firm of Walker-McGough-Foltz & Lyerla, is a third test that combines the factor of time with physical testing and ballistics. Unlike H.P. White test or ASTM F1233, the

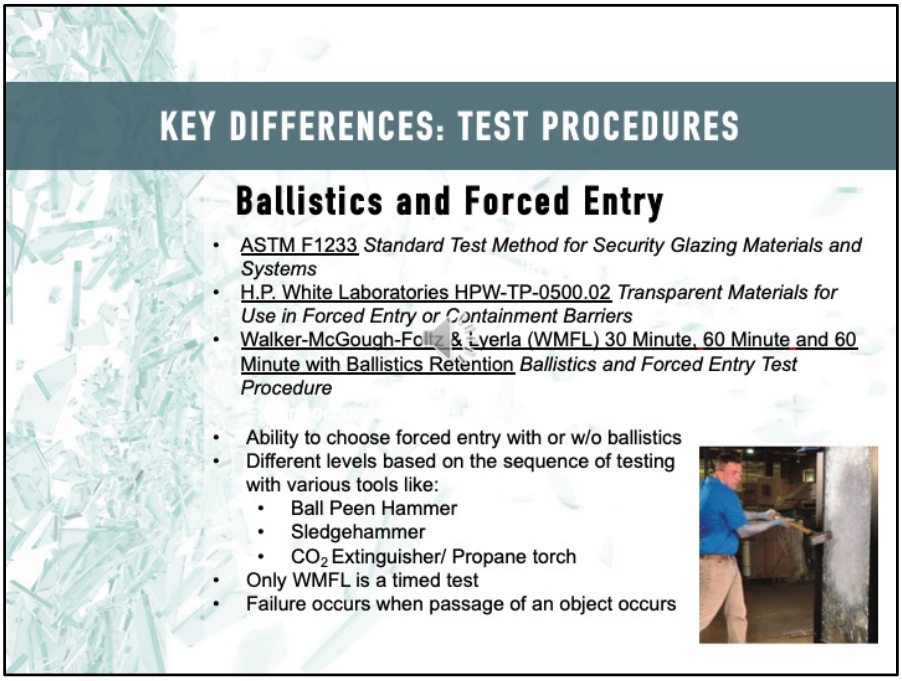
WMFL is NOT a no spall bullet resistant test. ASTM F1915 is a shift from physical attack to a mechanical impact test designed for greater repeatability. Two ballistics only tests are UL 752 and the National Institute of Justice Standard 0108.01. And finally there is UL 972, a drop ball test for burglar resistant glazing. It should be noted that although WMFL isn't used anymore, that test is still referenced in older documents. Most users have migrated to ASTM International and UL standards.



Level	Ammunition	Grain	Velocity (fps)	Number of Shots
1	9mm Full Metal Copper Jacket with Lead Core	124	1175-1293	3
2	.357 Magnum Jacketed lead Soft Point	158	1250-1375	3
3	.44 Magnum Lead Semi-Wadcutter Gas Checked	240	1350-1495	3
4	.30 Caliber Rifle Lead Core Soft Point	180	2450-2794	1
5	7.62mm Rifle Lead Core Full Metal Copper Jacket, Military Ball	150	2750-3025	1
6	9mm Full Metal Copper Jacket with Lead Core	124	1400-1540	5
7	5.56mm Rifle Full Metal Copper Jacket with Lead Core	55	3080-3388	5
8	7.62mm Rifle Lead Core Full Metal Copper Jacket, Military Ball	150	2750-3025	5

The three primary test procedures for ballistic threats are:
- UL 752 – Ratings of Bullet-Resistant Materials
- NIJ Standard 0109.01 – Ballistic Resistant Protective Materials
- ASTM F1233 – Standard Test Method for Security Glazing Materials and Systems

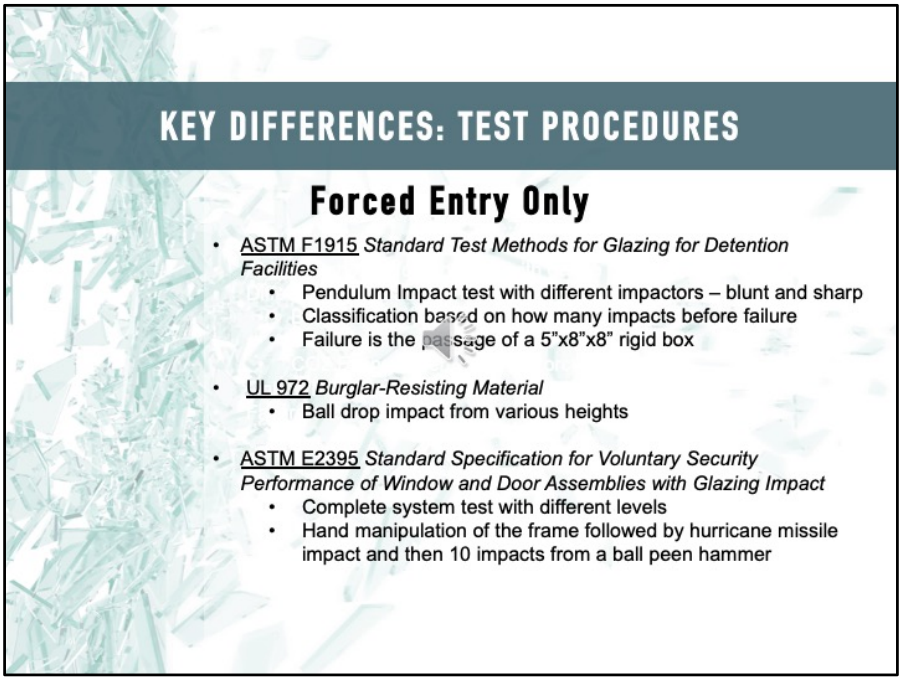
In each standard, an application may pass varying levels of resistance based on several factors including the ammunition type, speed and number of shots resisted.



The three primary test procedures applicable to both ballistic and forced entry threats are:

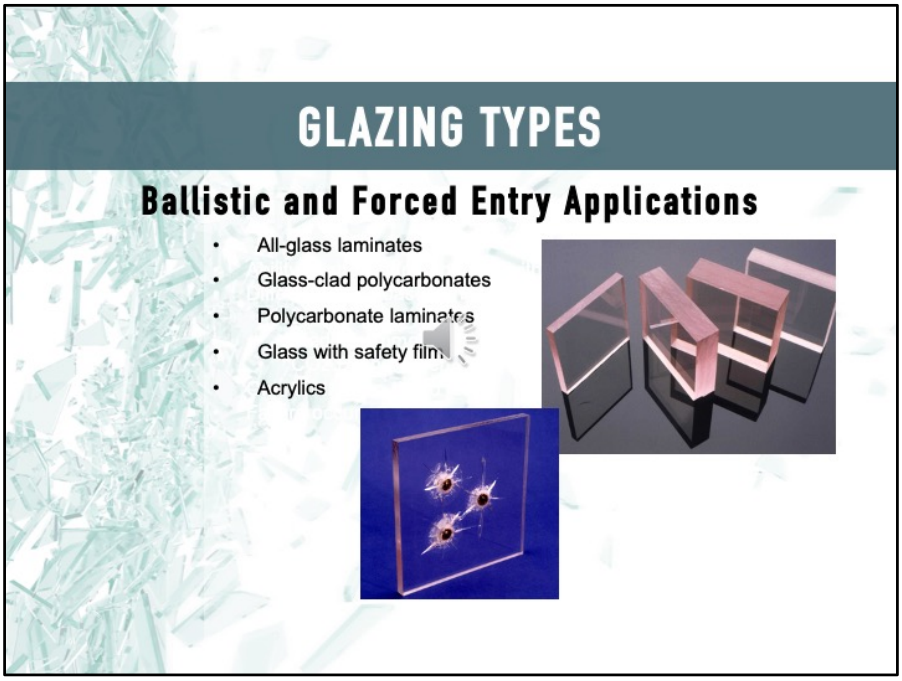
- ASTM F1233 – Standard Test Method for Security Glazing Materials and Systems
- HP White's procedure for Transparent Materials for Use in Forced Entry or Containment Barriers
- WMFL's ballistics and forced entry test procedures

As with the ballistics procedures, there are key differences between each test including the types of tools used and if it is a timed test.

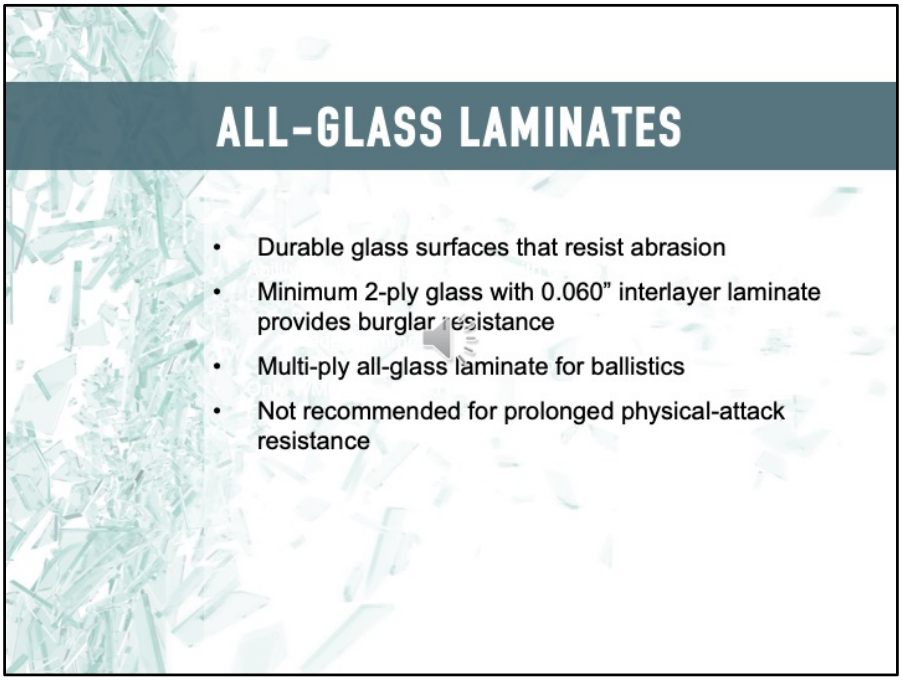


The three primary test procedures for forced entry threats are:
ASTM F1915 – Standard Test Method for Glazing in Detention Facilities
UL 972 – Standard Burglary Resisting Glazing Material
ASTM E2395 – Standard Specification for Voluntary Security Performance of Window and Door Assemblies with Glazing Impact

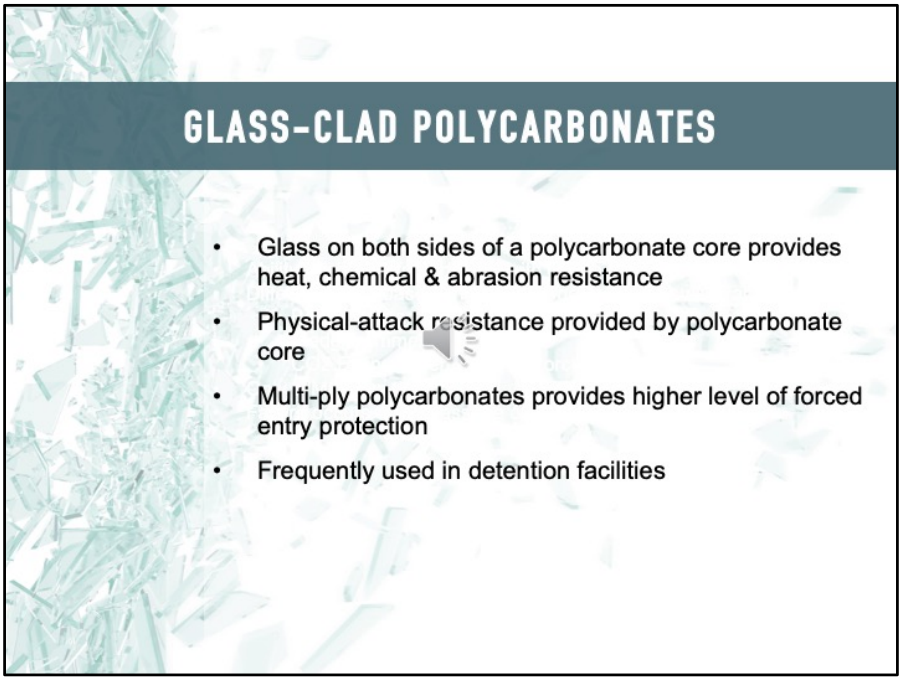
You'll see each test differs in the type of impact test employed.



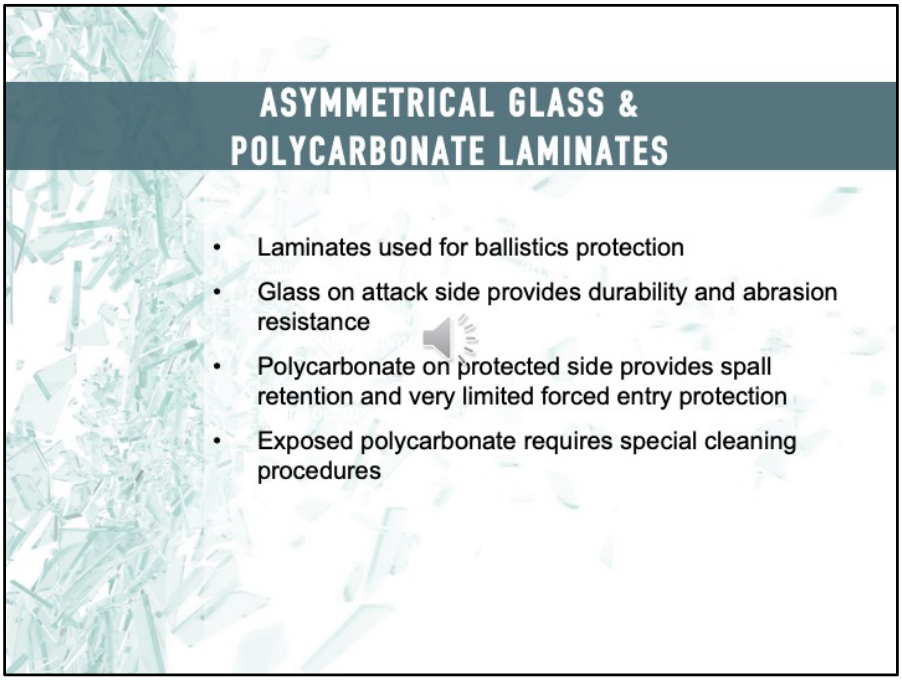
There are five types of glazing products using for ballistic and forced-entry applications. They are all-glass laminates, glass clad polycarbonates, laminated polycarbonates, safety film applied glass, and acrylics. While these products are different, they are all tested to the same standards of performance.



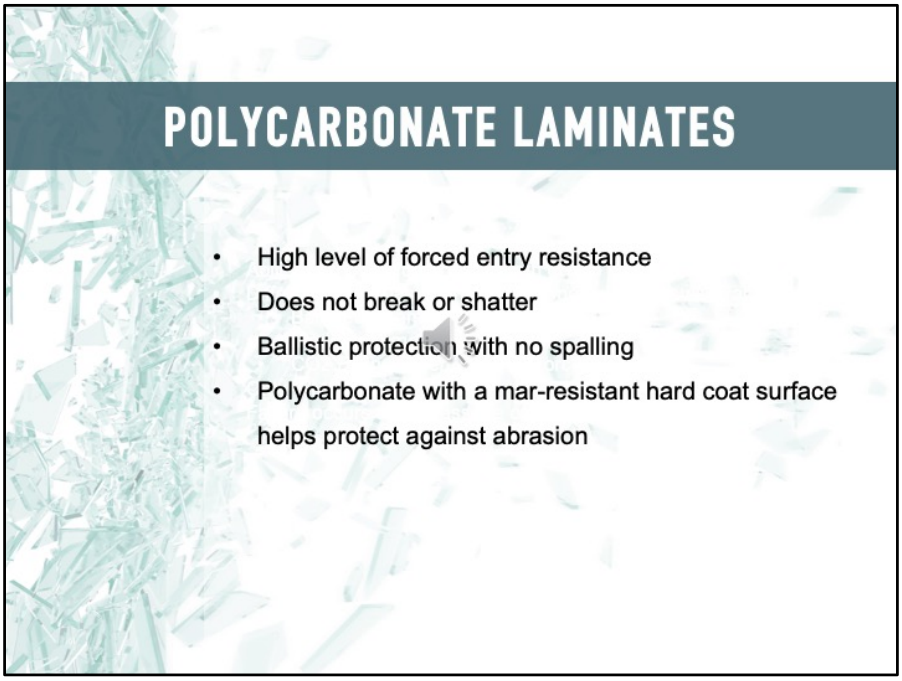
All-glass laminates are constructed with two or more plies of glass and interlayer. Burglar resistance laminates are typically two plies of glass and a 60-mil interlayer. Ballistic resistant laminates will require multiple plies of glass and interlayer. The outer glass surfaces are easy to clean and offer excellent resistance to abrasion. All-glass laminates should not be used for prolonged physical attack resistance.



Glass clad polycarbonates are made with outer plies of glass and inner sheets of polycarbonate; this is considered a balanced construction. The outer glass plies provide abrasion resistance and the inner core of polycarbonate improves physical attack resistance. There may be one sheet of polycarbonate inside the laminate or multiple sheets of polycarbonate to provide higher levels of forced entry protection. Glass Clad polycarbonates are often used in detention facilities.



Asymmetrical constructions of glass and polycarbonate, also known as unbalanced construction, are typically associated with ballistics protection. Multiple lites of glass are positioned on the attack side, absorbing the energy of the bullet and providing improved durability. Polycarbonate with a hard coat is placed on the protected side of the laminate to prevent glass spray, or spall, into the protected area. Considerations for maintenance and cleaning are particularly important with this construction.



Laminated polycarbonates provide a high level of forced entry resistance. These laminates will not break or shatter and offer no-spall ballistics protection. To minimize abrasion on the outside polycarbonate sheets, a hard coat polycarbonate is incorporated into the laminate on the attack and protected surfaces.

Applying safety film to glass is another means to increase protection from forced entry. Notably, the applied safety film will help retain broken glass within the unit and limit spall. It can offer some additional protection from forced entry itself, often delaying damage to the window or frame.

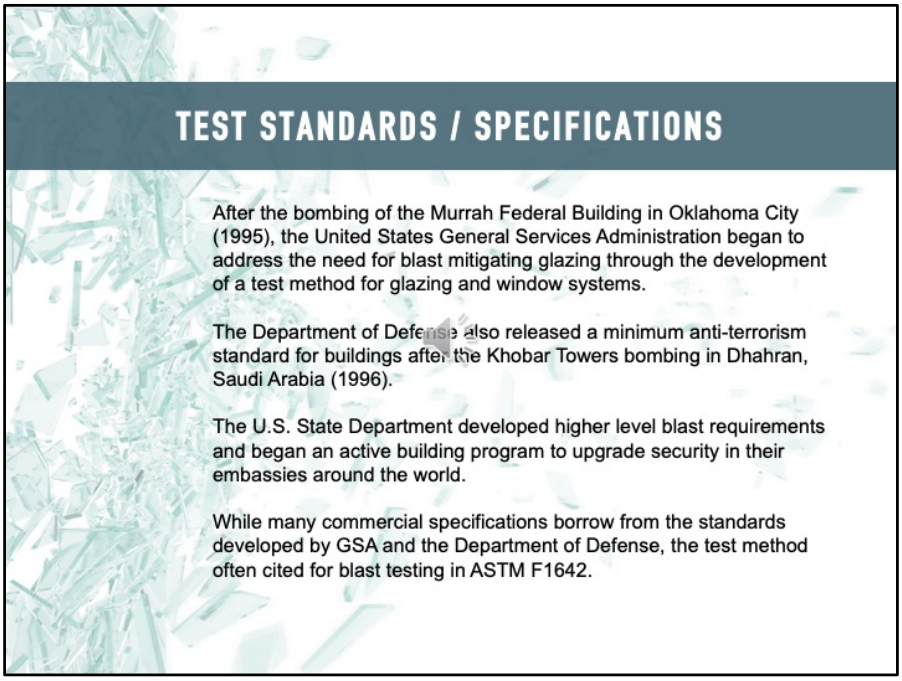
Safety films come in a range of thicknesses and constructions, and do require special cleaning procedures so as not to damage the film itself.

Before specifying ballistic and/or forced-entry glazing, it is critical to understand the security threats associated with the project. Once it has been determined there is a ballistic or forced entry threat, the appropriate standards can be used to select a security level.

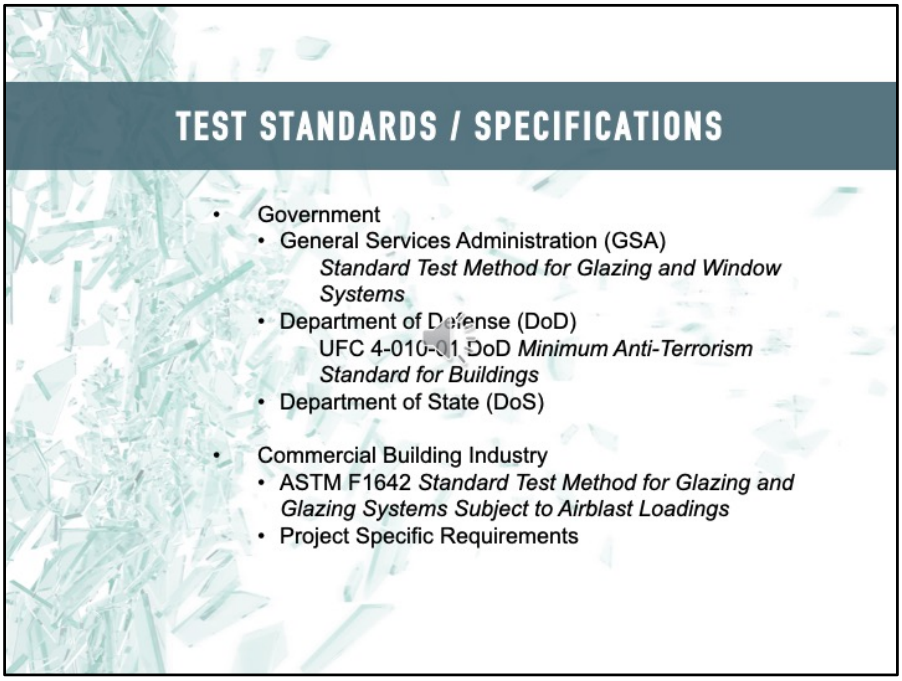
The next protective glazing application we'll review is blast mitigation.

Blast protection has been part of government and military specifications for years. Today an increasing number of commercial buildings are requiring blast protection.

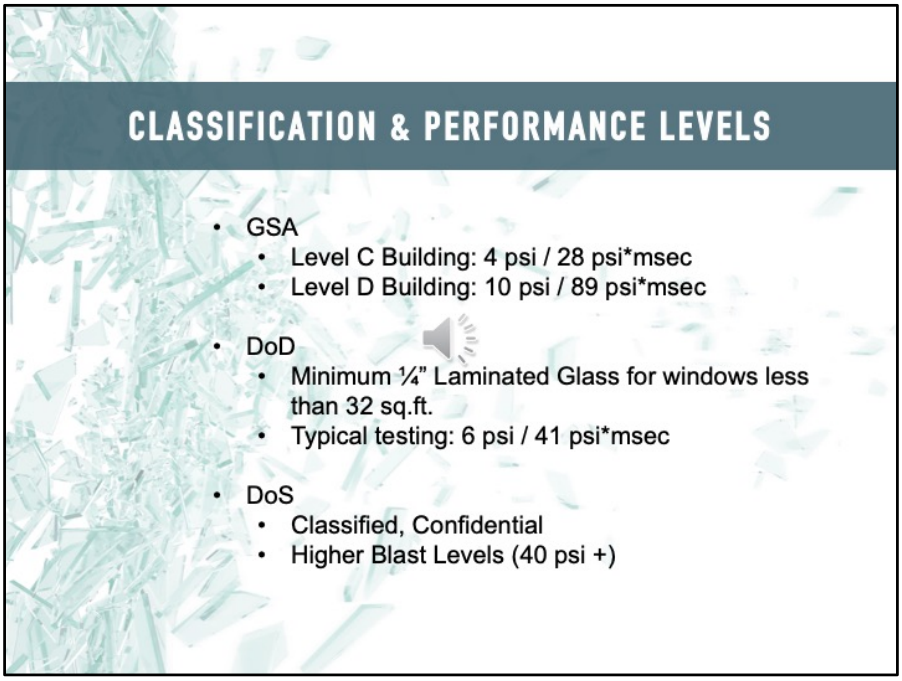
Blast mitigating glazing plays an important role in protecting people inside a building from flying glass. Besides providing a life safety function, blast mitigating glazing can reduce interior damage and provide some security even after a bomb has been exploded.



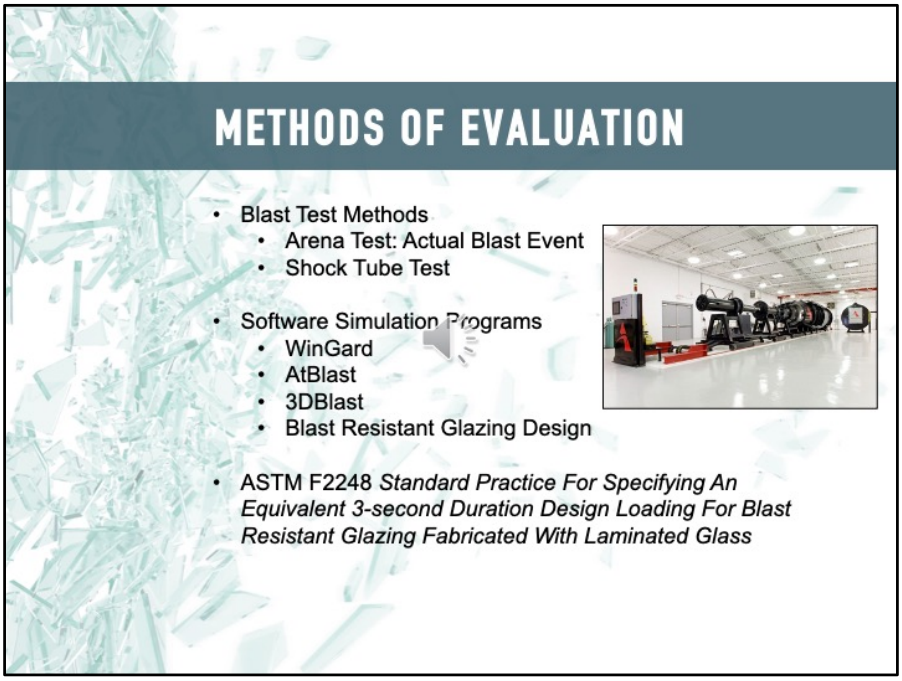
The subject of blast protection has been addressed by government agencies, the U.S. military, and the private sector. After the bombing of the Murrah Federal Building in Oklahoma City (1995), the United States General Services Administration began to address the need for blast mitigating glazing through the development of a test method for glazing and window systems. The Department of Defense also released a minimum anti-terrorism standard for buildings after the Khobar Towers bombing in Dhahran, Saudi Arabia (1996). The U.S. State Department developed higher level blast requirements and began an active building program to upgrade security in their embassies around the world. While many commercial specifications borrow from the standards developed by GSA and the Department of Defense, the test method often cited for blast testing in ASTM F1642.



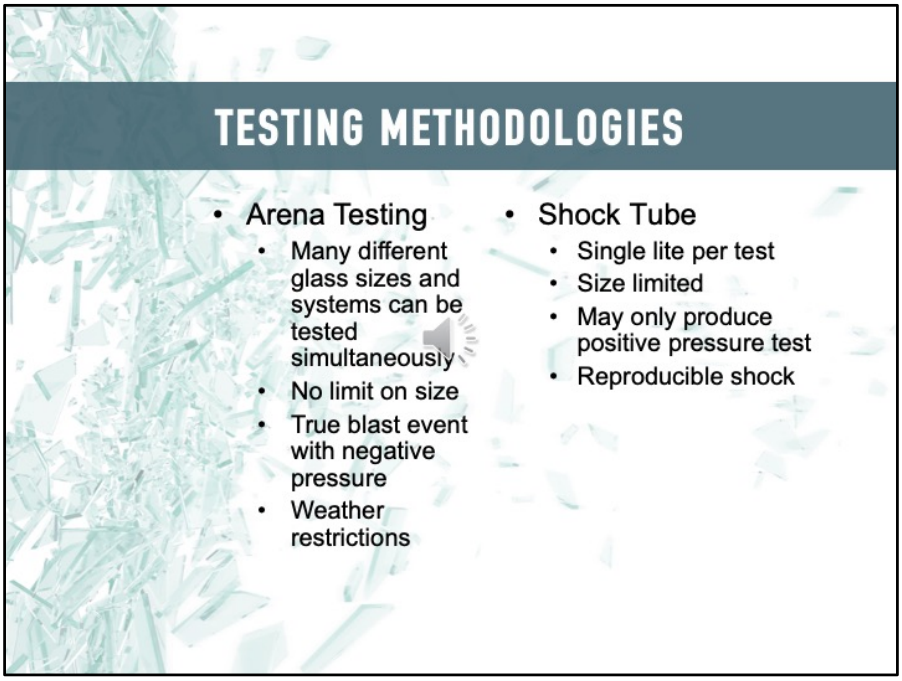
The three primary test standards for blast mitigation are:
GSA – Standard Test Method for Glazing and Window Systems
The Dept of Defense issued Minimum Anti-Terrorism Standard for Buildings
And, ASTM F1642 – Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings.



The classification of blast requirements differs from one agency to another. When blast requirements were first established they were initially based on static loads classified by square footage of frame and glass. The standards now reflect Performance, or Protection, Levels that are defined by the amount and distance glass shards penetrate into an occupied space. The lowest Level of Protection can allow for ¼" laminated glass. Manufacturers typically test to a 6 psi peak pressure to establish their system as blast resistant.



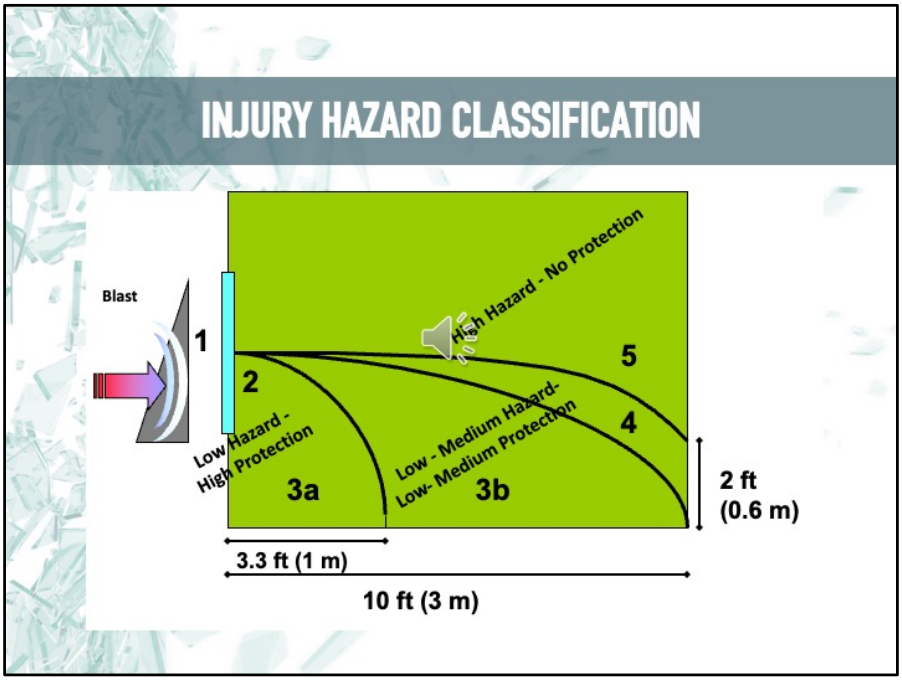
Product evaluation may require physical testing of glazing or systems in either a shock tube or arena environment. Due to costs and the project-specific nature of blast requirements and design, the Standards allow software analysis to be used to determine the framing system and laminate construction based on specific project input. The government has an established software program- that they make available for approved users. The program along with design criteria are considered classified information and access is strictly controlled. Government building projects will have limited information provided except to qualified blast engineers and designers. Public projects will often include more definitive design criteria in their specifications and allow for use of programs from private software developers. The Department of Defense specifies the use of ASTM F2248, a Standard Practice for specifying an Equivalent 3-second duration design loading for blast resistant glazing fabricated with laminated glass. This standard is used in conjunction with design charts taken from ASTM E1300.



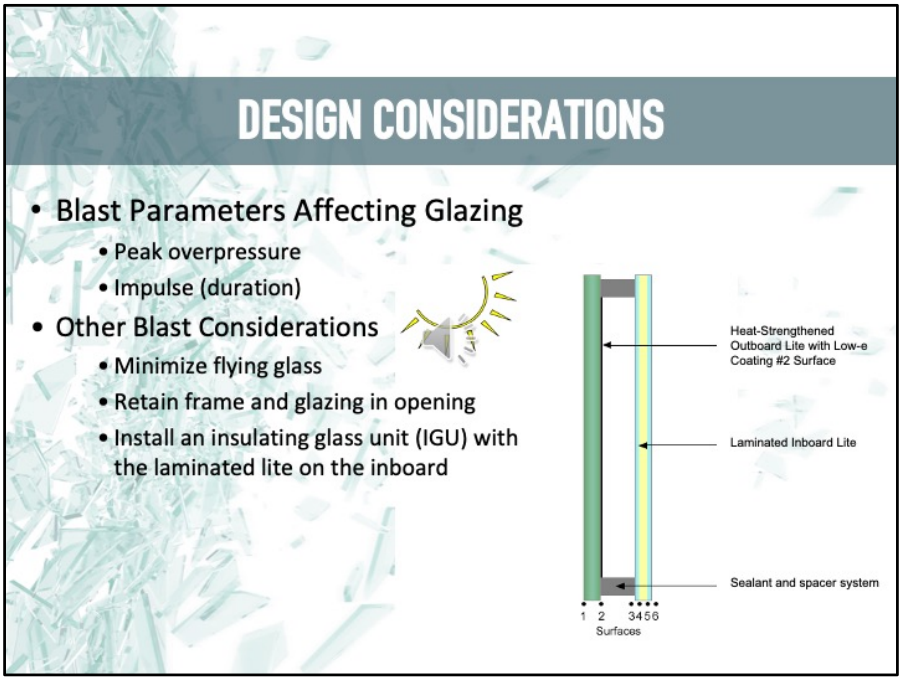
There are pros and cons to using shock tube versus arena testing. With arena testing, different systems can be tested simultaneously. An actual explosion will have a positive and negative phase, and this is best replicated through an arena test. There is greater flexibility in testing large-scale test specimens. With arena testing, weather is always a factor and inclement weather can postpone testing. Shock tube testing is based on testing of a single specimen and the size may be restricted based on the capability of the shock tube. Some shock tubes have difficulty producing the negative phase. On the positive side, shock tube testing is highly reproducible with less variability in the outcome of testing.

A typical blast

wave is shown with a rise representing the positive phase and a dip representing the negative phase of an explosion. The entire event occurs in milliseconds.



Once the blast occurred, a 10 foot box behind the test specimen helps classify the resulting hazard level. If the glass does not break or cracks but does not fall out, the glazing is determined to present a low hazard with a high degree of protection. If glass shards fly into the space, the hazard level is determined by the location and height the shards fall within the 10 foot area.

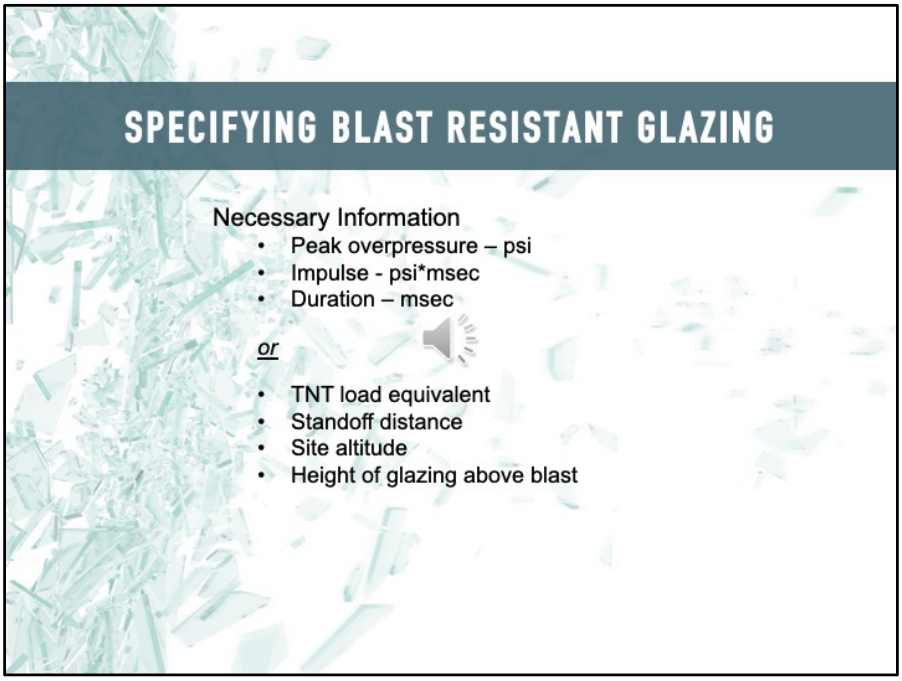


Basic information, such as the peak overpressure and impulse, or duration, of the blast, is required to design a glazing system. Other considerations are the ability of the glazing to minimize flying glass and keep the window system integral even if the glass is cracked or broken. When insulating glass units are specified for energy performance, the laminated lite should be positioned on the inboard of the unit.

Laminated glass can incorporate annealed, heat strengthened, or tempered glass with a 30-mil or 60-mil interlayer that bonds the glass together. Heat strengthened glass offers twice the mechanical strength of annealed glass and breaks in a similar breakage pattern. Tempered glass is four times as strong as annealed glass with a considerably smaller particle size after breakage. All blast projects should be wet glazed.

Safety film may also be used for select levels of blast protection. Attachment to the frame is imperative. Consult the film manufacturer to select the proper film

and glass combination for the level of protection desired.

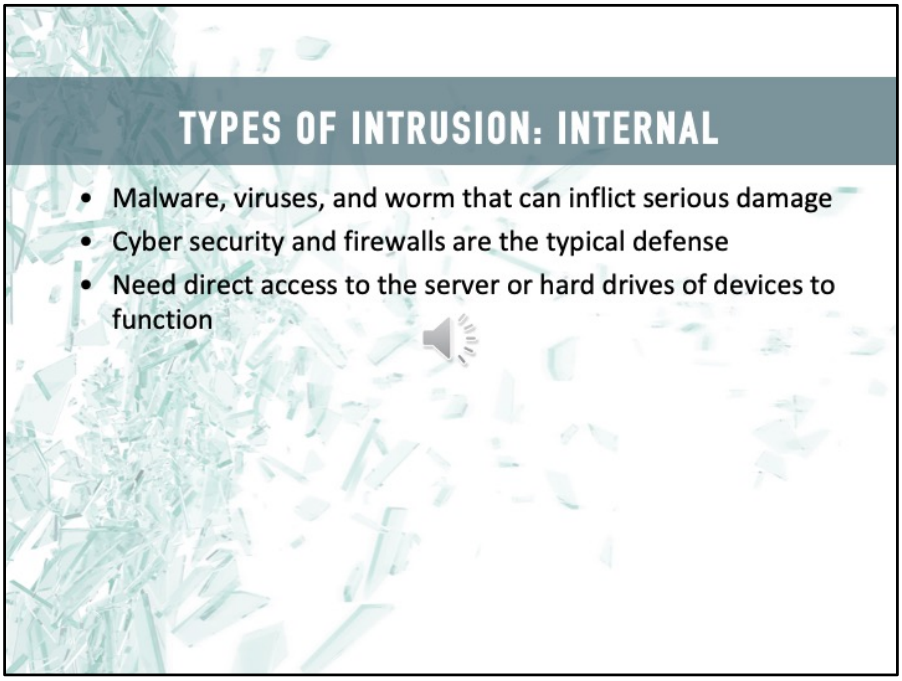


A blast resistant glazing can be specified by calling out the peak overpressure, impulse and duration of the blast or the TNT load equivalent, standoff distance, site altitude, and height of the glazing above the blast. Since projects require the complete system to be analyzed, the final glazing will be confirmed during the calculation, or project-specific mockup testing, phase.

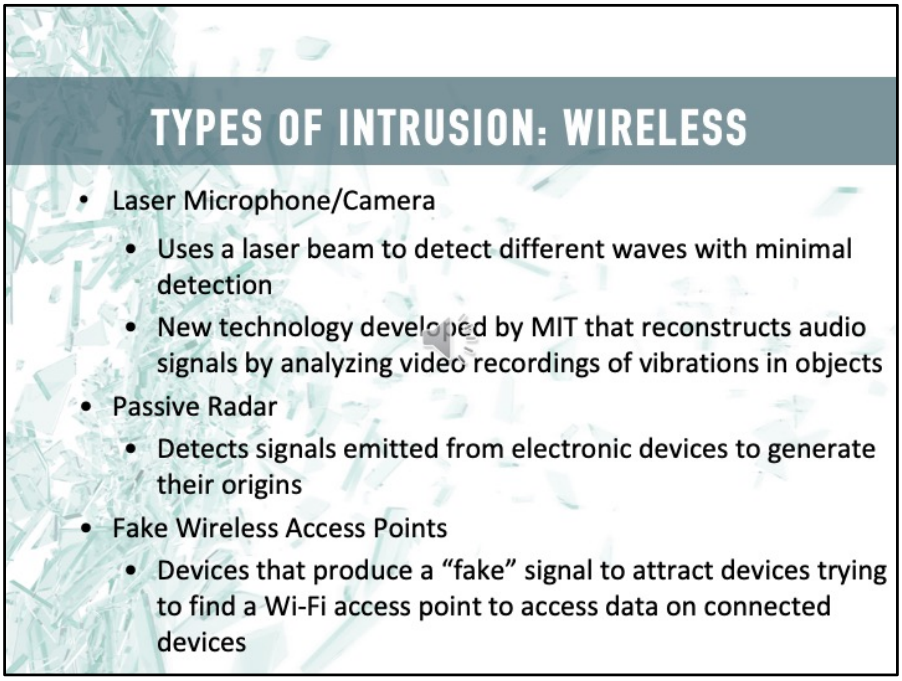
Next, we'll discuss some of the latest threats posed by electronic devices.

The threat of electronic breach is a relatively new issues as compared with other forms of intrusion. As noted here, security, privacy and even biological threats are of concern.

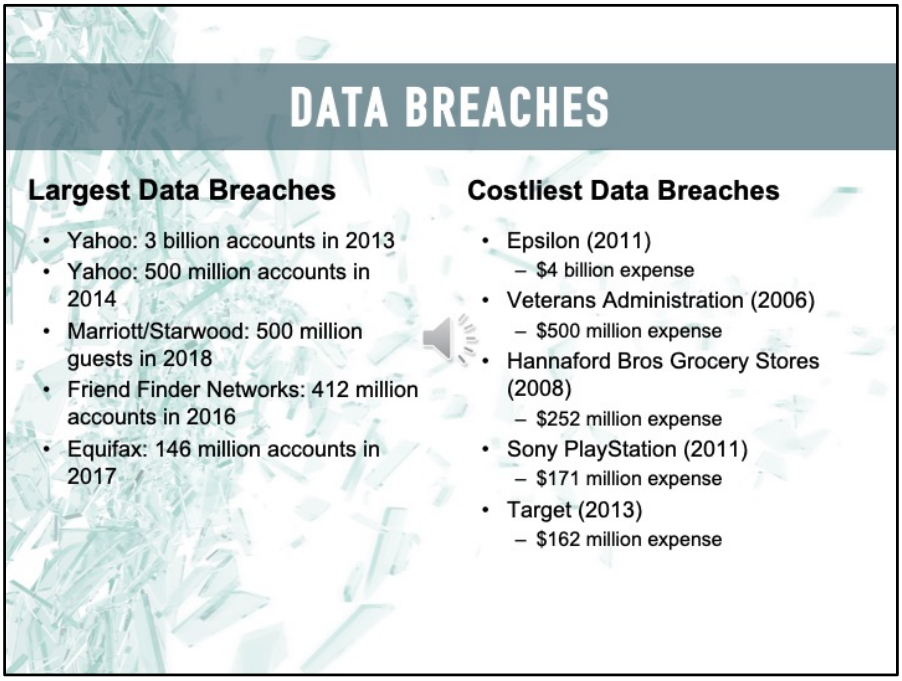
Gemalto, a leading digital security company, found that 90% of consumers lack confidence in the security of Internet of Things (IoT) devices. This comes as more than two-thirds of consumers and almost 80% of organizations support governments getting involved in setting IoT security.



Internal intrusions are those characterized by damage caused directly to devices that impairs or prohibits functioning. Malware, viruses or hacking into systems or servers are often results of internal electronic intrusion.

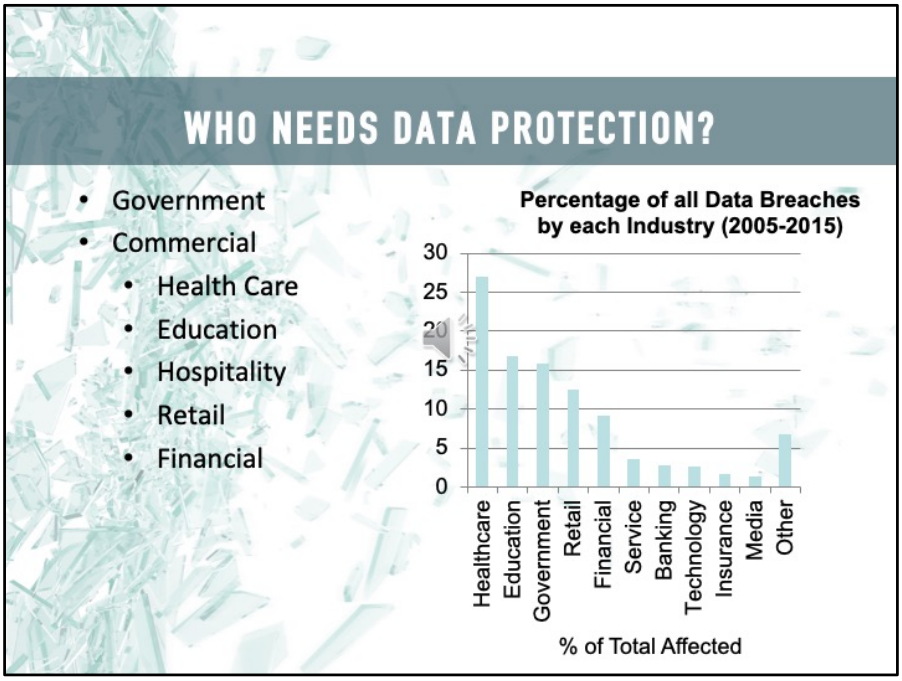


Wireless intrusions are those characterized by damage caused by access made through signals that can be sent through a building. Laser and audio signals, as well as establishing fake WiFi access points are additional ways electronic threats affect our daily world.

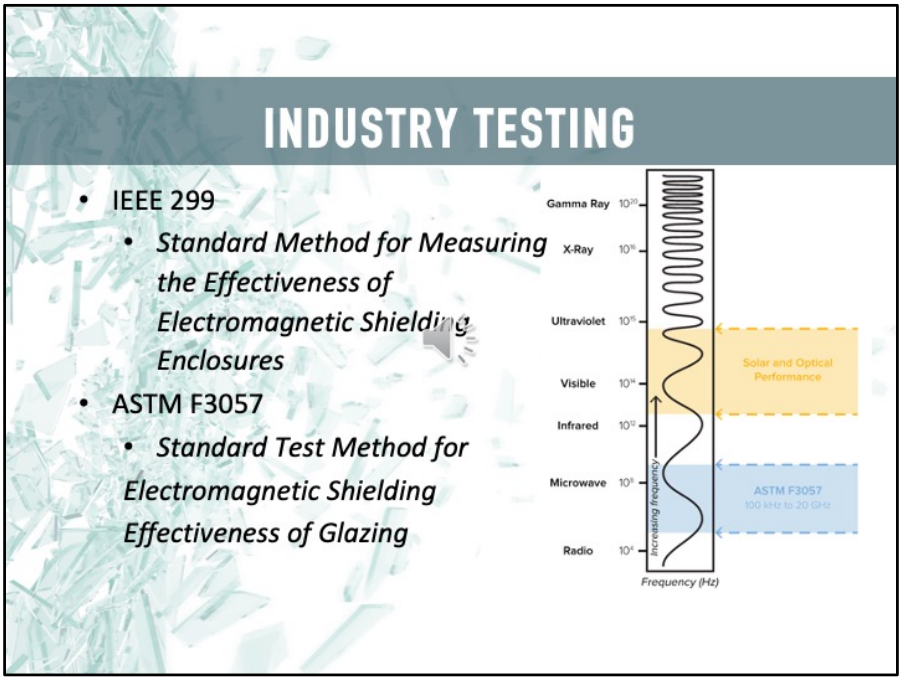


Listed here are some of the largest and/or costliest data breaches that have occurred in the last decade or so, all achieved through electronic intrusion.

Other large data breaches you may recall include those affecting TJ Maxx, Sony, Target, Home Depot, JP Morgan Chase and Anthem. As consumers at many of these companies, an electronic intrusion not only affects the operations of the company itself but trickles down to the customers these companies serve.

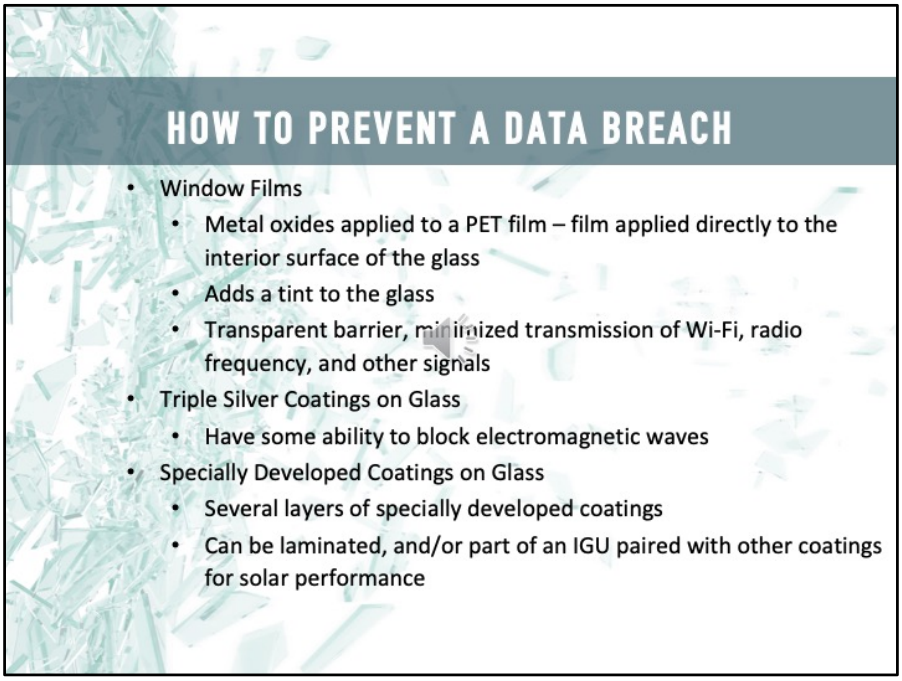


So, who actually needs data protection? Based on this chart, there are specific industries that appear to be affected more than others or that have differing levels of security already in place. As our world continues to become more virtually-based and digitally-driven – protection from electronic intrusion continues to grow in importance for business with operations based in the cloud.



Test methods and protocols are already in existence that can guide any company seeking to heighten its protection from electronic intrusion.

IEEE-299 is the Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures, and is often used by government agencies. This standard was developed by the Institute of Electrical and Electronics Engineers (IEEE).
ASTM F3057 is the Standard Test Method for Electromagnetic Shielding Effectiveness of Glazing



Regarding the protection of a building from electronic intrusion through the glazing, there are several methods to heighten a building's security.

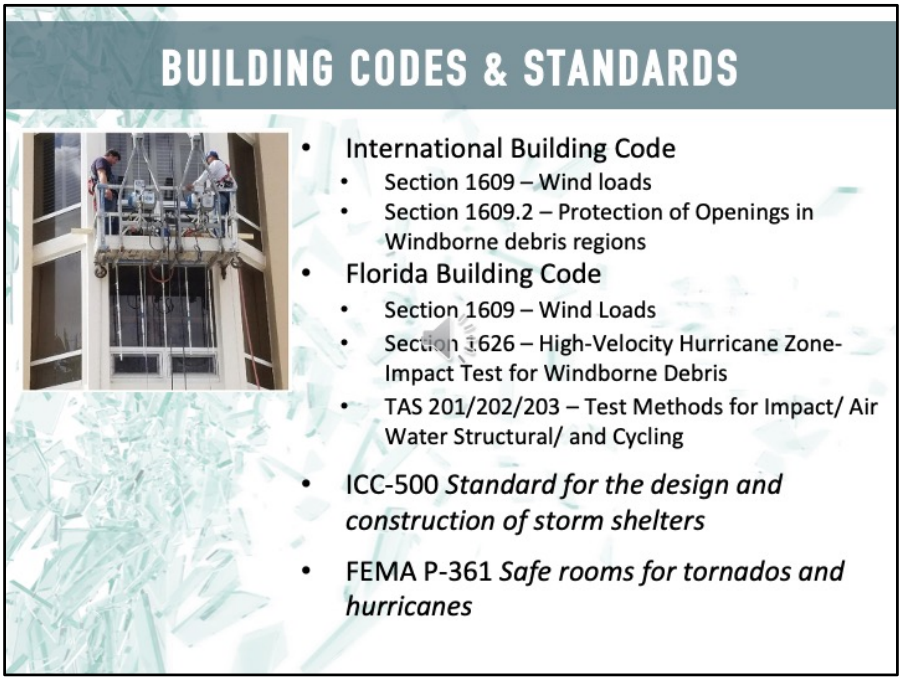
Certain window films are available that retain the daylight of the window opening while relying on metal oxides to intercede WiFi, radio or other frequencies.

Triple-silver coatings can been applied to the glass to aid in blocking electromagnetic waves. Discuss with your glass fabricator to determine the best combination of coatings to employ, and on which surfaces to apply them.

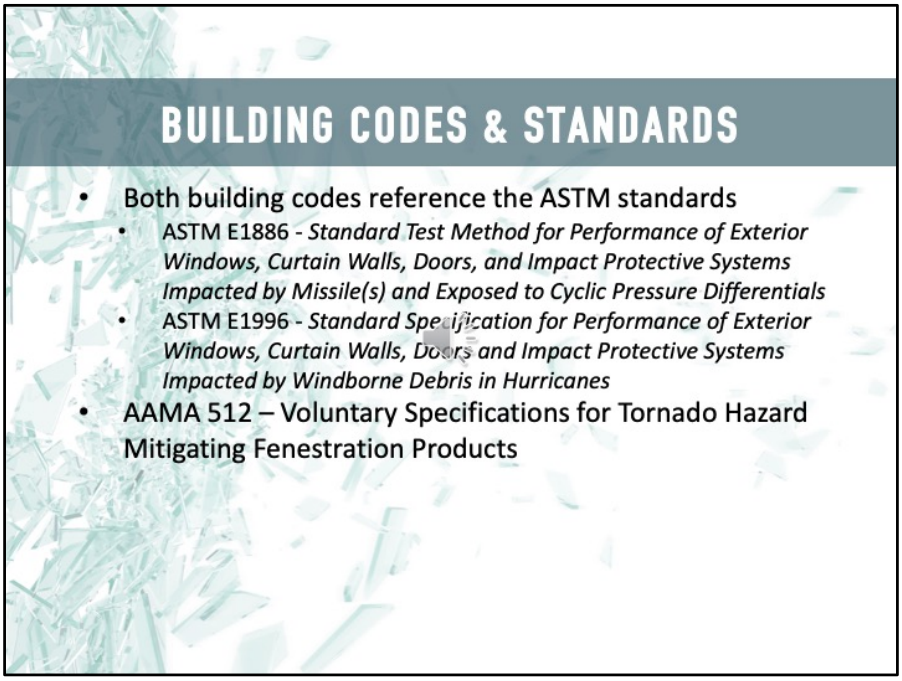
Finally, other specially-developed coatings can be considered specifically with your glass fabricator. These can be paired with other coatings and glass make-ups to achieve safety or solar performance goals.

Natural disasters can also cause harm to a building and its occupants. Let’s review these types of threats and the applicable glazing applications to address safety.

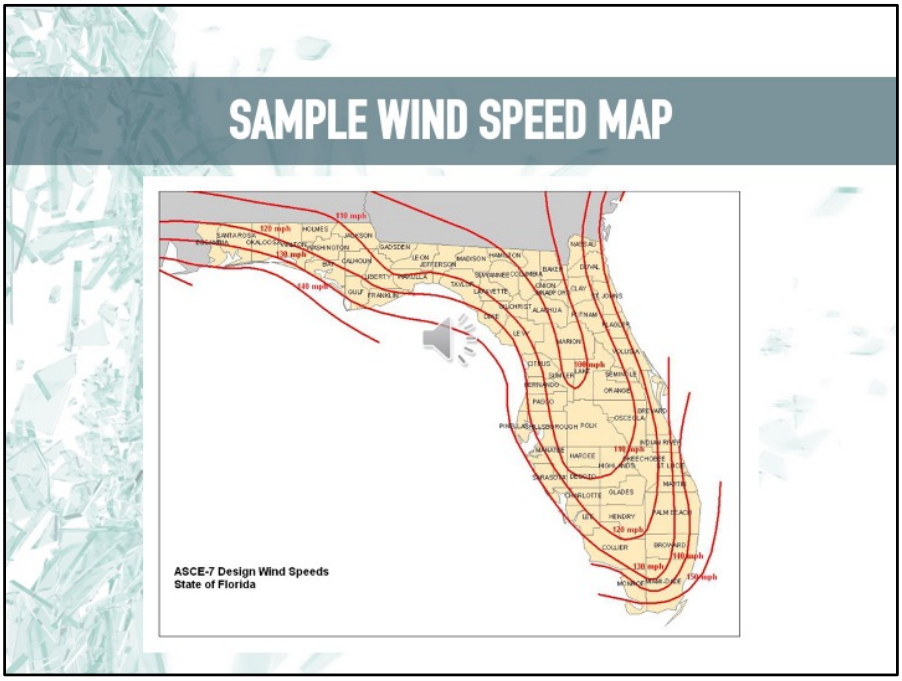
First, we'll review hurricane and tornado events.



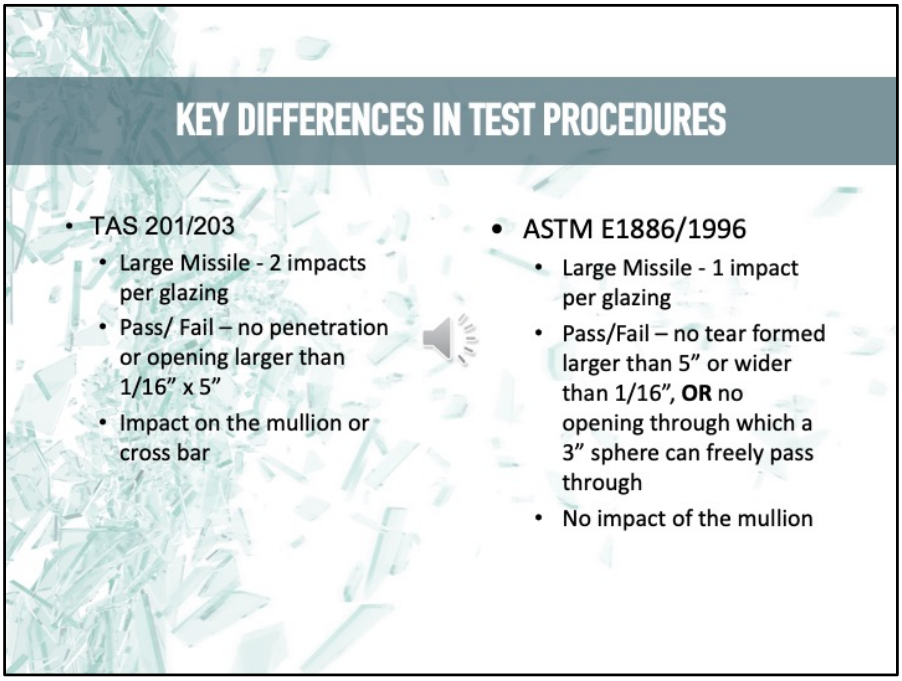
The Miami-Dade County Building Department first developed building code requirements for glazing performance after Hurricane Andrew. As the code was revised and updated the requirements have been incorporated into the current Florida Building Code as High Velocity Hurricane Zone. These standards are TAS 201 (impact testing), TAS 202 (air/water testing) and TAS 203 (cycle testing). The International Building Code, which has been used as a model for state building codes throughout the United States, also contains requirements for glazing in wind-borne debris regions.



Both the Florida Building Code and the IBC reference two ASTM standards, ASTM E 1886 and ASTM E1996. ASTM E1886 is the standard test method for missile impact and pressure cycling and ASTM E 1996 is the accompanying specification for testing windows, curtain walls, doors and impact protective systems.

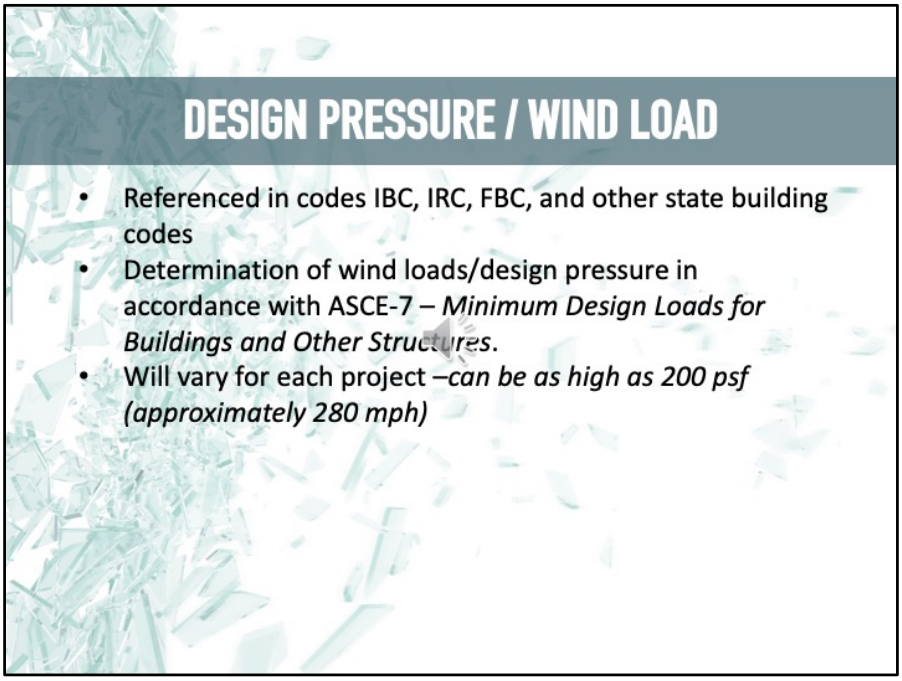


Wind borne debris protection is required in specific wind zones which are based on specific wind speeds. Here is a sample wind speed map of the State of Florida where wind zones have been delineated. The highest speeds are found at the southern tip of Florida.



The Florida Building Code contains High Velocity Hurricane Zone ("HVHZ") requirements that apply to the counties of Miami-Dade and Broward. In addition to the large missile test requiring two impacts per glazing with a maximum tear of 1/16 inch by five inches and no penetration of the impacted glass, an impact on the mullion or cross bar is required. There is not a provision for an additional 4th sample.

As noted on the previous slide, ASTM E1996 is one test method employed to define the missile level and type of impactor, as well as the protection level needed based on wind zone. Here is a sample of the test method which shows how missile levels are applied to protection levels and types of dwellings.

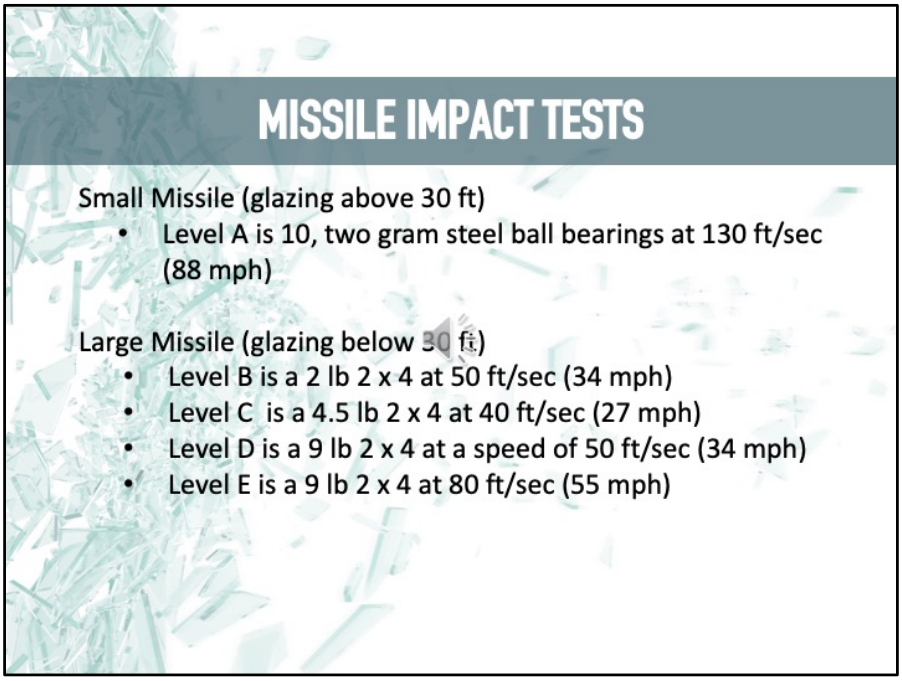


The design pressure must be identified prior to testing. If the design pressures are not provided in the project documents this pressure is calculated using the American Society of Civil Engineering standard ASCE 7. The design pressure will vary for each project.

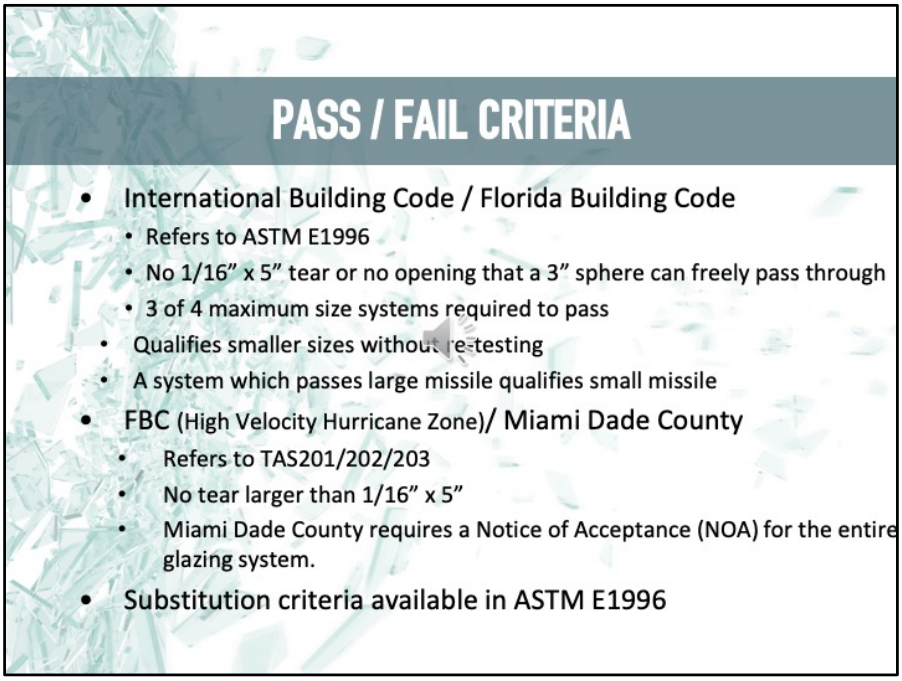
CYCLIC WIND PRESSURE TEST

Inward Positive Pressure		Outward Negative Pressure	
Range	Cycles	Range	Cycles
0.2 P_{max} – 0.5 P_{max}	3500	0.3 P_{max} – 1.0 P_{max}	50
0.0 Pmax – 0.6 P_{max}	300	0.5 P_{max} – 0.8 P_{max}	1050
0.5 P_{max} – 0.8 P_{max}	600	0.0 P_{max} – 0.6 P_{max}	50
0.3 P_{max} – 1.0 P_{max}	100	0.2 P_{max} – 0.5 P_{max}	3350

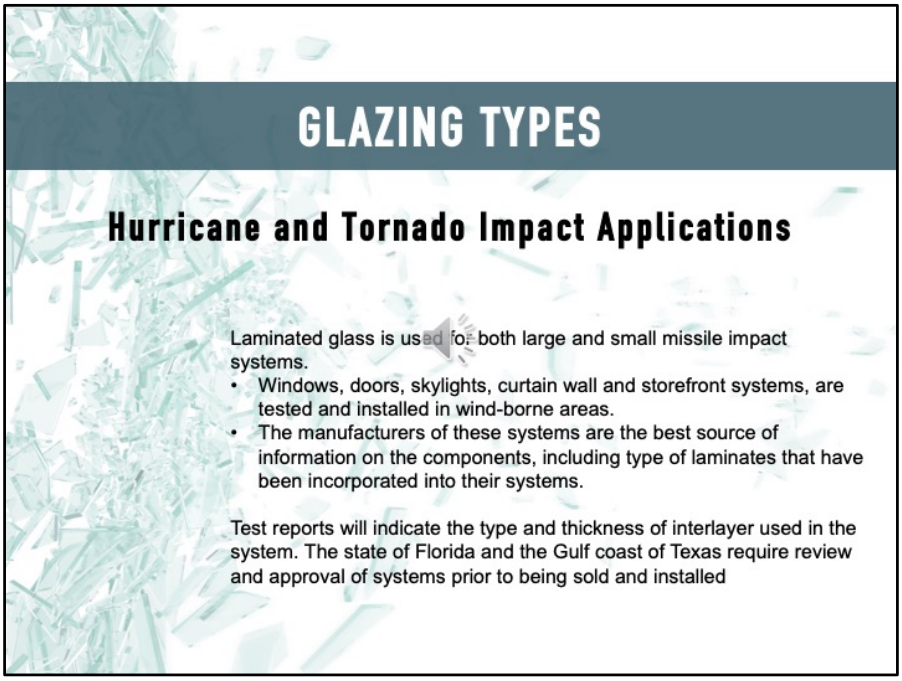
ASTM E1886 determines the performance of small and large missile impact testing. The large missile impact test applies in areas of the building below 30 feet in elevation and the small missile test applies in areas above 30 feet. Passing large missile testing qualifies small missile testing, but passing small missile testing does not qualify large missile. Once impacted, glazing systems go through pressure cycling consisting of a total of 4500 positive and 4500 negatives cycles of pressure.



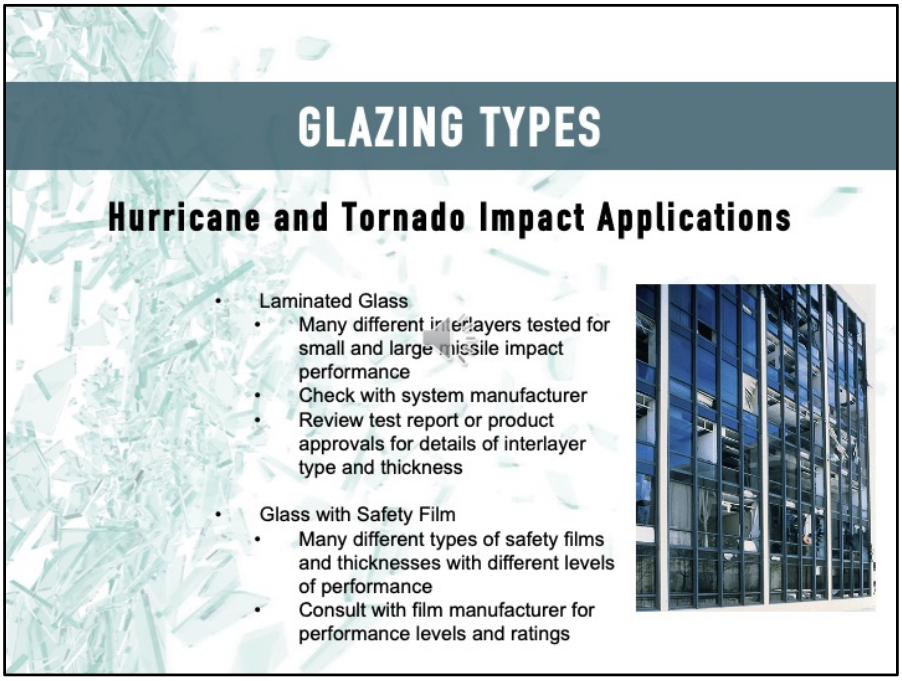
Missile impact testing requirements are based on wind zones. The small missile test level is designated as Level A and consists of 10 two-gram ball bearings traveling at 130 feet per second. There are several levels for large missile testing. The most common is the Level D missile, a 9 pound 2 x 4 traveling at a speed of 50 feet per second.



ASTM E1996 requires three out of four systems to pass testing. Because the maximum size of each system is required for testing, smaller sizes of the same glass makeup are automatically qualified without re-testing. Once the specimen has been impacted by the 2 x 4 timber, the glazing is inspected to see if any tears have developed. ASTM E1996 contains substitution criteria that clarifies if additional testing is needed based on variations to the originally tested system. The TAS standards for HVHZ and NOAs require passing 3 out of 3 mockups.



Laminated glass is used for both large and small missile impact systems. Windows, doors, skylights, curtain wall and storefront systems, are tested and installed in wind-borne areas. The manufacturers of these systems are the best source of information on the components, including type of laminates that have been incorporated into their systems. Test reports will indicate the type and thickness of interlayer used in the system. The state of Florida and the Gulf coast of Texas require review and approval of systems prior to being sold and installed. They have approval drawings available on their websites showing approved glass, frame configurations and wind speeds. Most manufacturers will direct you to these documents.
Safety films may also be applied to the glass; varying thicknesses of the film will provide different levels of impact performance. Again, consult with the film manufacturer to select the proper film for the application and desired performance.



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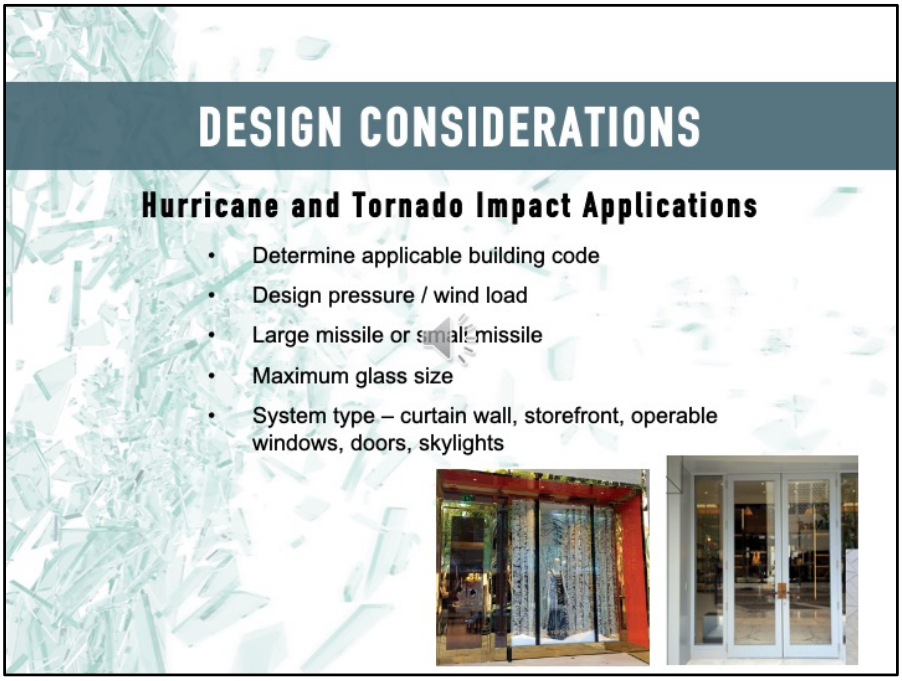
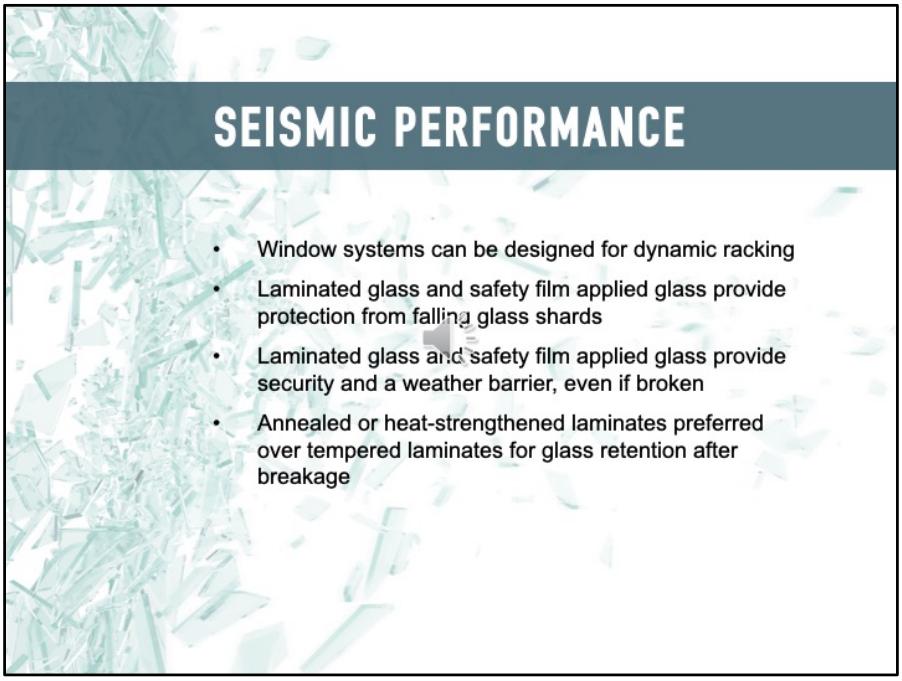
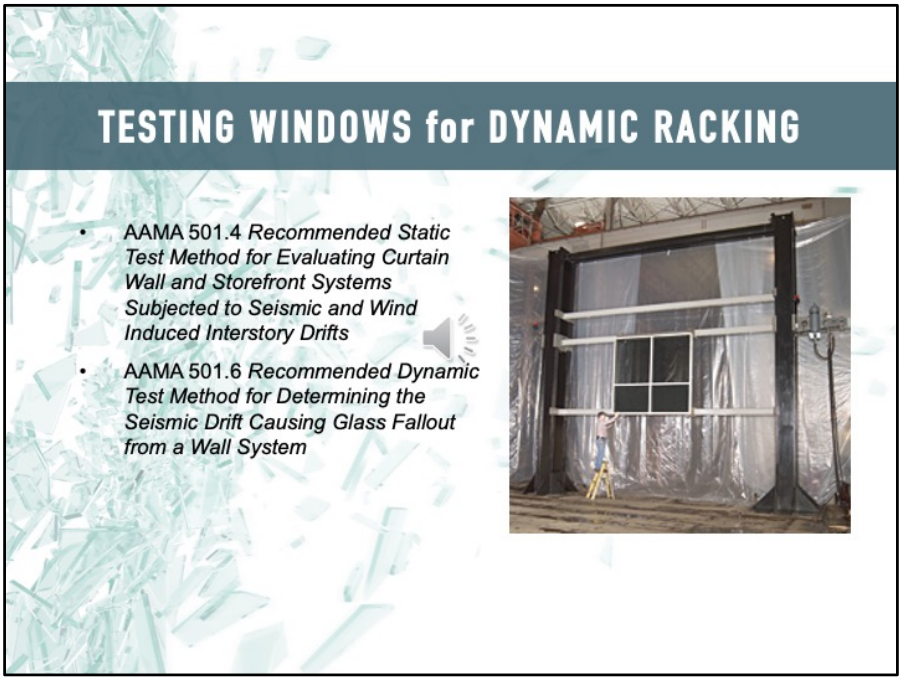


The considerations for selecting an impact system depend on building code requirements, the design pressure required, as well as the intended location of the glazing system in the building. Glazing systems that require testing and certification in certain jurisdictions include curtain walls, storefronts, windows, doors, and skylights.

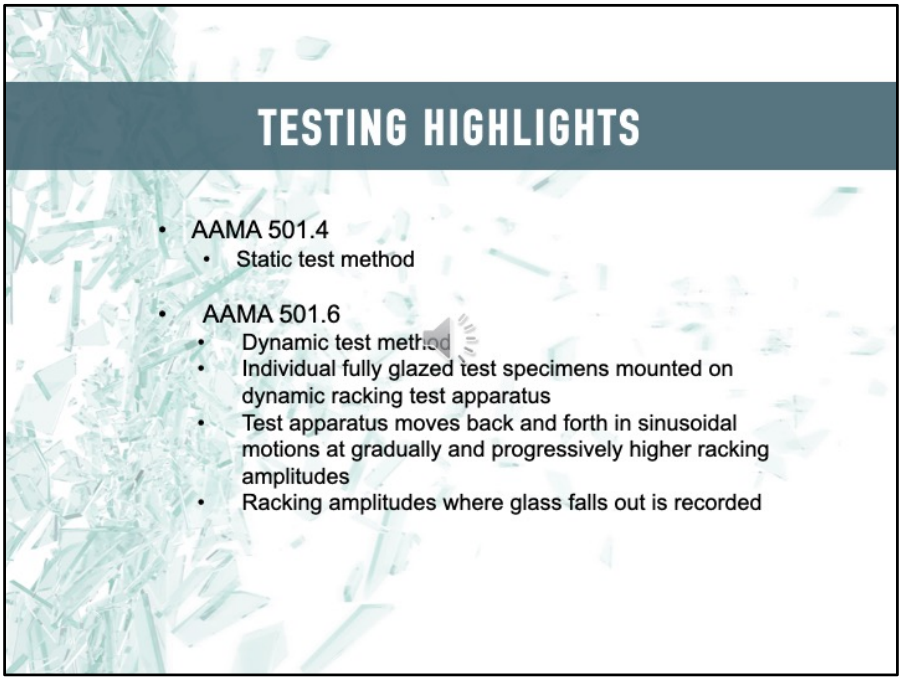
Now, let’s consider glazing for seismic applications.



Earthquakes present a different challenge to the design of glazing systems. Unlike hurricanes, where wind-borne debris and high winds are present, earthquakes can create stress on the window system from side to side, up and down movement. Laminated glass or safety film applied glass offers several advantages over monolithic glass. First it protects people from falling glass after an earthquake event, and secondly, it provides security and a weather barrier after glass breakage. Annealed or heat-strengthened glass types are preferred over tempered laminates for glass retention after breakage.

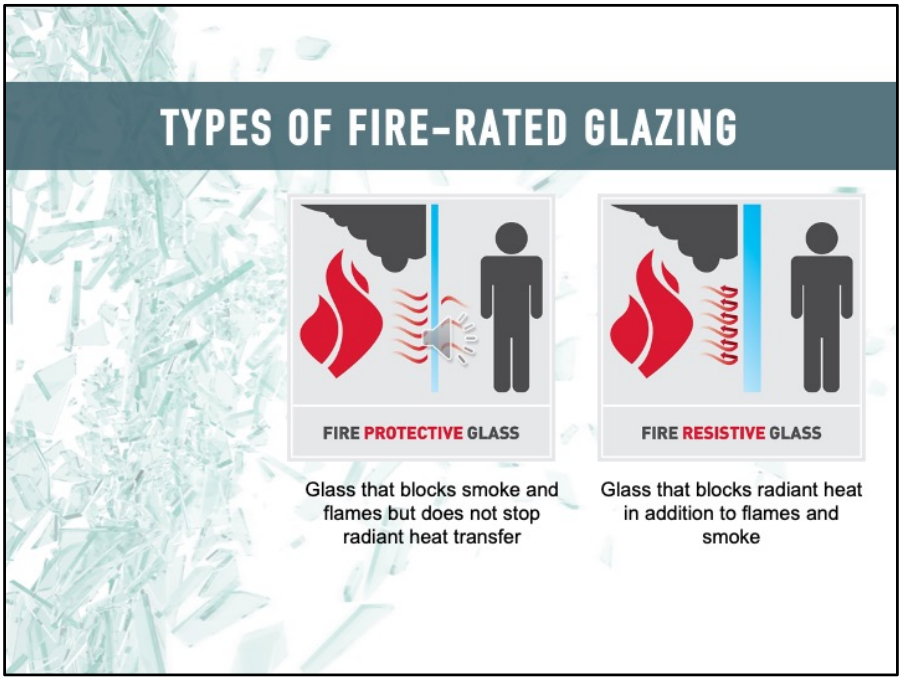


The American Architectural Manufacturers Association, AAMA, has developed two laboratory test methods to evaluate the racking of glazed systems. The first is a static test method (AAMA 501.4) used to evaluate curtain wall and storefront systems. The second is a dynamic test method (AAMA 501.6) that determines seismic drift that causes glass fallout. The static test, also referenced as Servicability, is limited to 1.5% of design displacement.



The AAMA 501.6 test method calls for individual fully glazed test specimens to be mounted on a dynamic racking test apparatus. In order to simulate the dynamic movements produced during an earthquake, the test apparatus moves back and forth at gradually and progressive higher racking amplitudes until the glass falls out, the limit of the test chamber is met or until it meets a preselected limit. Sometimes referred to as Life Safety it may be specified at 2.5% design displacement.

Finally, let’s review the types of fire-rated glazing and when each application should be employed.



This is a depiction of fire protective glass and fire resistive glass. The person depicted in the drawing on the right will not experience any of the effects of flames, smoke, or radiant heat associated with a fire.

Fire-protective glass is governed by the standards and test methods shown here.

The National Fire Protection Association standard NFPA 257 is a standard fire test for window and glass block assemblies. NFPA test 252 applies to door assemblies. In the United States, windows and doors designed for fire protection of 45 minutes or greater go through a fire endurance test, followed by a hose stream test.

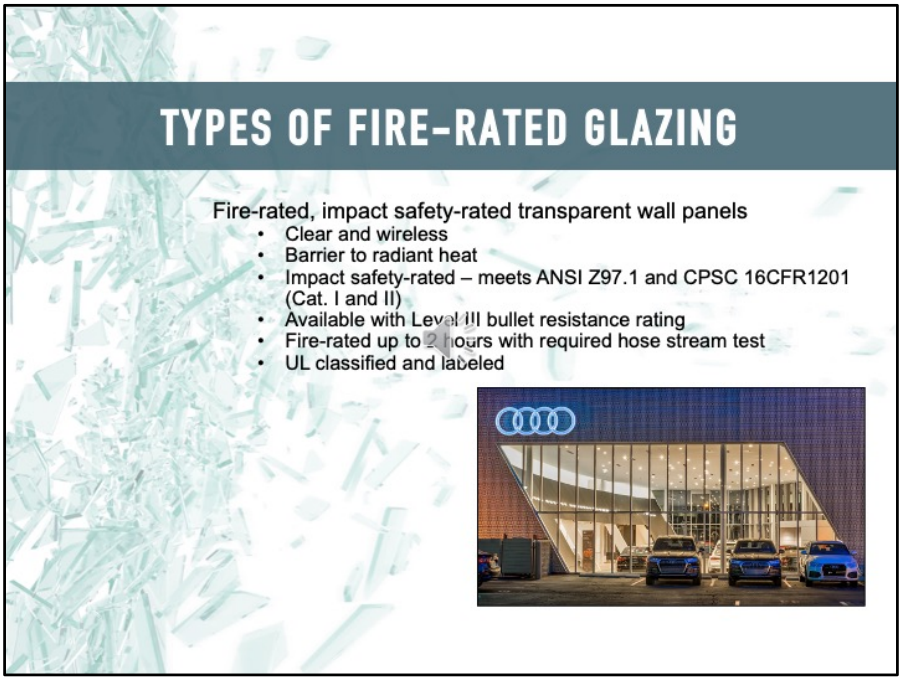
Fire-resistive glass is governed by the standards and test methods shown here: ASTM E119 and UL 263.

Fire Resistive glass must pass a fire endurance test, a hose stream test, and a radiant heat test.

Whether fire-resistive or fire-protective, there are several types of fire-rated glazing material that can be used in various circumstances.

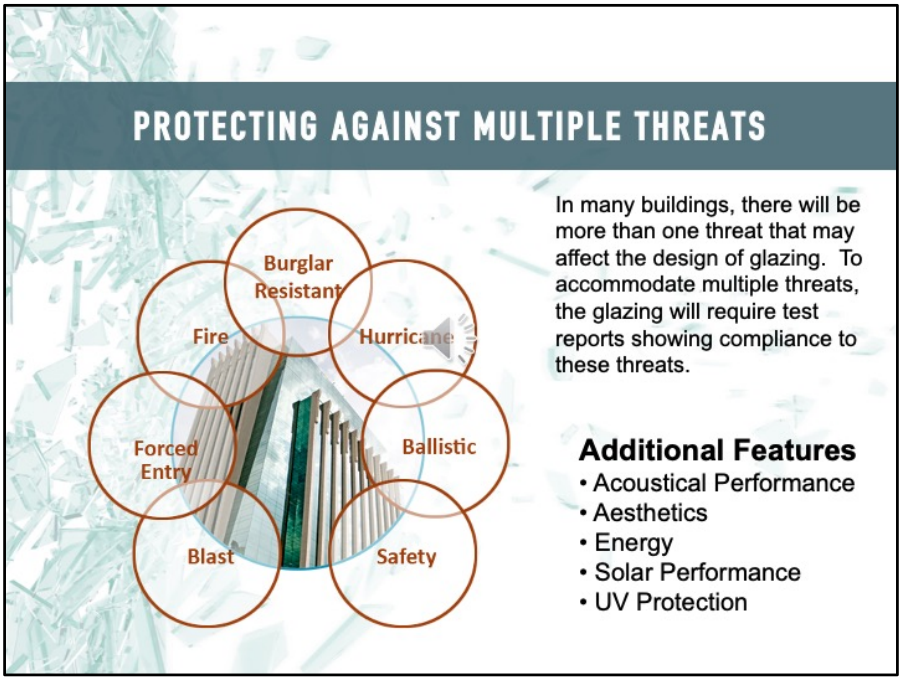
Traditional wired-glass was the original solution for fire-rated glazing applications. When the glass breaks due to high heat, the wires hold the glass in place, maintain the fire barrier. However, it is not considered safety glazing and can limit design aesthetic.

Fire-rated ceramic glass is clear and wireless. It is available in larger sizes, can be additionally fabricated to meet safety glazing requirements and meets select fire-rating testing marks.



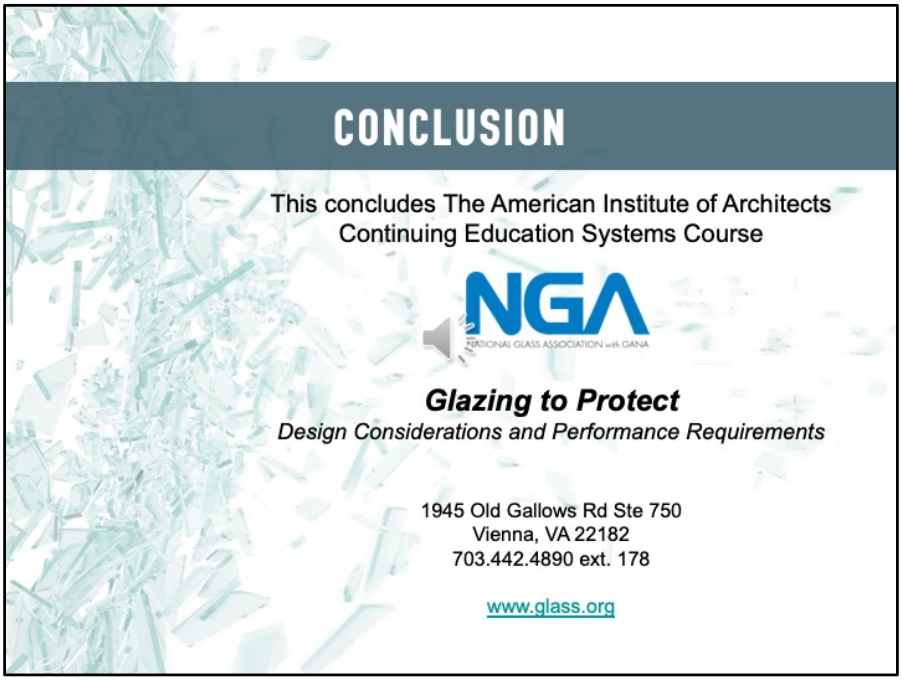
Fire resistive fire-rated glazing is available as impact safety-rated wall panels.

This type of glass is clear and wireless. In addition to passing fire-endurance tests, it also achieves impact safety ratings by passing ANSI Z97.1 or CPSC 16CFR1201 and can provide a barrier to radiant heat. It can also be subject to bullet or ballistic testing.



In many buildings, there will be more than one threat that may affect the design of glazing. To accommodate multiple threats, the glazing will require test reports showing compliance to these threats. In addition, other attributes, such as sound attenuation, ultraviolet resistance, and energy performance may be required. The glazing system may incorporate high performance coatings to achieve better energy performance or tinted interlayers or glass for aesthetics. The final specification of the security glazing is based on a comprehensive review of the desired performance attributes.

These resources aid the designer in understanding building code requirements, standards of performance, and technical attributes of security glazing.



This concludes the presentation. Now—more than ever before, you see that life-safety can be achieved without restricting daylighting and design aesthetics.

Thank you for attending Glazing to Protect: Design Considerations and Performance Requirements.

For additional resources specifically on glass and glazing, please consider browsing the National Glass Association's other related resources as listed here.